Institute of Mathematics,
Physics and Chemistry

Department of Chemistry

Technical chemistry laboratory

Laboratory exercise

Reactions of salt with water

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EXERCISE SHEET

<table>
<tr><td rowspan="5">1</td><td colspan="3">Relation to subjects: ESO/25, 27 DiRMiUO/25, 27 EOUNiE/25, 27</td></tr>
<tr><td>Specialty/Subject</td><td>Learning outcomes for the subject</td><td>Detailed learning outcomes for the subject</td></tr>
<tr><td>ESO/26 Chemistry of water, fuels and lubricants</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP3 – Water quality indicators;
SEKP6 – Performing determinations of selected indicators of technical water quality;</td></tr>
<tr><td>DiRMiUO/26 Chemistry of water, fuels and lubricants</td><td>EKP3
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<tr><td>EOUNiE/26 Chemistry of water, fuels and lubricants</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP3 – Water quality indicators;
SEKP6 – Performing determinations of selected indicators of technical water quality;</td></tr>
<tr><td>2</td><td colspan="3">Purpose of the exercise:
mastering basic chemical concepts related to solutions of acids, bases and salts as well as acquiring practical skills in the field:
– determining the pH of solutions and measuring them,
– calculating the pH of solutions of strong and weak acids and bases,
– determining the reaction of individual types of salts after hydrolysis based on the reaction,
– calculating the pH of specific salt solutions and buffer mixtures.</td></tr>
<tr><td>3</td><td colspan="3">Prerequisites:
general knowledge of pH, solution reaction, hydrolysis of salts, knowledge of the key issues of ionic dissociation acquired during the previous exercise, knowledge of the principles of work in a chemical laboratory</td></tr>
<tr><td>4</td><td colspan="3">Description of the laboratory workplace:
a set of laboratory glassware, a set of reagents and indicators for testing pH and hydrolysis,</td></tr>
<tr><td>5</td><td colspan="3">Risk assessment:
the likelihood of chemical burns from exposure to 0.2 M sulfuric acid is very small, and the effects are minor,
Final assessment – VERY SMALL THREAT
Security measures required:
1. Lab coats, gloves and safety glasses.
2. Health and safety cleaning products, paper towels.</td></tr>
<tr><td>6</td><td colspan="3">The course of the exercise:
1. Getting to know the workplace manual (appendix 1).
2. Carrying out the experiments provided for in the manual.</td></tr>
<tr><td>7</td><td colspan="3">Exercise report:
1. Develop an exercise in accordance with the instructions contained in the workplace manual.
2. Solve the given task and/or answer the questions included in the set of tasks and questions to be completed by the student.</td></tr>
<tr><td>8</td><td colspan="3">Archiving of research results:
report on exercises – prepared in accordance with the rules applicable in the laboratory</td></tr>
</table>

	– should be submitted in writing to the academic teacher during the next classes.
9	**Assessment method and criteria:** a) EKP1, EKP2 – checking the knowledge of basic chemical concepts of pH and hydrolysis in class, b) SEKP4 – the detailed learning outcome for an individual student will be assessed on the basis of the solutions to tasks and problems presented in the report, given for independent solution/development: – mark 2,0 – the student has a general knowledge of pH and salt hydrolysis, but cannot use it in practice to solve basic problems, – mark 3,0 – has basic chemical knowledge of pH and salt hydrolysis and can use it to a small extent to solve potential problems in his specialty, – mark 3,5 – 4,0 – has extensive chemical knowledge in the field of pH, salt hydrolysis and is able to use it to a basic extent to determine the pH and calculate the pH of various electrolyte solutions and to solve problems on the ship, – mark 4,5 – 5,0 – has complete chemical knowledge in the field of pH and salt hydrolysis and is able to use in practice complex chemical knowledge to determine and calculate the pH of individual acid, alkali, salt and buffer solutions and to solve complex problems,
10	**Literature:** 1. Kozłowski A., Workplace instruction for laboratory exercises: *pH roztworów. Reakcje soli z wodą,* AM Szczecin, 2013. 2. Stundis H., Trześniowski W., Żmijewska S.: *Ćwiczenia laboratoryjne z chemii nieorganicznej*. WSM, Szczecin 1995. 3. Śliwa A., Chemical calculations. A collection of tasks. PWN Warsaw, 1994. 4. Jones L., Atkins P., *Chemia ogólna. Cząsteczki, materia reakcje*, WN PWN, Warsaw, 2004. 5. Bielański A., *Chemia ogólna i nieorganiczna*, PWN, Warsaw, 1996. 6. Kozłowski A., *Materiały dydaktyczne z chemii technicznej*, developed for the purposes of auditorium classes (not published).
11	Notes

