# Practical Session n°13: How to measure the pH of a solution

## 1- PROBLEM

In a chemistry lab, a technician has prepared two solutions of same concentration $C = 1.0 \times 10^{-2}$ mol.L$^{-1}$: one solution of hydrochloric acid and another of ethanoic acid. He put them in two identical bottles. He wrote each name of solution on each bottle. Unfortunately, when he wanted to use these solutions, the indications had disappeared. Could you please help him to identify the contents of each bottle?

## 2- DOCUMENTS AT YOUR DISPOSAL

### Doc 1: The pH scale

The concept of pH was introduced by Søren Sørensen in 1909.
p stands for "potenz" (a German word meaning power) and H for "hydrogen". The **pH** of a solution is related to the concentration of oxonium ions, $H_3O^+$, that are present in solution: **pH = - log[$H_3O^+$]** i.e. **[$H_3O^+$] = $10^{-pH}$**

### Doc 2: Acid-base couples

An **acid** is a chemical species that can give at least one proton (hydrogen ion) $H^+$: $HA \longrightarrow A^- + H^+$
A **base** is a chemical species that can accept at least one proton (hydrogen ion) $H^+$: $A^- + H^+ \longrightarrow HA$
An **acid/base couple** is defined by the **half acid-base equation**: $HA \rightleftharpoons A^- + H^+$ (or $BH^+ \rightleftharpoons B + H^+$)
The double arrow indicates that the exchange can occur in both directions. It can be replaced by an equals sign.
The couple are denoted **$HA/A^-$** (or **$BH^+/B$**).
*Example*: methanoic acid/methanoate ion i.e. $HCO_2H_{(aq)}/HCO_2^-{}_{(aq)}$ corresponds to $HCO_2H_{(aq)} \rightleftharpoons HCO_2^-{}_{(aq)} + H^+{}_{(aq)}$

### Doc 3: Acid-base reaction

An **acid-base reaction** involves two acid/base couples. It results from the transfer of a proton $H^+$ from the acid of one of the couples to the base of the other couple.

Example: reaction between $NH_4^+{}_{(aq)}/NH_{3(aq)}$ and $HCO_2H_{(aq)}/HCO_2^-{}_{(aq)}$ :

$$HCO_2H_{(aq)} \rightleftharpoons HCO_2^-{}_{(aq)} + H^+{}_{(aq)}$$
$$NH_{3(aq)} + H^+{}_{(aq)} \rightleftharpoons NH_4^+{}_{(aq)}$$
$$HCO_2H_{(aq)} + NH_{3(aq)} \rightleftharpoons HCO_2^-{}_{(aq)} + NH_4^+{}_{(aq)}$$

### Doc 4: Strong acids and weak acids

An acid HA is **weak** if its reaction with water is **not total**: $HA_{(aq)} + H_2O_{(l)} \rightleftharpoons A^-{}_{(aq)} + H_3O^+{}_{(aq)}$
Therefore, the acid HA is not completely converted into $A^-$ ions. The reaction is symbolized by a double arrow.
Example: Ethanoic acid is a weak acid.

An acid HA is **strong** if its reaction with water is **total**: $HA_{(aq)} + H_2O_{(l)} \rightarrow A^-{}_{(aq)} + H_3O^+{}_{(aq)}$
Therefore, the acid HA is completely transformed into $A^-$ ions. The reaction is symbolized by a single arrow →.
Example: Hydrochloric acid HCl is a strong acid.

### Doc 5: How to calibrate a pH meter

To accurately measure the pH of an aqueous solution, we use a **pH meter**.

It contains a measuring probe connected to an electronic voltmeter calibrated in pH units.
The voltage which appears across the terminals of the probe is an affine function of the pH (U = a + b.pH where a and b depend on temperature and on the nature of the electrodes).
As a result, **it is necessary to calibrate the pH meter before using it**.

To calibrate a pH meter (i.e. to set a and b), you have to record the temperature and to measure the pH of two solutions of known pH called **buffer solutions** (see the help card).

Between each measurement, it is necessary to rinse the pH probe out and to dry it carefully with a filter paper.

## 3- WORK TO BE DONE

### 3.1- UNDERSTANDING THE DOCUMENTS

- *Calculate the concentration in oxonium ions for a solution of pH = 2.*
- *What can be said about the pH of an acidic solution? What can be said about its concentration in oxonium ions?*
- *Answer the same questions for a basic solution.*
- *Fill in the blanks with the correct conjugated acid or base.*
  … / $ClO^-_{(aq)}$ ; $CH_3NH_3^+{}_{(aq)}$ / … ; $H_3O^+_{(aq)}$ / … ; $H_2O_{(l)}$ / …
- *Write down the acid-base reaction of nitric acid $HNO_3$ with water.*

### 3.2- PRELIMINARY EXPERIMENTS

- Place a beaker on a magnetic stirrer and pour 50 mL of distilled water in this beaker. Measure the pH of distilled water. *Record your result:* $pH_{water}$ = ……
- **Take great care when adding a few drops of concentrated ethanoic acid by wearing gloves and safety glasses**. Stir and measure the pH of the aqueous solution obtained. *Record your result:* $pH_1$ = ……
- *How does the pH vary? Using document 1, deduce the evolution of the concentration in oxonium ion.*
- *Write down the equation of the acid-base reaction between ethanoic acid and water.*

- Add 0.5 g of sodium ethanoate $CH_3CO_2Na_{(s)}$.
- Stir to dissolve the solid and measure the pH. *Record your result:* $pH_2$ = ……
- *How does the concentration in oxonium ions vary?*
- *In which direction has the chemical system evolved: forward or reverse direction with regard to the reaction equation?*

### 3.3- FINDING A SOLUTION TO THE PROBLEM

- *Propose a procedure to solve the problem.*
- *Carry out and exploit your procedure.*
- *Conclude.*

#### HELP CARD TO SOLVE THE PROBLEM

**Method 1**

- *Determine the amount of ethanoic acid (expressed in moles) in 50 mL of the solution of concentration $C = 1.0.10^{-2}$ $mol.L^{-1}$.*
- *Determine the amount of oxonium ions (expressed in moles) in this solution.*
- *Deduce the amount of ethanoic acid that has reacted.*

- *Determine the amount of hydrochloric acid (expressed in moles) in 50 mL of the solution of concentration $C = 1.0.10^{-2}$ $mol.L^{-1}$.*
- *Determine the amount of oxonium ions (expressed in moles) in this solution.*
- *Deduce the amount of hydrochloric acid that has reacted.*

**Method 2**

- *Draw an advancement table.*
- *Let $x_f$ be the final advancement of the reaction, that is to say the advancement obtained when the chemical system does not vary any more.*
- *Let $x_{max}$ be the maximal advancement of the reaction, that is to say the advancement that could be obtained if the reaction was total.*
- *Calculate $x_f$ and $x_{max}$ for each case.*