


Solutions to Exam KJE100 Chemistry part

Autumn 2019

Hint: Use the formelsamling. Concentrations can be used to approximate activities.

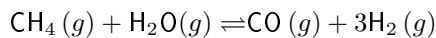
Note: The point distribution within the subproblems is only a guideline to indicate which steps/explanations were expected.

Problem A (10 points)

- (2 points) Write the systematic names of the following substances (0.5 points per name)
 - SnS **Tin sulfide** *Tinnsulfide*
 - NaH₂PO₄ **Sodium dihydrogen phosphate** *Natriumdihydrogenfosfat*
 - I₂ **Iodine (molecule), Di-iodine, Iodine, Jod, Jod gass, Dijod ... (NOT Dljodid)**
 - HClO₃ **Chloric acid** *Klorsyre, Hydrogenklorat*
- (2 points) Write the chemical formulas for the following substances (0.5 points per formula)
 - Aluminium bromide **AlBr₃**
 - Hydrogen selenide **H₂Se**
 - Sulfuric acid **H₂SO₄**
 - Potassium carbonate **K₂CO₃**
- (1 points) (0.5 points per name/sketch)
 - Sketch 2,3-difluoro-propan-1-ol
$$\begin{array}{c} \text{F} & \text{F} & \text{H} \\ | & | & | \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ | & | & | \\ \text{H} & \text{H} & \text{H} \end{array}$$
 - The trivial name of the compound depicted here is glycine 
What is its systematic name?
2-Aminoethanoic acid *2-aminoetansyre*
- (2 points) Balance the following equations
 - 2 HNO₃ + Na₂CO₃ → 2 NaNO₃ + H₂O + CO₂**
 - 2SO₂ + O₂ ⇌ 2SO₃**
- (3 points) What is a buffer solution? What does it consist of and what is it used for?
A buffer solution is an aqueous solution of a (typically) weak acid and its conjugate base (1 points). It is used to keep the pH value of a solution close to a certain pH (1 point), even upon addition of moderate amounts of acid or base (1 point) .

Problem B (10 points)

Steam reforming of natural gas is an industrial process to produce molecular hydrogen according to the reaction



An experiment, conducted at 101.325 kPa total pressure and different temperatures, T , finds the following equilibrium constants, K_{eq}

T/K	K_{eq}
300	$6.5 \cdot 10^{-8}$
400	$5.8 \cdot 10^{-5}$
750	$3.3 \cdot 10^{-3}$

and a heat of reaction that can be approximated to $\Delta H = 206 \text{ kJ/mol}$ over the temperature range measured. Approximate all gases to be ideal.

- (1 point) Express the equilibrium constant, K_{eq} , by concentrations.

$$K_{eq} = \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]}$$

- (2 point) Is the measured trend of equilibrium constants what you would qualitatively expect? Why?
 Yes, the measured trend is as expected. Higher equilibrium constants mean relatively more product (1 point). The reaction is endothermic (consumes heat) as indicated by the positive heat of reaction. According to the Le Chatelier principle, an increase in temperature shifts the equilibrium to the product side for an endothermic reaction (1 point).

- (2 points) The industrial process is typically initiated at high pressure, but then continued at low pressure 'to favour products'. Give a brief explanation why low pressure 'favours products' in the equilibrium.

According to the Le Chatelier principle, a lowering of the pressure shifts the equilibrium to the side of higher volume (1 point). This is the product side because there are more (ideal gas) molecules. Approximating all gases as ideal, the volume is proportional to the number of moles of the gas. There are 2 moles of reactant gas molecules (1 CH_4 + 1 H_2O) but 4 moles on the product side (1 CO +3 H_2), so the volume of the (ideal gas) products is twice as high as the volume of the (ideal gas) reactants. (Product volume is higher than reactant volume 1 point).

- (5 points) The above steam reforming reaction has been carried out with stoichiometric amounts at a pressure of $p = 101.325 \text{ kPa}$ and $T = 750 \text{ K}$. After an equilibrium has been reached, 17.4 litres of molecular hydrogen are found in the equilibrium mixture. How much (in g) methane does the mixture still contain?

