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An Analysis of the Recognition on Definition and Mechanism of Electrolysis for University Students Major in Science Education

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Abstract

This study has been investigated the conceptions for university students major in science education on definition and mechanism of electrolysis by a questionnaire.

From this result, we found that much of students could not explain electrolysis as an oxidation-reduction reaction or chemical reaction, but they defined it as a separation or decomposition reaction of ions and electrolytes in the solution. Also, they showed little understanding about charge disproportion which was induced by oxidation-reduction reaction on the surface of electrode and a relationship between the migration of ions and overall reaction.

It is also obtained that some descriptive mistakes were in Korean chemistry textbooks. And, it could be said that university students were affected by the descriptive mistakes on their concept formation.

Keywords: Conception, Text description, Electrolysis

INTRODUCTION

Students have been formed misconceptions on electrochemistry because it is a subject not kind to direct observations. Garnett and Treagust [1-3] studied common misconceptions formed by students on electric circuits, oxidation-reduction reactions, galvanic cells, and electrolysis cells through interviews with students. Ogude and Bradley [4-5] reported that college students held various misconceptions on the topic of electrochemistry. And Özkaya [6] reviewed for difficulty of understanding the concept of electrochemistry even in pre-teachers.

Several efforts helped systematize studies on student-held misconceptions on electrochemical reactions, and more researches are currently in progress to prevent such misconceptions in classroom environment and to improve the learning process on the topic [7-10, 11]. Yang *et al*., [12] did a study on the effect of interactive software on reducing student's misconceptions on electrolytic cells, and Niaz *et al.* [13,14] devised class strategies with varying concepts that increase the comprehensibility of electrochemistry.

However, studies on electrolysis in electrochemical sections are carried out in domestic study field by only few numbers of researchers and they have their limitations. Most of these studies are merely a questionnaire performed on current students and student teachers [15]. Kim *et al*., [16], Lim *et al*., [17] and Shin and Choi., [18] tried analyzing pre-service teachers of chemistry through a questionnaire on concepts of galvanic cells and electrolytic cells, but only fractional part of materials on electrolysis were covered in this study. The covered concepts were electrode classification, understanding of generation and flow of electric currents, and understanding of salt bridge. Park *et al*., [19-22] tried analyzing the difficulties by high school students, student teachers, and current teachers in understanding the concept of electrolysis, but it does not fully cover the intent of a long-term awareness study covered in this paper.

This study gathers data of college students level of understanding of the concept of electrolysis over a long period of time in order to successfully fuse newly amended chemistry education curriculum to high school classroom and effectively manage the education curriculum [23-26]. It also categorizes different concepts of electrolysis, and studies the trend in the level of understanding over time. Studying the trend in student understanding and paying attention to student feedbacks regarding a concept of science is considered critical in research of education curriculum.

EXPERIMENTAL

The questionnaire was structured as followed: 1) definition of electrolysis and 2) understanding the reaction mechanism of electrolysis.

Questionnaire was presented in percent scale for multiple-choice questions, and questions that required reasoning and explanations were categorized into different response types and were presented by respondent percentage of each type.

This study also analyzed ten different Chemistry II textbooks published during 6^{th} revision of National Education Curriculum, eight different Chemistry II textbooks published during 7^{th} revision of National Education Curriculum, and four different Chemistry II textbooks published during 2007 amendment of National Education Curriculum [27-44].

The international textbooks reviewed were three from Singapore, one from Australia, five from United Kingdom, one from Canada, one from France, one from Australia, one from United States, one from Brazil, one from Argentina, one from Germany, and eleven from Japan for total of 26 from 11 countries [45-56].

RESULTS AND DISCUSSIONS

Student's response on definition of electrolysis

Student responses to the question, "definition the electrolysis", could be broadly categorized into five different types as illustrated in table 1 and figure 1. A) Separation (or destroy) of material by electricity energy, B) Non-simultaneous reaction by using electricity energy, C) Change of electricity energy to chemical energy, D) Chemical change (redox reaction), E) No response

Most students defined the electrolysis as "breaking (or separation) of a chemical substance using electric energy". In 2007 survey, 17 students (71%) made such response, and 8 students (80%) made such response in 2010 survey. 4 students (67%) did so in 2014 survey. Three separate investigations all produced similar results. Some other response types were "driving of a non-spontaneous reaction using electric energy", "transformation of electric energy into chemical energy", and "a process of chemical change (redox reaction)".

