Institute of Mathematics,
Physics and Chemistry

Department of Chemistry

Technical chemistry laboratory

Laboratory exercise

The Electrochemical Series

Elaborated by:
dr inż. Andrzej Kozłowski
dr inż. Agnieszka Kalbarczyk-Jedynak
dr Magdalena Ślączka-Wilk
dr inż. Konrad Ćwirko
mgr inż. Czesław Wiznerowicz
Grażyna Gorzycka

KIEROWNIK
Zakładu Chemii
dr inż. Agnieszka Kalbarczyk-Jedynak

Szczecin 2022

EXERCISE SHEET

<table>
<tr><td rowspan="4">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
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>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 the basic chemical concepts of corrosion and acquiring practical knowledge in the fields:
– galvanic cells and processes taking place in the cell,
– the galvanic series (or electrochemical-series),
– electrochemical corrosion mechanism,
– anodic protection,
– processes taking place in the cell.</td></tr>
<tr><td>3.</td><td colspan="3">Prerequisites:
general knowledge of oxidation and reduction processes, properties and corrosion of metals, knowledge of the principles of work in a chemical laboratory.</td></tr>
<tr><td>4.</td><td colspan="3">Description of the laboratory workplace:
laboratory glassware kit, multimedia projector, metal sample kit, electrochemical corrosion reagent kit, phenolphthalein, ferroxide indicator.</td></tr>
<tr><td>5.</td><td colspan="3">Risk assessment:
Chemical burns resulting from contact with 0.2 M sulphuric acid and caustic soda are very unlikely, the possible 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) and the kit for testing electrochemical corrosion.
2. Carrying out chemical reactions.</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>
</table>

8.	**Archiving of research results:** report on exercises – prepared in accordance with the rules applicable in the laboratory – 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 corrosion during classes. 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 does not have basic knowledge of metals and their corrosion, or is unable to use it in practice to solve the problems of protecting structures and devices against corrosion; – **mark 3,0** – has basic chemical knowledge of the activity of metals, the mechanism of electrochemical corrosion and protection against corrosion, and can use it to a small extent to solve potential problems in his specialty; – **mark 3,5 – 4,0** – has extensive chemical knowledge of corrosion and its mechanisms, methods of protection against corrosion, operation of electrochemical cells and is able to use it in a wide range in his profession; – **mark 4,5 – 5,0** – has complete chemical knowledge of corrosion and electrochemical cells, their mechanisms and is able to use complex chemical knowledge to identify the mechanism of electrochemical corrosion and select the best protection method in complex corrosion cases.
10.	**Literature:** 1. Kozłowski A., Gabriel-Półrolniczak U., Workplace instruction for laboratory exercises *Korozja i ochrona przed korozją,* AM Szczecin, 2014. 2. Stundis H., Trześniowski W., Żmijewska S.: *Ćwiczenia laboratoryjne z chemii nieorganicznej*. WSM, Szczecin 1995. 3. Jones L., Atkins P., *Chemia ogólna. Cząsteczki, materia reakcje*, WN PWN, Warsaw, 2004. 4. Baszkiewicz J., *Podstawy korozji materiałów*, Oficyna Wydawnicza PW, Warsaw, 1997. 5. Bielański A., *Chemia ogólna i nieorgani*czna, PWN, Warsaw, 1996. 6. Śliwa A., Chemical calculations, PWN, Warsaw 1987 Wranglén G., *Podstawy korozji i ochrony metali*, WNT, Warsaw 1985. 7. Wranglén G., *Podstawy korozji i ochrony metali*, WNT, Warsaw 1985. 8. Kozłowski A., *Materiały dydaktyczne z chemii technicznej*, 2013 (not published), available on the website of the Maritime University of Szczecin. 9. Borzdyński J., Elektronik, Online edition: 412. Batteries. A revolution on the market? 10. Chemistry. Virtual textbook. *Ogniwa w zastosowaniu praktycznym*, http://www.chemia.dami.pl/liceum/liceum12/elektrochemia5.htm 11. Multimedia presentation „*Korozja elektrochemiczna*" from the resources of the AGH e-learning center in Krakow: http://zasoby1.open.agh.edu.pl/dydaktyka/chemia/a_e_chemia/filmy/wmv/
11.	Notes

APPENDIX 1 – MANUAL

1. SCOPE OF THE EXERCISE:

Issues and keywords:

- electrochemical series,
- reducing and oxidizing properties of metals,
- standard potential.

