IN DEPTH

50. Sodium bicarbonate and effervescent aspirin

An effervescent tablet is a tablet designed to fragment and dissolve rapidly in water or other liquid, releasing carbon dioxide (CO_2). This release induces effervescence and fragmentation of the tablet.

Given :

- This study is performed at 25 °C.
- The ionic product constant of water : $K_w = 1.0 \times 10^{-14}$.
- $M_{(NaHCO_3)} = 84\ g.mol^{-1}$

Acid/Base pair	HCO_3^- / CO_3^{2-}	$(CO_2,H_2O) / HCO_3^-$	H_2O / HO^-	H_3O^+ / H_2O	$R\text{-}COOH / R\text{-}COO^-$
pK_a	10.3	6.4	14	0	3.8

Document 1

The sodium hydrogen carbonate $NaHCO_3$ known commercially as bicarbonate of soda is widely used in everyday life. It reduces the duration of cooking, it is recommended in the case of indigestion and in the preparation of medications like effervescent aspirin.

1. **Study of the acid-base character of sodium bicarbonate $NaHCO_3$**

   1.1. With reference to **document 1**, and to the 2 pairs to which the HCO_3^- ion belongs. Write the equations of the reactions between the hydrogen carbonate ion HCO_3^- and the water.

   1.2. Determine the K_R constant of each reaction.

   1.3. Deduce the most Preponderant form of the HCO_3^- ion in water.

   1.4. What particular character presents the HCO_3^- ion.

2. **Preparation of a solution of sodium bicarbonate**

   A solution (S) of sodium bicarbonate, of concentration $C_S = 0.1\ mol.L^{-1}$, is prepared by dissolving a mass **m** of this solid in distilled water in order to have a solution of volume $V_S = 1\ L$.

   2.1. Calculate **m**.

   2.2. Choose from **document 2**, the material needed to prepare this solution.

- Volumetric pipette : 5, 10 and 20 mL. - Watch glass - Spatula - Precise balance
- Volumetric flask : 50, 100 and 1000 mL. - Test tube 50 mL - Funnel

Document 2

3. **Sodium bicarbonate and effervescent aspirin**

   Aspirin or acetylsalicylic acid denoted as R-COOH may damage the mucosa of the stomach, while its conjugate base is without side effect. For this, the effervescent aspirin is prepared by mixing R-COOH with $NaHCO_3$.

When an effervescent aspirin tablet is introduced into the water an acid-base reaction will take place :

3.1. Place the acid/base pairs given in **document 1** on a vertical axis of pK_a.
3.2. Specify the major species that will react with each other.
3.3. Write the equation of the main reaction that takes place.
3.4. Determine the K_R constant of this reaction.
3.5. Justify that the reaction is more advanced to the right.
3.6. Indicate what the effervescence is due to.
3.7. Deduce its effect on the displacement of the reaction to the right.
3.8. Why effervescent aspirin has no side effects on the mucosa of the stomach.

S1. Hypochlorous acid

Hypochlorous acid is a weak acid, which is in the form of a solution and has the chemical formula HCℓO. It is used as a deodorant or disinfectant. For example, it is used to disinfect water of swimming pools. Its disinfectant property is activated in contact with water.

Given :

- A species A is ultra-major as compared to a species B if $\frac{[A]}{[B]} > 100$.
- Measurements are made at 25 °C. $K_w = 10^{-14}$.

Acid/Base pair	$HC\ell O/C\ell O^-$	H_3O^+/H_2O	H_2O/HO^-
pK_a	$pK_{a1} = 7.5$	$pK_{a2} = 0$	$pK_{a3} = 14$

Document 1

1. **Dissociation of hypochlorous acid HCℓO in water**

A solution (S) of hypochlorous acid of concentration $C = 1.0 \times 10^{-2}$ mol.L^{-1} is prepared.

1.1. Write the equation for the reaction of hypochlorous acid with water.
1.2. Establish the relation between the dissociation coefficient of hypochlorous acid α, the concentration C and the pH of this solution.
1.3. The solution (S) is diluted ten times, a solution (S') of concentration C' is obtained. We Measure the new pH of the solution (S') we find the results given in **document 2** :

Solution	**S**	**S'**
C (mol.L^{-1})	1.0×10^{-2}	1.0×10^{-3}
pH	4.75	5.25
dissociation coefficient	0.0018	α'

Document 2

1.3.1. Calculate the value of α' in the solution S' which is missing in the table of **document 2.**

1.3.2. Compare α and α' and give a conclusion about the effect of dilution on the dissociation of a weak acid.

1.4. Determine from what pH hypochlorous acid can be considered as ultra-majo

2. **Reaction of hypochlorous acid with a strong base**

A volume $V_a = 20$ mL of the solution (S) is mixed with a volume $V_b = 10$ mL of sodium hydroxide solution NaOH with a concentration of 10^{-2} mol.L^{-1}.