Looking at the student responses in table 1 reveals that students tended to respond by linguistically breaking down the term "electrolysis" rather than defining the chemical phenomenon comprehensively. Less than 25% of the respondents answered using terms, "reduction" and "oxidation", showing very small percentage of students understand electrolysis in terms of redox reactions.

Table 1: Students' cognition about the definition of electrolysis

Category of student's response		Response ratio		
		2007'	**2010'**	**2014'**
A	Separation (or destroy) of material by electricity energy	17(71%)	8(80%)	4(67%)
B	Non-simultaneous reaction by using electricity energy	0(00%)	0(00%)	0(00%)
C	Change of electricity energy to chemical energy	1(04%)	1(10%)	0(00%)
D	Chemical change (redox reaction)	6(25%)	1(10%)	0(00%)
E	No response	0(00%)	0(00%)	2(33%)
Total (number)		**24**	**10**	**6**

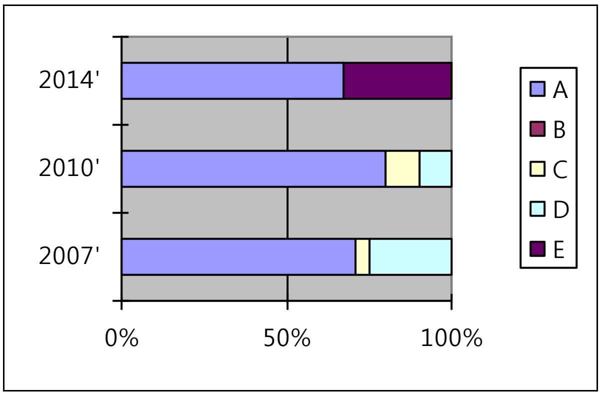


Figure 1. Diagram of change of students' cognition about the definition of electrolysis.

To investigate the reason of Korean students' misconception, we first looked at textbooks which was published at 6^{th}, 7^{th} and 8^{th} National Education Curriculum (table 2, table 3, figure 2).

Most of textbooks (80%) tended to define electrolysis as a chemical change or redox reaction in 6^{th} chemistry textbooks. However, textbooks that defined electrolysis in terms of chemical change still used the term "breaking" or "separating" as in textbook, for example, "in many cases, water molecules instead ion electrolytes break during electrolysis" [57].

Frequent use of such terms is one of the factors that contributed to student thinking treating electrolysis as a breaking (separation) of a substance. When you take a look at latter part of the chapter dealing with Faraday's Law and application of electrolysis, most chemistry textbooks state, "The amount of precipitates formed during reaction of positive and negative charge during electrolysis is proportional to the amount of electric charge". Also, the text mentions electroplating and smelting that form precipitate of metallic ions as an example of electrolysis application. Such examples are considered to have contributed to student's ability to recall electrolysis as a separation and breaking of ions within the solution.

And, in 7^{th} chemistry textbooks, they defined electrolysis as "breaking or separation of a substance" increased (50%) whereas the portion of textbooks defining electrolysis as "a chemical change" decreased (37%) compared to 6^{th} revision of National Education Curriculum [57].

And in 2007 chemistry textbooks, the portion of textbooks that defined electrolysis as "breaking or separation of a substance" decreased (25%) while the portion of textbooks that defined electrolysis as "non-spontaneous redox reaction" increased compared to the Seventh Revision of Education curriculum [57].

Table 2: The definition of electrolysis in Korean high school Chemistry II textbooks

		Textbook definitions
6^{th} National Curriculum	6A	Electrolysis is a chemical change of a substance caused by applying an electric current.
	6B	Oxidation-reduction reaction occurs when two electrodes are dipped in the electrolytic solution and direct current is externally applied to them. This is called electrolysis.
	6C	Electrolysis is creating a non-spontaneous oxidation-reduction reaction using electric energy.
	6D	Electrolysis is breaking of an electrolyte when electric current is applied to the electrolytic solution.
	6E	Electrolysis is creating of an oxidation-reduction reaction by applying direct current to a solution with electrolytes such as acid, base, and salt dissolved in it.
	6F	When electrolyzing a solution using platinum electrode and direct current, anions (-) are oxidized at the positively charged electrode and cations (-) are reduced at the negatively charged electrode.