We find how many mol of hydrogen molecules 17.4 litres correspond to (1 point). We use the ideal gas law, solved for the number of mol, n

$$pV = nRT$$

$$n = \frac{pV}{RT}$$

and put in the given values

$$n(\text{H}_2) = \frac{101.325 \text{ kPa} \cdot 0.0174 \text{ m}^3}{8.3144 \frac{\text{J}}{\text{K} \cdot \text{mol}} \cdot 750 \text{ K}}$$

$$= \frac{101.325 \cdot 10^3 \text{ N/m}^2 \cdot 0.0174 \text{ m}^3}{8.3144 \frac{\text{Nm}}{\text{K} \cdot \text{mol}} \cdot 750 \text{ K}}$$

$$n(\text{H}_2) = 0.28 \text{ mol}$$

We are given only the amount of hydrogen. The chemical equation tells us that we have 3 times as many mol hydrogen molecules in the equilibrium mixture as CO-molecules. So we get (1 point)

$$n(\text{CO}) = \frac{n(\text{H}_2)}{3} = 0.0942 \text{ mol}$$

With the product concentrations (number of moles per unknown container volume), we calculate the combined reactant concentrations from the equilibrium constant K_{eq} (750K), setting each of the reactant's concentration to x , since we have for each 1 mol CH_4 -molecules reacting 1 mol water molecules (1 point):

$$\begin{aligned} K_{eq} &= \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]} \\ 3.3 \cdot 10^{-3} &= \frac{0.09 \cdot 0.28^3}{x \cdot x} \end{aligned}$$

Carrying out the calculation, we find x (1 point)

$$\begin{aligned} x^2 &= \frac{0.09 \cdot 0.28^3}{3.3 \cdot 10^{-3}} \\ x^2 &= \frac{2.13 \cdot 10^{-3}}{3.3 \cdot 10^{-3}} \\ x^2 &= 0.65 \\ x &= 0.80 \end{aligned}$$

which is identical to the number of mols CH_4 - molecules and to the number of H_2O -molecules in the equilibrium mixture

$$n(\text{CH}_4) = x = 0.80 \text{ mol}$$

$$n(\text{H}_2\text{O}) = x = 0.80 \text{ mol}$$

what is left is to calculate the mass corresponding to 0.80 mol CH_4 - molecules (1 point). The molecular mass of CH_4 is

$$M(\text{CH}_4) = (12.01 + 4 \cdot 1.008) \text{ g} = 16.042 \frac{\text{g}}{\text{mol CH}_4}$$

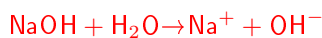
We multiply

$$0.8 \text{ mol CH}_4 \cdot 16.042 \frac{\text{g}}{\text{mol CH}_4} = 12,89 \text{ g}$$

Problem C (16 points)

Consider an aqueous solution of $0.001 \frac{\text{mol}}{\text{l}}$ NaOH and another one made with $0.1 \frac{\text{mol}}{\text{l}}$ acetic acid (HAc).

- (4 points) What is the pH values of the Na OH solution?
(1 for complete dissociation reaction, 1 for OH concentration, 1 for pOH, 1 for pH): For the strong base



we have

$$[\text{OH}^-] = 0.001 \frac{\text{mol}}{\text{l}}$$

corresponding to

$$pOH = 3$$

and

$$pH = 14 - pOH = 11$$

2. (6 points) What is the pH value of the HAc solution?

For the weak acid ($K_a = 1.8 \cdot 10^{-5}$), we have to consider the equilibrium (1 point)



with (1 point)

$$K_a = \frac{[\text{Ac}^-][\text{H}_3\text{O}^+]}{[\text{HA}]}$$

to calculate the resulting $[\text{H}_3\text{O}^+]$. Using e.g. an ICE table

mol/l	HA	Ac-	H ₃ O ⁺
I	0.1	0	0
C	-x	+x	+x
E	0.1-x	x	x

we can rewrite (1 point)

$$1.8 \cdot 10^{-5} = \frac{x^2}{0.1 - x}$$

and solve this for x (1 point)