APPENDIX 1 – MANUAL

1. SCOPE OF THE EXERCISE

Issues and keywords:

- hydrolysis (definition), hydrolysis of various types of salts and reactions of their solutions, the constant and degree of hydrolysis, Henderson-Hasselbalch equation.

1.1. Reactions of salt with water (salt hydrolysis)

Hydrolysis is a reaction of some chemical compounds with water that leads to a violation of the balance of water self-ionization, and thus to a change in the pH of the environment. Salts whose ions have the ability to donate or attach protons in the aqueous environment react particularly easily with water. This property is exhibited by the salts resulting from the neutralization of:

- weak acids with strong hydroxides,
- weak acids with weak hydroxides,
- strong acids with weak hydroxides

Salts formed as a result of neutralizing strong acids with strong hydroxides do not react with water, because their ions in the water environment do not accept or give up protons. Insoluble salts are also not subjected to hydrolysis.

An example of a hydrolysis reaction of salt formed from a weak acid and a strong hydroxide can be CH_3COONa, which undergoes dissociation

$$CH_3COONa \rightleftarrows CH_3COO^- + Na^+$$

Acetate ion CH_3COO^- in aqueous solution has the ability to attach a proton, so the reaction with water follows the equation

$$CH_3COO^- + H_2O \rightleftarrows CH_3COOH + OH^-$$

The reaction of the solution, after establishing the hydrolytic equilibrium, is basic (Na^+ ions resulting from the dissociation of sodium acetate do not combine with OH^-, ions, because NaOH is a strong electrolyte, almost completely dissociated into ions).

An example of a strong acid and weak hydroxide salt is NH_4Cl which undergoes dissociation

$$NH_4Cl \rightleftarrows NH_4^+ + Cl^-$$

Ammonium ion NH_4^+ is able to donate a proton in an aqueous solution

$$NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$$

After the reaction, due to the presence of the hydronium H_3O^+, ion, the solution will be acidic.

An example of a salt of another type is ammonium acetate CH_3COONH_4, which is formed by the reaction of weak acetic acid and weak ammonium hydroxide. As a salt, ammonium acetate undergoes dissociation:

$$CH_3COONH_4 \rightleftarrows CH_3COO^- + NH_4^+$$

In an aqueous solution, the acetate ion is able to accept a proton, and the ammonium ion to give back a proton, the process follows the equations

$$CH_3COO^- + H_2O \rightleftarrows CH_3COOH + OH^-$$

$$NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$$

In this case, water acts as both an acid and a hydroxide. The mentioned hydrolytic reactions run until the equilibrium state is established, in accordance with the values of the dissociation constants of the weak electrolytes formed. 1 mole of H_3O^+ ions and 1 mole of OH^- ions are formed, the equilibrium between the concentration of these ions in the solution is not disturbed.

The pH of an aqueous solution of this type of salt depends on the numerical values of the dissociation constants of weak acid (K_a) and weak hydroxide (K_b), if:

$K_a = K_b$, or they do not differ much – neutral reaction,
$K_a > K_b$ more than three orders of magnitude – slightly acidic reaction,
$K_a < K_b$ more than three orders of magnitude – weakly alkaline reaction,