	6G	A chemical change occurs at the electrode when an electric current is applied to an electrolytic solution or electrolyte in the molten state. This phenomenon is called electrolysis.
	6H	Electrolysis is causing a chemical change with electric current.
	6I	A chemical change occurs at each of two electrode surfaces when the electrodes are dipped in an electrolytic solution and direct current is applied to them externally. This is called electrolysis and also sometimes called electrolytic cells.
	6J	A chemical change occurs at each of two electrodes when the electrodes are dipped in an electrolytic solution and electric current is applied to them externally. This phenomenon is called electrolysis.
7th National Curriculum	7A	Breaking of a substance by transforming electric energy into chemical energy using oxidation-reduction reaction within an electrolytic solution is called electrolysis and sometimes called electrolytic cells.
	7B	Electric energy is used for creating a non-spontaneous reaction, and use of electric energy for creating a non-spontaneous oxidation-reduction reaction is called electrolysis.
	7C	When an electric current is applied to an electrolytic solution, cations (+) become reduced at the negatively charged electrode and anions (-) become oxidized at the positively charged electrode. Such chemical breaking of a substance into elemental atoms by electric current is called electrolysis.
	7D	Breaking of a molten salt or a solution due to applied electric current is called electrolysis.
	7E	A chemical change occurs at each of two electrodes when electrodes are dipped in an electrolytic solution and electric current is externally applied. This is called electrolysis.
	7F	A phenomenon of electric current stirring up a chemical change is called electrolysis.
	7G	Electrolysis is using electric energy to break a chemical compound.
	7H	It is called electrolysis when a chemical change occurs at each of two electrodes as electrodes are dipped in an electrolytic solution and applied with direct current.
2007th National Curriculum	8A	It is called electrolysis when electric energy is used to create a non-spontaneous oxidation-reduction reaction.
	8B	Electrolysis is applying electric energy to an electrolytic solution to create a non-spontaneous chemical reaction.
	8C	A non-spontaneous oxidation-reduction can occur when external electric energy is applied. Such process is called electrolysis.
	8D	Electrolysis is breaking of a substance using electric energy.

Table 3: Categorization of definitions of electrolysis in chemistry textbooks. A) Breaking or separating a substance (electrolyte) using electric energy, B) Transformation of electric energy into chemical energy, C) Chemical change (reaction), D) Oxidation-reduction reaction, E) Non-spontaneous redox reaction

Category of student's response		Response ratio		
		6th	**7th**	**2007th**
A	Breaking or separating a substance (electrolyte) using electric energy	1(10%)	4(50%)	1(25%)
B	Transformation of electric energy into chemical energy	0(00%)	0(00%)	0(00%)
C	Chemical change (reaction)	5(50%)	3(37%)	0(00%)
D	Oxidation-reduction reaction	3(30%)	0(00%)	0(00%)
E	Non-spontaneous redox reaction	1(10%)	1(13%)	3(75%)
Total (number)		**10**	**8**	**4**

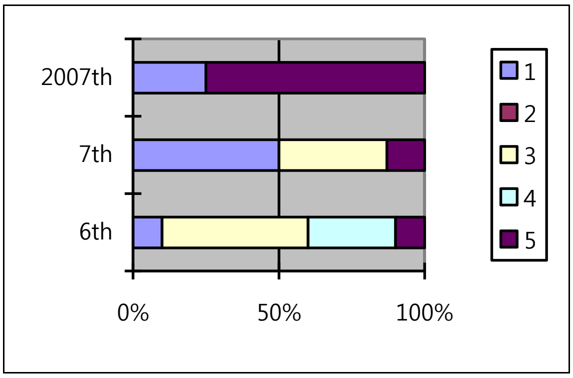


Figure 2. Diagram of change of textbook descriptions about the definition of electrolysis.

Next step was to look at frequency of scientific terms used for defining electrolysis [58]. The term "electrode" appeared in definition of electrolysis in five of the textbooks of 6th revision of National Education Curriculum, and the term "electrolyte" was used in six of the textbooks. The term "external power (or current)" was used in ten of the textbooks. The term "redox reaction" or "chemical reaction" was used in nine of the textbooks. However, only four the textbooks defined electrolysis using all the mentioned terms.

In textbooks of 7th revision of National Education Curriculum, the term "electrode" appeared in three of the textbooks, "electrolyte" in six, "external power (current)' in seven textbooks, and "redox reaction (chemical reaction)" appeared in six textbooks. Only two of the textbooks defined electrolysis using all the mentioned terms [57].