2. THEORETICAL INTRODUCTION TO THE EXERCISE

2.1. The electrochemical series (the activity-series)

The combination of elements according to increasing values of the standard potentials is called the electrochemical series (Fig. 1).

Standard Electrode Potentials E^0 established by measuring the potentials of various electrodes versus standard hydrogen electrode at 25°C

Electrode	Electrode Reaction	E^0 [Volts] at 25°C
Li^+/Li	$Li^+ + e^- \rightleftharpoons Li$	– 3,000
K^+/K	$K^+ + e^- \rightleftharpoons K$	– 2,922
Ba^{2+}/Ba	$Ba^{2+} + 2e^- \rightleftharpoons Ba$	– 2,920
Ca^{2+}/Ca	$Ca^{2+} + 2e^- \rightleftharpoons Ca$	– 2,840
Na^+/Na	$Na^+ + e^- \rightleftharpoons Na$	– 2,713
Mg^{2+}/Mg	$Mg^{2+} + 2e^- \rightleftharpoons Mg$	– 2,370
Al^{3+}/Al	$Al^{3+} + 3e^- \rightleftharpoons Al$	– 1,660
Mn^{2+}/Mn	$Mn^{2+} + 2e^- \rightleftharpoons Mn$	– 1,180
Zn^{2+}/Zn	$Zn^{2+} + 2e^- \rightleftharpoons Zn$	– 0,763
Cr^{3+}/Cr	$Cr^{3+} + 3e^- \rightleftharpoons Cr$	– 0,710
Fe^{2+}/Fe	$Fe^{2+} + 2e^- \rightleftharpoons Fe$	– 0,441
Cd^{2+}/Cd	$Cd^{2+} + 2e^- \rightleftharpoons Cd$	– 0,402
Co^{2+}/Co	$Co^{2+} + 2e^- \rightleftharpoons Co$	– 0,277
Ni^{2+}/Ni	$Ni^{2+} + 2e^- \rightleftharpoons Ni$	– 0,236
Sn^{2+}/Sn	$Sn^{2+} + 2e^- \rightleftharpoons Sn$	– 0,136
Pb^{2+}/Pb	$Pb^{2+} + 2e^- \rightleftharpoons Pb$	– 0,126
Fe^{3+}/Fe	$Fe^{3+} + 3e^- \rightleftharpoons Fe$	– 0,040
$2H_3O^+/H_2+2H_2O$	$2H_3O^+ + 2e^- \rightleftharpoons H_2+2H_2O$	0,000
Cu^{2+}/Cu	$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+ 0,368
Cu^+/Cu	$Cu^+ + e^- \rightleftharpoons Cu$	+ 0,522
$I_2/2I^-$	$I_2 + 2e^- \rightleftharpoons 2I^-$	+ 0,536
$Hg_2^{2+}/2Hg$	$Hg_2^{2+} + 2e^- \rightleftharpoons 2H$	+ 0,798
Ag^+/Ag	$Ag^+ + e^- \rightleftharpoons Ag$	+ 0,799
Hg^{2+}/Hg	$Hg^{2+} + 2e^- \rightleftharpoons Hg$	+ 0,854
$Br_2/2Br^-$	$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+ 1,066
Pt^{2+}/Pt	$Pt^{2+} + 2e^- \rightleftharpoons Pt$	+ 1,200
$Cl_2/2Cl^-$	$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+ 1,359
Au^{3+}/Au	$Au^{3+} + 3e^- \rightleftharpoons Au$	+ 1,420
Au^+/Au	$Au^+ + e^- \rightleftharpoons Au$	+ 1,680
$F_2/2F^-$	$F_2 + 2e^- \rightleftharpoons 2F^-$	+ 2,850

ACTIVE

NOBLE

Fig. 1. The Electrochemical Series of Elements

On the basis of the galvanic series, the direction of the spontaneous redox reaction can be predicted. The lower the value of the standard potential, the greater the reducing capacity of the metal; the higher the value of the standard potential of the metal, the greater its oxidizing capacity.