Table 1

List of types of salt hydrolysis reactions

salt hydrolysis		
$NH_4Cl \rightarrow$ $NH_4^+ + Cl^-$	$CH_3COONa \rightarrow$ $CH_3COO^- + Na^+$	$CH_3COONH_4 \rightarrow$ $CH_3COO^- + NH_4^+$
$NH_4^+ + H_2O \rightleftarrows$ $NH_3 \cdot H_2O + H^+$	$CH_3COO^- + H_2O \rightleftarrows$ $CH_3COOH + OH^-$	$CH_3COO^- + NH_4^+ + H_2O \rightleftarrows$ $CH_3COOH + NH_3 \cdot H_2O$
cationic hydrolysis the cation is hydrolysed	anionic hydrolysis anions are hydrolysed	cationic-anionic hydrolysis cations and anions are hydrolysed
acidic nature of aqueous solution of salt	alkaline (basic) nature of aqueous solution of salt	neutral nature of aqueous solution of salt when $K_{base} = K_{acid}$
salts derived from strong acids and weak hydroxides	salts derived from strong hydroxides and weak acids	salts derived from weak acids and weak hydroxides

When the salt is dissolved in water or during the neutralization process, a dynamic equilibrium is established in the solution. The hydrolysis of each salt is characterized by such values as: the degree of hydrolysis, the hydrolysis constant and the concentration of hydronium ions or the concentration of hydroxyl ions.

1.1.1. Constant (K_h) and degree of hydrolysis (β)

The mentioned quantities will be derived only on the example of the hydrolysis of weak acid salt and strong hydroxide CH_3COONa.

It is enough to consider the hydrolysis of the anion itself. Denoting with the symbol C_s – the total concentration of salt in the solution, the symbol β – is the degree of acetic ion hydrolysis, and knowing that

$$\beta = \frac{C_h}{C_o} = \frac{concentration\ of\ hydrolysed\ particles}{initial\ concentration\ of\ particles}$$

then the reaction will follow the equation

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

After the process is established, the equilibrium constant (K_c) can be approximated by the relationship

$$K_c = \frac{[CH_3COOH]\,[OH^-]}{[CH_3COO^-]\,[H_2O]}$$

or

$$K_c \cdot [H_2O] = \frac{[CH_3COOH]\,[OH^-]}{[CH_3COO^-]}$$

The product of $K_c \cdot [H_2O]$ as a constant quantity at T = const. was named the hydrolysis constant denoted by the symbol K_h

$$K_h = \frac{[CH_3COOH] \cdot [OH^-]}{[CH_3COO^-]}$$

where: square brackets denote the concentration expressed in [mol/dm^3] of the respective ions and molecules at equilibrium.

If the numerator and denominator of the equation are multiplied by the concentration of hydronium ions $[H_3O^+]$, the expression for the constant K_h is obtained

$$K_h = \frac{[CH_3COOH]\cdot[OH^-]\cdot[H_3O^+]}{[CH_3COO^-]\cdot[H_3O^+]}$$

so

$$K_h = \frac{K_w}{K_a}$$

where:

K_w – the ion- product constant of water, which is equal to 10^{-14};

K_a – weak acid dissociation constant.

By introducing the notations $[CH_3COOH] = C_s \cdot \beta$,

$[OH^-] = C_s \cdot \beta$ and $[CH_3COO^-] = C_s \cdot (1 - \beta)$ into the relationship, another form of the equation for the hydrolysis constant is obtained

$$K_h = \frac{C_s \cdot \beta^2}{1 - \beta}$$

where:

C_s – salt concentration,
β – degree of hydrolysis.

If the value of β is very small, it can be represented as

$$K_h = C_s \cdot \beta^2$$

where:

C_s – salt concentration,
β – degree of hydrolysis.

When a salt of a weak acid and a strong hydroxide (e.g. CH_3COONa) reacts with water, the solution will be basic. The concentration of hydroxyl ions should be calculated assuming that $[OH^-] = C_s \cdot \beta$, then we obtain

$$\left[OH^-\right] = \sqrt{K_h \cdot C_s}$$

However, the exponent of the concentration of these ions (pOH) is calculated from the relationship

$$\mathrm{pOH} = -\log\sqrt{K_h \cdot C_s} = -\log\sqrt{\frac{K_w}{K_a} \cdot C_s}$$

knowing that

$$K_w = 10^{-14}$$

we obtain

$$\mathrm{pOH} = 7 - \frac{1}{2}\log C_s + \frac{1}{2}\log K_a$$

where:

C_s – salt concentration,
K_a – acid dissociation constant.