In textbooks of 2007 amendment of National Education Curriculum, the term "electrode" appeared in one of the textbooks, and other terms such as "electrolyte", "electric current", and "redox reaction (chemical reaction)" was not put to use.

Such lack of use of technical terms in defining electrolysis in chemistry textbooks is the main cause of student's inability to define electrolysis with scientific terms.
And then, to compare the Korean textbook description, we looked the description at international chemistry textbooks (table 4 and figure 3).

Table 4: Definitions of electrolysis in international chemistry textbooks

Nation	Description
Japan 1	Cation of the aqueous solution is an electronically receiving electronic reaction that gave a negative ion.
Japan 2	If two electrodes are added in electrolyte solution, and the direct current are supplied, the redox reactions are happened. Electrolysis of this manipulation.
Japan 3	Redox reaction that doesn't happen voluntarily, the electrical energy from outside provoke a manipulation.
Japan 4	Causing oxidation and reduction as compulsory with the electrical energy.
Japan 5	Redox reaction to it.
Japan 6	Redox reaction.
Japan 7	Redox reaction that doesn't happen in nature to proceed with the help of electrical power operation.
Japan 8	Redox reaction.
Japan 9	Mandatory that triggers the oxidation and reduction.
Japan 10	Redox the electrode
Japan 11	Oxidation-reduction to provoke a reaction.
Canada	The process that takes place in an electrolytic cell is called electrolysis.
France	An electrolyze consists of a vessel, two electrodes and an electrolyte solution. That is to say a solute dissociates into ions
Singapore 1	Electrolysis is the chemical decomposition of an ionic substance (molten or in solution) using electricity
Singapore 2	When an electric current is passed through an ionic compound, the compound is decomposed in a chemical reaction.
Singapore 3	The conduction of electricity by an ionic compound, when molten or dissolved in water, leading to its decomposition is called electrolysis.
UK 1	The word electrolysis means splitting with electricity.
UK 2	the salt or electrolyte is split up in a chemical process called electrolysis. Chemical Process
UK 3	Electrolysis is a Chemical change caused by passing en electric current through a compound which is either molten or in solution.
UK 4	Chemical Process
UK 5	The change brought about by electrical energy in an electrolytic cell is known as electrolysis.
USA	The process in which electrical energy is used to bring about such a chemical change is called electrolysis.
Brazil	The reverse process, in which the passage of electric current through a liquid system where there are ions produces chemical reactions, it is not spontaneous and called electrolysis
Argentina	Electric energy to chemical energy
Germany	The decomposition of a connection by means of the electric current designated

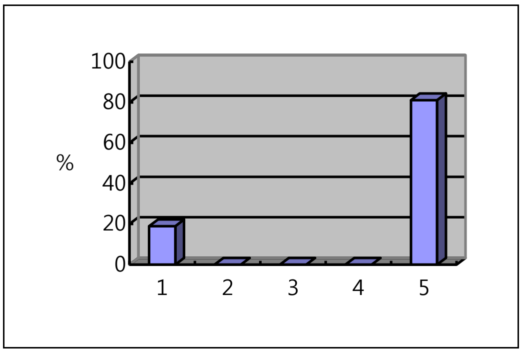


Figure 3. Diagram of international textbook descriptions about the definition of electrolysis. Categorization of definitions of electrolysis in chemistry textbooks.1) Breaking or separating a substance (electrolyte) using electric energy, 2) Ionization of a substance due to redox reaction, 3) Transformation of electric energy into chemical energy, 4) Process of a chemical change (oxidation-reduction reaction), 5) No relevant explanation.

Most Japanese textbooks define electrolysis using the concept of oxidation-reduction reaction, and most of them are meticulous with use of scientific terms. Japanese textbooks use specific and accurate scientific terms because Japan requires auditing of textbooks for scientific terms defined in chemistry handbook published by Ministry of Education, Culture, Sports, Science and Technology.