The location of the metal in the electrochemical series is also of great practical importance:

– the most electropositive metals (Li, K, Ba, Ca, Na) displace hydrogen from water:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

– a metal with a higher potential is displaced from the salt solution, e.g. zinc immersed in copper(II) sulphate(VI) becomes covered with copper:

$$CuSO_4 + Zn \rightarrow ZnSO_4 + Cu$$

– base metals located above hydrogen in the galvanic series, displace hydrogen from non-oxidizing acids, i.e. they „dissolve" in acids:

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

– semi-precious metals, lying in the galvanic series below hydrogen, „dissolve" in oxidizing acids without releasing hydrogen, e.g. nitrogen from the +5 degree of oxidation in the acid HNO_3 changes to the +2 degree of oxidation in the nitric oxide:

$$3Cu + 2NO_{3\,(dis)}^{-} + 8H_3O^{+} \rightarrow 3Cu^{2+} + 2NO + 12H_2O$$

Metals lying in the electrochemical series above hydrogen have reducing properties and they become stronger the more negative their standard potential is. The metals below hydrogen in this series have oxidizing properties the stronger the more positive their standard potential is. The EMF of the cell will be the greater the farther apart the metals are placed in the voltage series.

3. PERFORMING THE EXERCISE

Experiment 1 – Reactions of metals with acids

Materials and reagents:

Rack with test tubes, measuring cylinder, concentrated hydrochloric acid (conc. HCl), diluted hydrochloric acid (2 M HCl), diluted nitric acid(V) (2 M HNO_3), concentrated nitric acid(V) (conc. HNO_3), pieces of zinc (Zn), copper (Cu)

Performance:

The bars or plates of the tested metals should be thoroughly cleaned with sandpaper, approx. 2 cm wide, then rinse their ends with plain water, and then with distilled water. To two test tubes, pour successively 1 cm^3 of hydrochloric acid (2 M HCl) – to the first and nitric(V) (2 M HNO_3) – to the second test tube. Pour 1cm^3 of these acids, but concentrated (conc. HCl; conc. HNO_3) into two next test tubes. Dip previously cleaned pieces of metals into each acid of different concentrations and observe the reactions taking place. Repeat the reactions for each metal and observe the occurring phenomena. Record the observations in the summary table (Table 1).

Table 1

Summary of observations and results of experiment 1

Test tube number	Type of acid	Metal	The ongoing reaction	Change in the oxidation state	Observations
1.	2 M HCl	Zn			
2.	2 M HNO_3	Zn			
3.	concentrated HCl	Cu			
4.	concentrated HNO_3	Cu			

Elaboration of the results:

1. Based on the observed reaction products, write down the equations of reactions taking place in the test tubes.
2. Explain the reactions taking place by the position in the voltage series of metals in relation to hydrogen.

Experiment 2 – Reactions between metals and salt solutions

Materials and reagents:

Rack with test tubes, solutions: iron(II) sulphate (5% $FeSO_4$), copper(II) sulphate(VI) (1% $CuSO_4$), silver nitrate(V) (0.1 M $AgNO_3$), pieces of zinc (Zn), copper (Cu), small nails (Fe)

Performance:

Pour about 1 cm^3 of the solution indicated in items 1 – 7 of the table into the next seven test tubes, and then place the appropriate metal indicated in the table in it and observe the phenomenon taking place in the subsequent test tubes (e.g. gas evolution, metal dissolution or reduction, sediment colour). Record the observed results in Table 2.

Table 2

Summary of observations and results of experiment 2

Test tube number	Solution	Metal	The ongoing reaction	Change in the oxidation state	Observations
1.	1% $CuSO_4$	Zn			
2.	0.1 M $AgNO_3$	Zn			
3.	5% $FeSO_4$	Zn			
4.	1% $CuSO_4$	Fe			
5.	0.1 M $AgNO_3$	Fe			
6.	5% $FeSO_4$	Cu			
7.	0.1 M $AgNO_3$	Cu			

Elaboration of the results:

1. Based on the observed reaction products, write down the equations of reactions taking place in the test tubes.
2. Explain the occurring/non-occurring reactions with the location of metals in the electrochemical series.