The exponent of the concentration of hydronium ions (pH) is determined from the equation

$$\mathrm{pH} = 7 + \frac{1}{2}\log C_s - \frac{1}{2}\log K_a$$

where:

C_s – salt concentration,
K_a – acid dissociation constant.

Note

The previously mentioned values for the remaining types of salt are derived in the same way, and their values are given in Table 2.

Table 2

Formulas for calculating characteristic quantities for salts reacting with water

Salt type	NH_4Cl	CH_3COONa	CH_3COONH_4
K_h constant	$\frac{10^{-14}}{K_b}$	$\frac{10^{-14}}{K_a}$	$\frac{10^{-14}}{K_b \cdot K_a}$
β degree	$\sqrt{\frac{10^{-14}}{K_b \cdot C_s}}$	$\sqrt{\frac{10^{-14}}{K_a \cdot C_s}}$	$\sqrt{\frac{10^{-14}}{K_a \cdot K_b}}$
$[H_3O^+]$	$\sqrt{\frac{C_s \cdot 10^{-14}}{Kb}}$	$\sqrt{\frac{K_a \cdot 10^{-14}}{C_s}}$	$\sqrt{\frac{K_a \cdot 10^{-14}}{K_b}}$
pH	$7 + \frac{1}{2} log\, K_b - \frac{1}{2} log\, C_s$	$7 - \frac{1}{2} log\, K_a + \frac{1}{2} log\, C_s$	$7 - \frac{1}{2} log\, K_a + \frac{1}{2} logKb$

3. PERFORMING THE EXERCISE

Experiment 1 – Testing the pH of an aqueous salt solution

Materials and reagents:

Rack with test tubes, measuring cylinder, micro spatula, indicators: universal, phenolphthalein, sodium sulphide solution (2M Na_2S), zinc chloride solution (2M $ZnCl_2$), copper(II) sulphate(V) ($CuSO_4$), sodium carbonate (Na_2CO_3), potassium nitrate(V) (KNO_3), sodium sulphate(VI) (Na_2SO_4), sodium acetate (CH_3COONa), ammonium chloride (NH_4Cl).

Performance:

Pour 4 cm^3 of distilled water into nine test tubes, then add 5 drops of the universal indicator to each of them. Leave the first test tube as a control sample, and successively add small amounts of salt specified in Table 6 to the next ones (**do not mix** !!!) and observe the colour of the indicator. Repeat the experiment using phenolphthalein as an indicator.

Table 3

Summary of the results of the experiment 2

No	Salt name	Salt formula	Colour of the indicator		pH	State whether aqueous solution of salt is acidic/basic/neutral
			Universal	Phenolphthalein		
1.	Control sample					
2.	Copper(II) sulphate(VI)					
3.	Sodium carbonate					
4.	Potassium nitrate(V)					
5.	Sodium sulphide *					
6.	Zinc chloride *					
7.	Sodium sulphate(VI)					
8.	Sodium acetate					
9.	Ammonium chloride					

* aqueous solution

Table 4

Colour change of the universal indicator according to Yamada depending on the exponent of the concentration of the hydronium ion (depending on the pH)

pH	Colour of the indicator
4.0	red
5.0	orange
6.0	yellow
7.0	green
8.0	blue
9.0	dark blue
10.0	purple

Elaboration of the results:

1. Fill in the Table 3.
2. For each salt, identify the acid and hydroxide from which the salt was formed; write down and complete the neutralization reactions leading to salt formation; specify the type of salt.
3. Write hydrolysis reactions of salts summarised in the Table 3. Justify the pH of the aqueous solution of salts.
4. Based on your previous knowledge and obtained results, make generalization by answering the questions:
   a) are all types of salt hydrolysed?
   b) what types of salts are and are not hydrolysed?
   c) what is the characteristic reaction of an aqueous solution for each type of salt?

Experiment 2 – Study of the influence of temperature on the salt hydrolysis reaction

Materials and reagents:

Rack with test tubes, measuring cylinder, solutions: sodium acetate (0.1M CH_3COONa), indicator: phenolphthalein.