2.1. Indicate the major species present in this mixture before any reaction.

2.2. Place the acid/base pairs given in **document 1** on a vertical axis of pK_a.

2.3. Specify according to this classification and according to the major species present in the mixture the main acid-base reaction that may take place.

2.4. Write the equation for this reaction.

2.5. Show that this reaction is quasi-complete.

2.6. Deduce the pH of the mixture obtained.

52. Benzoic acid and ammonia

Benzoic acid C_6H_5COOH, weak acid, is a white solid that is poorly soluble in water. This compound is used as a preservative in the food industry for refreshing beverages.

Ammonia NH_3 is a weak base used in aqueous solution to clean glass.

Given :

Molar volume of a gas under the conditions of the experiment is : $V_m = 24$ L.mol^{-1}

- The ammonia gas is very soluble in water.
- Measurements are made at 25°C. $K_w = 10^{-14}$.

Molar mass in g.mol^{-1} : benzoic acid $M_1 = 122.52$.

acid/base pair	H_3O^+/H_2O	NH_4^+/NH_3	$C_6H_5COOH / C_6H_5COO^-$	H_2O/HO^-
pK_a	0	9.2	4.2	14

Document 1

1. **Preparation of the solution (S_1) of benzoic acid**

The solution (S_1) is prepared by introducing a mass of 305 mg of benzoic acid in an aqueous solution of volume 250 mL, the whole mass of the solid solute is dissolved.

1.1. Show that the molar concentration of this solution is $C_a = 10^{-2}$ mol.L^{-1}.

1.2. The pH measurement of this solution gave a value of 3.1.

1.2.1. Justify that benzoic acid is a weak acid.

1.2.2. Write the equation of the reaction benzoic acid with water.

1.2.3. Indicate the predominant species in the solution (S_1). Justify.

1.3. The solution (S_1) is diluted ten times. Choose by justifying which of the 3 pH values given below is correct :

a. pH = 2.6 b. pH = 4.1 c. pH = 3.6

2. Reaction of ammonia with water

A solution (S_2) of ammonia is prepared by dissolving 24 mL of the ammonia gas in an aqueous solution of 100 mL volume. The pH measurement of this solution gives a value of 10.6.

2.1. Determine the concentration C_b of the solution (S_2).

2.2. Write the equation of the reaction of ammonia with water.

2.3. Express the concentrations of species present at equilibrium as a function of C_b and $[HO^-]$.

2.4. Show that the acidity constant of this pair can be expressed as :

$$K_a = 10^{-14} \frac{(C_b - [HO^-])}{[HO^-]^2}.$$

2.5. Justify the value of the pK_a of the pair NH_4^+ / NH_3, given in **document 1**.

3. Reaction between benzoic acid and ammonia

A volume $V_1 = 20$ mL of the solution S_1 is mixed with a volume $V_2 = 10$ mL of the solution S_2.

3.1. Write the balance equation of the total reaction that occurs between benzoic acid and ammonia.

3.2. Determine the pH of the mixture obtained.

53. Evolution of a chemical system

Available aqueous solutions of methanoic acid and benzoic acid with the same molar concentration of solute $C = 1.0 \times 10^{-2}$ mol.L^{-1}. Measuring the pH of a volume $V = 10$ mL of each solution gave the following results : aqueous solution of methanoic acid : $pH_1 = 2.9$; Aqueous solution of benzoic acid : $pH_2 = 3.1$.

Given :

$HCOOH / HCOO^- : pK_{a1} = 3.8$; $C_6H_5COOH / C_6H_5COO^- : pK_{a2} = 4.2$

1. Study of aqueous solutions of methanoic acid and benzoic acid of the same concentration

1.1. Determine the degree of ionization α of methanoic acid HCOOH.

1.2. From the comparison of the pH values of the aqueous solutions of methanoic acid and benzoic acid, specify for which acid the reaction with water is the most advanced.

2. Evolution of a chemical system

Consider the following chemical reaction :

$$HCOOH + C_6H_5COO^- \rightleftarrows HCOO^- + C_6H_5COOH$$

2.1. Express the equilibrium constant of this reaction and then calculate its value.

2.2. We dispose aqueous solutions of methanoic acid and sodium benzoate of the same molar concentration C each and aqueous solutions of benzoic acid and sodium methanoate of the same molar concentration C' each.

Equal volumes $V = 10.0$ mL of the above four solutions are mixed. The molar concentrations C and C' have the following values : $C = 1.0 \times 10^{-2}$ mol.L^{-1} and $C' = 5.0 \times 10^{-3}$ mol.L^{-1}. Calculate the quotient of reaction in the initial state.

2.3. In what direction will the chemical system evolve? Justify.

Given : The reactions with water of benzoate and methanoate ions are limited.

2.4. By keeping $V = 10.0$ mL and $C = 1.0 \times 10^{-2}$ mol.L^{-1}, calculate the value that would have to be given to C' so that the system will be in equilibrium.