$$\begin{aligned} 1.8 \cdot 10^{-5} (0.1 - x) - x^2 &= 0 \\ x^2 + 1.8 \cdot 10^{-5}x - 1.8 \cdot 10^{-6} &= 0 \end{aligned}$$

$$\begin{aligned} x_{1,2} &= -\frac{1.8 \cdot 10^{-5}}{2} \pm \sqrt{\left(\frac{1.8 \cdot 10^{-5}}{2}\right)^2 + 1.8 \cdot 10^{-6}} \\ &= -0.9 \cdot 10^{-5} \pm \sqrt{(0.9 \cdot 10^{-5})^2 + 1.8 \cdot 10^{-6}} \\ &= -0.9 \cdot 10^{-5} \pm \sqrt{8.1 \cdot 10^{-10} + 1.8 \cdot 10^{-6}} \\ &= -0.9 \cdot 10^{-5} \pm \sqrt{8.1 \cdot 10^{-4} + 1.8 \cdot 10^{-3}} \\ &= -0.9 \cdot 10^{-5} \pm 0.00134 \\ x_1 &= -0.001350671 \\ x_2 &= 0.001332671 \end{aligned}$$

of which only the positive solution for x is physically meaningful. The H_3O^+ (and also Ac-) -ion concentration in the equilibrium is thus (1 point)

$$[\text{H}_3\text{O}^+] = 0.001332671 \text{ mol/l}$$

That is (1 point)

$$\text{pH} = 2.88$$

3. (2 points) 100 ml of each of the two solutions (NaOH and HAc) are combined, stirred, and equilibrated to give 200ml of a mixed solution. Write the chemical equations of the reaction(s) that take place upon mixing. How are such kind of reaction(s) called?



(1 point) where spectator ions are crossed out. Such reactions are called neutralisation (1 point).

4. (4 points) Calculate the pH value in the final solution.

Upon mixing, the volume is doubled, so $[\text{OH}^-]_{mix} = 0.0005 \frac{\text{mol}}{\text{l}}$ and $[\text{H}_3\text{O}^+]_{mix} = 0.000666335 \frac{\text{mol}}{\text{l}}$ (1 point). All present OH^- -ions from the strong base neutralise H_3O^+ -ions, such that (1 point)

$$[\text{OH}^-]_{mix} = 0$$

and (1 point)

$$\begin{aligned} [\text{H}_3\text{O}^+]_{final} &= [\text{H}_3\text{O}^+]_{mix} - [\text{OH}^-]_{mix} \\ &= 0.000666335 \frac{\text{mol}}{\text{l}} - 0.0005 \frac{\text{mol}}{\text{l}} \\ &= 0.000166335 \frac{\text{mol}}{\text{l}} \end{aligned}$$

corresponding to (1 point)

$$\text{pH} = 3.78$$

Not asked (give up to 2.5 extra points if done this way): the neutralisation of the H_3O^+ -ions by OH^- -ions causes the acid base equilibrium of HAc to shift to the right. We consider the equilibrium concentration of HAc (in mol/l)

$$[\text{HAc}] = 0.1 - x = 0.1 - 0.00133267 = 0.09866733$$

and divide it by for the value in the mixture (1 extra point)

$$[\text{HAc}]_{mix} = 0.049333665$$

With all H_3O^+ -ions removed by neutralisation, this can be regarded as a new initial concentration, for the new equilibrium reaction



leading to new equilibrium H_3O^+ -ion concentration (same calculation as above, but using 0.049 instead of 0.1 as initial concentration. There are also non-zero initial concentrations of H_3O^+ and Ac^- (1 extra point).

mol/l	HAc	Ac-	H_3O^+
I	0.049	0.00066	0.00017
C	-y	+y	+y
E	0.049-y	0.00066+y	0.00017+y

$$1.8 \cdot 10^{-5} = \frac{(0.00066 + y)(0.00017 + y)}{0.049 - y}$$

$$1.8 \cdot 10^{-5} (0.049333665 - y) = y^2 + 0.00083y + 1.10835 \cdot 10^{-7}$$

and solve this for y (not to confuse with x again) (1 extra point)

$$y^2 + 0.00085y - 7.7717 \cdot 10^{-7} = 0$$

$$y_1 = -0.0014041516081879926$$

$$y_2 = 0.0005534806351100176,$$

and thus (0.5 extra point)

$$[\text{H}_3\text{O}^+]_{new} = y + 0.00017 = 0.00072$$

and

$$pH_{new} = -\log_{10}([\text{H}_3\text{O}^+]_{new}) = 3.14$$

Problem D (14 points)