Performance:

Pour 4 cm^3 of sodium acetate solution (0.1M CH_3COONa), into a test tube, add 2 – 3 drops of phenolphthalein. Then boil the solution and cool it. Observe and record any colour changes.

Elaboration of the results:

1. Write hydrolysis reaction of sodium acetate (CH_3COONa).
2. What is the influence of temperature on the course of the chemical reaction and the colour change of the solution? Justify why.

Experiment 3 – (theoretical) – writing down hydrolysis reactions of selected salts, identifying the type of salt hydrolysis reactions as well as stating whether aqueous solutions of given salts are acidic/basic/neutral

Elaboration of the results:

1. Determine the pH of the aqueous solutions of the given salts: $NaCl$; $Fe_2(SO_4)_3$; Na_2CO_3; $MgCl_2$; $MgCO_3$.
2. Write the hydrolysis reaction of K_2CO_3, determine the type of hydrolysis.
3. Write the hydrolysis reaction of $FeCl_2$, determine the type of hydrolysis.
4. Write the hydrolysis reaction of CH_3COONa, determine the type of hydrolysis.

4. DEVELOPMENT OF THE EXERCISES

1. Prepare a report according to the guidelines in the experimental section.
2. Place the cover sheet as the first page of the report.
3. After the theoretical part has been concisely developed, include in the report the study of individual experiments and the solved task/additional tasks given by the academic teacher.

5. THE FORM AND CONDITIONS FOR PASSING THE LABORATORY EXERCISE

1. Passing the so-called „entry test" before starting the exercise.
2. Submission of a correct written laboratory report on the performed exercise in accordance with the guidelines for the preparation of the laboratory report, please see the link below: https://www.am.szczecin.pl/en/facilities/institute-of-mathematics-physics-and-chemistry/department-of-chemistry/technical-chemistry/tech-chemistry-lab-manuals/

I. Examples of tasks with a solution

Example 1

Without writing down the chemical equations of the hydrolysis reactions, indicate which of the listed salts are subjected to hydrolysis and state the nature of aqueous solutions of given salts (acidic/basic/neutral): $(NH_4)_2SO_4$, K_2SO_4, K_2CO_3, K_2S, $NaNO_3$, $CuCl_2$, $(NH_4)_2CO_3$.

Solution:

- $(NH_4)_2SO_4$ – salt formed from a strong acid (H_2SO_4) and a weak hydroxide (NH_4OH), hydrolyses, the solution is acidic.
- K_2SO_4 – salt formed from a strong acid (H_2SO_4) and a strong hydroxide (KOH) does not hydrolyse, the solution is neutral.
- K_2CO_3 – salt formed from a weak acid (H_2CO_3) and a strong hydroxide (KOH) hydrolyses, the solution is alkaline (basic).
- K_2S – salt formed from a weak acid (H_2S) and a strong hydroxide (KOH) hydrolyses, the solution is alkaline (basic).
- $NaNO_3$ – salt formed from a strong acid (HNO_3) and a strong hydroxide (NaOH) does not hydrolyse, the solution is neutral.
- $CuCl_2$ – salt formed from a strong acid (HCl) and a weak hydroxide $Cu(OH)_2$ hydrolyses, the solution is acidic.
- $(NH_4)_2CO_3$ – salt formed from a weak acid (H_2CO_3) and a weak hydroxide ($NH_3 \cdot H_2O$) hydrolyses, the solution is neutral.

Example 2

Give two examples of salts whose aqueous solutions are:

a) acidic,
b) alkaline (basic),
c) neutral.

Solution:

a) acidic nature is present in aqueous solutions of salts formed from strong acids, e.g. HNO_3, HCl and weak hydroxides, e.g. $Cu(OH)_2$, $Zn(OH)_2$:
e.g. $Cu(NO_3)_2$ – copper(II) nitrate(V), $ZnCl_2$ – zinc chloride
b) alkaline (basic) nature is present in aqueous solutions of salts formed from-weak acids, e.g. H_2S, H_2CO_3 and strong hydroxides, e.g. KOH, $Ba(OH)_2$:
e.g. BaS – barium sulphide, K_2CO_3 – potassium carbonate
c) neutral nature is present in aqueous solutions of salts formed from weak acids, e.g. H_2SO_3, CH_3COOH and weak hydroxides, e.g. $Sn(OH)_2$, $Pb(OH)_2$:
e.g. $SnSO_3$ – tin(II) sulphate(IV) $(CH_3COO)_2Pb$ – lead acetate(II)

Example 3

Write hydrolysis reactions of given salts and state whether listed aqueous salt solutions are acidic/basic/neutral:

a) aluminium sulphate(VI),
b) sodium nitrate(III),
c) ammonium sulphate(IV),
d) potassium carbonate,
e) iron(II) chloride.