Experiment 3 – Reactions of iron (Fe) with acids

Materials and reagents:

Rack with test tubes, measuring cylinder, concentrated hydrochloric acid (conc. HCl), diluted hydrochloric acid (2 M HCl), diluted nitric acid(V) (2 M HNO_3), concentrated nitric acid(V) (conc. HNO_3), iron nails (Fe)

Performance:

To two test tubes, pour successively 1 cm^3 of diluted hydrochloric acid (2 M HCl) – to the first and diluted nitric(V) (2 M HNO_3) – to the second test tube. Pour 1 cm^3 of these acids, but concentrated (conc. HCl; conc. HNO_3) into the two next test tubes. Dip the previously cleaned iron nails into each acid of different concentrations and observe the reactions taking place. Record the observations in the summary table (Table 3).

Table 3

Summary of observations and results of experiment 3

Test tube number	Type of acid	Metal	The ongoing reaction	Change in the oxidation state	Observations
1.	2 M HCl	Fe			
2.	Concentrated HCl	Fe			
3.	2 M HNO_3	Fe			
4.	Concentrated HNO_3	Fe			

Elaboration of the results:

1. Based on the observed reaction products, write down the equations of reactions taking place in the test tubes.
2. Explain the reactions taking place with the position in the electrochemical series in relation to hydrogen.

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 a task with a solution

Example

Determine which of the following reactions will take place and list their products:

1) $Cu + MgCl_2$,
2) $Fe + AgNO_3$,
3) $Zn + HCl$.

The standard potentials of metallic electrodes are correspondingly:

Mg/Mg^{2+}	–2.34V
Zn/Zn^{2+}	–0.76V
Fe/Fe^{2+}	–0.44V
Cu/Cu^{2+}	0.34V
Ag/Ag^{+}	0.80V

Solution

We compare the standard potentials of both metals present in the reactants.

In reaction 1 the potential of the copper electrode (0.34 V) is higher than that of the magnesium electrode (–2.34 V), therefore the reaction will not take place.

1) $Cu + MgCl_2 \longrightarrow$ no reaction

In reaction 2, the potential of the iron electrode (–0.44 V) is lower than the potential of the silver electrode (0.80 V), therefore iron displaces silver from its salt according to the reaction:

2) $Fe + 2AgNO_3 \longrightarrow Fe(NO_3)_2 + 2Ag$

In reaction 3, the potential of the zinc electrode (–0.76 V) is lower than the potential of the hydrogen electrode (0 V), therefore zinc displaces the hydrogen from the acid according to the reaction:

3) $Zn + 2HCl \longrightarrow ZnCl_2 + H_2\uparrow$

II. Tasks and questions to be completed by the student

1. The following solutions were poured into three test tubes: $CuSO_4$, H_2SO_4 i $ZnSO_4$. A piece of iron was thrown into each of them. What are the reactions? Write molecular equations.
2. A cadmium plate with a mass of 100 g was immersed in a $CuSO_4$ solution. After some time, the plate was taken out, dried and weighed. Its weight was found to be 90.4 g. Calculate how many grams of copper have deposited on the plate.
3. An iron plate weighing 158 g was dipped into the $CuSO_4$ z solution. After removal from the solution, washing and drying, the mass of the plate was found to have increased by 2 g. How many grams of iron went into solution?
4. Which of the following substances may react with each other? Write the molecular form of chemical reaction:

a) $Zn(NO_3)_2 + Pb \longrightarrow$
b) $AlCI_3 + Mg \longrightarrow$
c) H_2SO_4 (dis.) + Ni $\longrightarrow$
d) HCl + Cu $\longrightarrow$
e) $Na_2SO_4 + Al \longrightarrow$

5. A nickel plate was placed in the silver nitrate solution. After some time, it was removed from the solution, washed, dried and weighed. The weight of the plate increased by 7.3 g. How many grams of silver were released on the plate?
6. Rank the following metals according to increasing reducing abilities:

   a) Cu, Zn, Cr, Fe;
   b) Li, Na, K, Mg;
   c) Ni, Sn, Au, Ag.

7. Mark which of the following reactions take place, fill in the products and stoichiometric coefficients:

   a) $Zn + HNO_3 \longrightarrow$
   b) Ag + HBr $\longrightarrow$
   c) Cu + $H_2SO_{4\ conc.}$ $\longrightarrow$

8. Complete the reactions and fill in the stoichiometric coefficients:

   a) $Zn + Pb(NO_3)_2$;
   b) $Pb + MgCl_2$;
   c) Fe + NaCl.

9. What chemical properties of a metal result from its position in the electrochemical series?