1. (5 points) How many gram of silver chloride can be dissolved in 1 l of a solution with $0.004 \frac{\text{mol}}{\text{l}}$ NaCl? When adding silver chloride to a solution that already contains chloride ions (from sodium chloride), we can do so only up to the solubility product (1 point)

$$K_{sp} = [\text{Ag}^+][\text{Cl}^-] = 2.0 \cdot 10^{-10}$$

where we have to take into account the concentration of chloride ions that are already present. We set the amount of Cl-ions ions that can be added to x . the amount of Ag+ ions is then also x , such that (1 point)

$$K_{sp} = x(0.004 + x) = 2.0 \cdot 10^{-10}$$

which we solve for x (1 point)

$$x^2 + 0.004x - 2.0 \cdot 10^{-10} = 0$$

$$\begin{aligned}x_{1,2} &= -0.002 \pm \sqrt{0.002^2 + 2.0 \cdot 10^{-10}} \\&= -0.002 \pm \sqrt{4 \cdot 10^{-6} + 2.0 \cdot 10^{-10}} \\&= -0.002 \pm \sqrt{4.0002} \cdot 10^{-3} \\&= -2 \cdot 10^{-3} \pm 2.000049999 \cdot 10^{-3} \\x_1 &= 0.000049999 \cdot 10^{-3} = 4.9999 \cdot 10^{-8} \\x_2 &= -4.000049999 \cdot 10^{-3}\end{aligned}$$

where only the positive solution for x is physically meaningful.

Finally, we calculate how many gram the x mol of AgCl correspond to. The molar mass is (1 point)

$$M(\text{AgCl}) = (107.87 + 35.45) \frac{\text{g}}{\text{mol}} = 143.32 \frac{\text{g}}{\text{mol}}$$

We can therefore add (1 point)

$$4.9999 \cdot 10^{-8} \text{ mol} \cdot 143.32 \frac{\text{g}}{\text{mol}} = 716.585668 \cdot 10^{-8} \text{ g}$$

(Not asked: check the solubility product):

$$4.9999 \cdot 10^{-8} \cdot (4.9999 \cdot 10^{-8} + 4 \cdot 10^{-3}) = 1.999999 \cdot 10^{-10} = K_{sp}$$

2. (3 points) An aqueous solution of sodium chloride is used to produce molecular chlorine via electrolysis. An unexpected brownish vapour emerges that is identified to be bromine. This unfortunate event is claimed to be due to impurities of sodium bromide in the sodium chloride used to prepare the solution. Do you agree with this possible explanation? Explain your answer.

The possibility has to be considered. The standard reduction potential for bromine to bromide is lower than the standard reduction potential for chlorine to chloride (1 point). Hence, oxidation of bromide is easier than that of chloride. Bromine is thus oxidised first and in addition, chlorine emerging from the electrolysis furthermore oxidises bromide ions (1 point) and is reduced to chloride ions (1 point)



3. (6 points) A platinum electrode is inserted into a 0.1 mol/l HCl solution and electrically connected to a Cu^{2+}/Cu half-cell. The experiment is conducted in an inert atmosphere such that molecular oxygen is absent. What happens qualitatively (increase, decrease, about the same) to the pH of the HCl solution? Explain your answer.

The connection makes the HCl solution and the copper half cell a galvanic cell. The Cu^{2+}/Cu half cell has the higher standard reduction potential and is therefore the cathode (1 point). The anode is a H^+/H_2 hydrogen element with non-standard concentration. H^+ is already the oxidised form, molecular hydrogen is not present (1 point). Oxygen is not present and is therefore not reduced (1 point). Water reduction has a lower standard reduction potential than copper reduction (1 point). Chloride is not reduced due to its higher standard reduction potential (1 point/2 points). The pH remains about the same. (1 point)