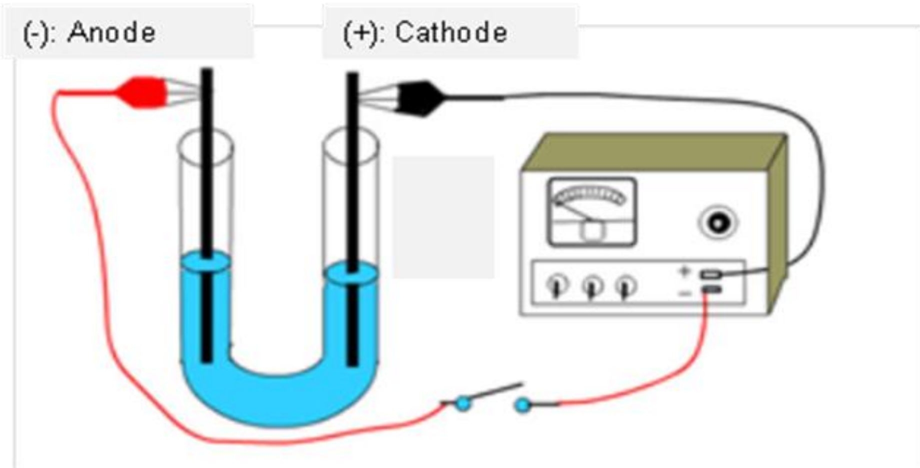
General chemistry textbooks and reference texts of electrochemistry used in universities and colleges [59-61] also define electrolysis in terms of redox reaction and not in narrow scopes of separation of a substance or precipitation of an ion.

In result, globally, most high school chemistry textbooks and general chemistry texts define electrolysis as a redox reaction or a chemical change because the main focus of electrolysis is the analysis of a chemical reaction taking place at each electrode. It is the focus of many researches in practice, and most researches on electrolysis target biological substance such as protein as well as organic compounds. Both qualitative and quantitative studies on electron transport system of such substances are currently taking place [62-64].

Korean textbooks that define electrolysis as "breaking of a substance using electric energy and its reaction" portrays only fractional part of the concept of electrolysis and it interferes with understanding the full concept. Therefore, textbooks to be published for newly amended education curriculum should be edited to define electrolysis in terms of redox reaction.

REVIEW OF THE REACTION MECHANISM OF ELECTROLYSIS

Q. We are stating the electrolysis experiment in the condition of as below as the experiment condition. In the 1M NaCl solutions, there is Na^+, Cl^-, H^+, OH^- and H_2O as solvent.



Select the numbers and write the order of electrolysis mechanism?

① Applied outlet voltage

② Ion among the ionic species in the solution migrate to the against charged electrode

③ Redox reaction happen on the surface of electrodes

④ Generation of gases at the electrode

⑤ Ionic diffusion in the solution caused by concentration difference near the electrodes

⑥ Completed the electronic circuit

Figure 4. Questionnaire for selecting the reaction mechanism of electrolysis in 1 M NaCl solution.

Student responses to the questionnaire (figure 4), "select and assign the order of electrolysis mechanism among the 6 items", could be broadly categorized into several different types as illustrated in table 5 and figure 5.

Only 40~67% of student included "⑤ Ionic diffusion in the solution caused by concentration difference near the electrodes" in their response. It shows that students lack understanding of the phenomenon of concentration difference near each electrode, or the charge imbalance caused by the electrode reaction. They also lack understanding of the need for ions to move toward the electrode in a solution for maintaining an electrolytic reaction.

Table 5: Students' cognition about the mechanism of electrolysis

Category of student's response		Response ratio		
		2007'	2010'	2014'
A	①→②→⑤→③→④→⑥	4(17%)	0(00%)	1(17%)
B	①→⑥→②→③→④	4(17%)	2(20%)	0(00%)
C	①→②→③→④→⑤→⑥	3(13%)	2(20%)	1(17%)
D	①→⑤→②→③→④→⑥	2(08%)	0(00%)	1(17%)
E	①→③→④→⑤→⑥	0(00%)	2(20%)	1(17%)
F	①→②→④→③	2(08%)	0(00%)	0(00%)
G	①→⑤→②→③→④	1(04%)	0(00%)	0(00%)
H	①→⑥→②→③→④→⑤	2(08%)	0(00%)	0(00%)
I	①→⑥→⑤→②→③→④	1(04%)	0(00%)	0(00%)
J	①→②→③→④→⑥	3(13%)	2(20%)	0(00%)
K	①→②→③→④	1(04%)	2(20%)	1(17%)
L	①→②→⑥→③→④→⑤	1(04%)	0(00%)	0(00%)
M	No response	0(00%)	0(00%)	1(17%)
Total (number)		24	10	6