Solution:

a) Ion notation of the aluminum sulphate(VI) $Al_2(SO_4)_3$ hydrolysis reaction:

$$2Al^{3+} + 3SO_4^{2-} + 6H_2O \longrightarrow 6H^+ + 3SO_4^{2-} + 2Al(OH)_3$$

In the ionic notation of the equation, we pay special attention to the number of moles of ions formed as a result of the dissociation of strong electrolytes:

1 mol $Al_2(SO_4)_3$ in aqueous solution dissociates into 2 moles of Al^{3+} ions and 3 moles of SO_4^{2-} ions, from which 3 moles of H_2SO_4 molecules are formed. They dissociate to form 6 moles of H^+ ions and 3 moles of SO_4^{2-} ions. The ions of 3 moles SO_4^{2-} which are repeated on both sides of the equation, are omitted and we obtain:

$$2Al^{3+} + 6H_2O \longrightarrow 6H^+ + 2Al(OH)_3$$

hydrolysis reaction; acidic nature of salt solution (caused by H^+ ions)

b) Ionic notation of the sodium nitrate (III) $NaNO_2$ hydrolysis reaction:

$$Na^+ + NO_2^- + H_2O \longrightarrow HNO_2 + Na^+ + OH^-$$

The ions that do not take part in the reaction (they repeat on both sides of the equation) are omitted and we obtain:

$$NO_2^- + H_2O \longrightarrow HNO_2 + OH^-$$

hydrolysis reaction; alkaline (basic) nature of salt solution (caused by OH^- ions)

c) Ionic notation of the ammonium sulphate (IV) $(NH_4)_2SO_3$ hydrolysis reaction:

$$2NH_4^+ + SO_3^{2-} + 2H_2O \longrightarrow H_2SO_3 + 2NH_3 \cdot H_2O$$

The salt solution has a neutral nature.

d) Ionic notation of the potassium carbonate K_2CO_3 hydrolysis reaction:

$$2K^+ + CO_3^{2-} + 2H_2O \longrightarrow 2K^+ + 2OH^- + H_2CO_3$$

We omit the K^+ ions repeating on both sides of the chemical reaction and we obtain:

$$CO_3^{2-} + 2H_2O \longrightarrow 2OH^- + H_2CO_3$$

hydrolysis reaction; alkaline (basic) nature of salt solution (caused by OH^- ions)

e) Ionic notation of the iron(II) chloride $FeCl_2$ hydrolysis reaction:

$$Fe^{2+} + 2Cl^- + 2H_2O \longrightarrow Fe(OH)_2 + 2H^+ + 2Cl^-$$

We omit the ions that do not participate in the chemical reaction and we obtain:

$$Fe^{2+} + 2H_2O \longrightarrow Fe(OH)_2 + 2H^+$$

hydrolysis reaction; acidic nature of salt solution (caused by H^+ ions)

II. Tasks and questions to be completed by the student

1. Write down hydrolysis reactions of given salts, identify the type of salt hydrolysis as well as state the nature of listed salts (acidic/basic/neutral):
   a) $AgNO_3$,
   b) K_2S,
   c) $(NH_4)_2CO_3$,
   d) CuS.

2. Write down hydrolysis reactions of given salts, identify the type of salt hydrolysis as well as state the nature of listed salts (acidic/basic/neutral):
   a) Barium nitrate (V),
   b) Lead (II) nitrate (V).

3. The aqueous $NaHCO_3$ solution is less alkaline than the Na_2CO_3 solution of the same concentration. Explain this phenomenon by creating appropriate chemical equations.