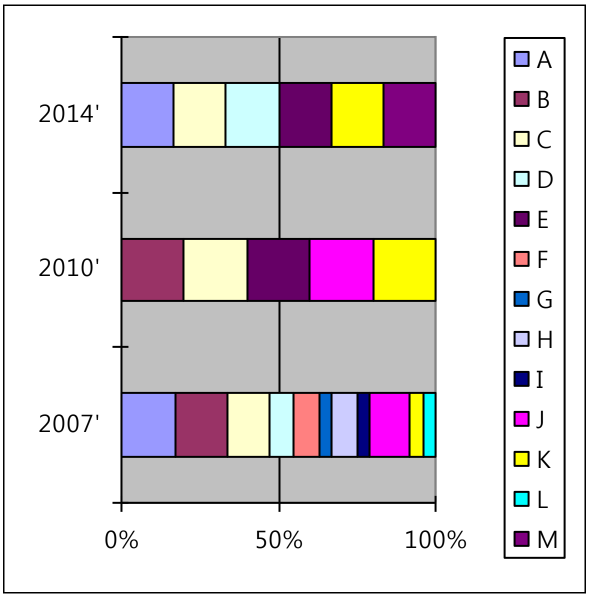


Figure 5. Diagram of students cognition about the reaction mechanism of electrolysis in 1M NaCl solution.

Similar response percentages were also obtained by Kim, Yeon-Mi *et al.,* [16]. Kim, Yeon-Mi *et al.,* construed that students' lack of micro understanding of ion movements in electrolytic cells was caused by lack of explaining in the textbook [16]. To investigate the origin of Korean students' misconception, we looked at textbooks which was published at 6^{th}, 7^{th} and 8^{th} National Education Curriculum (table 6 and figure 6).

Table 6: Textbook explanations of ion movement caused by externally applied voltage in Korean Chemistry textbook

		Description
6^{th} National Curriculum	6A	H^+ in the solution are drawn toward the negatively charged electrode to be reduced by gaining an electrode where as I^- move toward the positively charged electrode…
	6D	Cations in the electrolyte are attracted to the anode to become reduced, and anions are attracted to the cathode to become oxidized.
	6E	Cations (+) are drawn to the anode to gain electrons and become reduced whereas anions (-) are drawn to the cathode to lose electrons and become oxidized. Na^+ attracted to the anode…
	6F	SO_4^{2-} and OH^- are drawn to the positively charged electrode, Cu^{2+} and H^+ are drawn to the negatively charged electrode,
	6G	Na^+ and H^+ are drawn toward the negatively charged electrode meanwhile Cl^- and OH^- are drawn toward the positively charged electrode.
	6I	When a direct current is applied, cations Na^+ and H^+ are drawn toward the negatively charged electrode and anions Cl^- and OH^- are drawn toward the positively charged electrode.
7^{th} National Curriculum	7A	When direct current is applied, the negatively charged electrode draws in sodium ions and water, which is a polar molecule, and the positively charged electrode draws in chloride ions and water.
	7B	When direct current is applied to a copper (II) sulfate solution, cations, Cu^{2+} are attracted toward the negatively charged electrode to gain electrons to precipitate Cu. SO_4^{2-} attracted toward the positively charged electrode are not oxidized…
	7C	Reduction reaction occurs at the cathode (-) because cations (+) move toward oppositely charged cathode (-) to become reduced.
	7D	Cations of a molten salt are drawn toward the negatively charged electrode to gain electron from the electrolytic cell and become reduced.
	7E	When an electric current is applied, positively charged copper ions will gain electrons at the negatively charged electrode to become reduced to copper metal, and negatively charged chloride ions will lose electrons at the positively charged electrode to become oxidized to chlorine gas.
	7G	Cl^- are attracted toward the positively charged electrode to give up electron and become oxidized to Cl_2.
	7H	Cl^- in the solution are attracted toward the oppositely charged anode (+) to give up electron to become oxidized to chlorine element…
2007^{th}	8B	Sodium ion and water move toward the negatively charged electrode, and chloride ion and water move toward the positively charged electrode. When direct current is applied to an electrolytic solution or molten liquid, cations move toward the cathode (-) to gain electrons for reduction and anions move toward the anode (+) to lose electrons for oxidation.

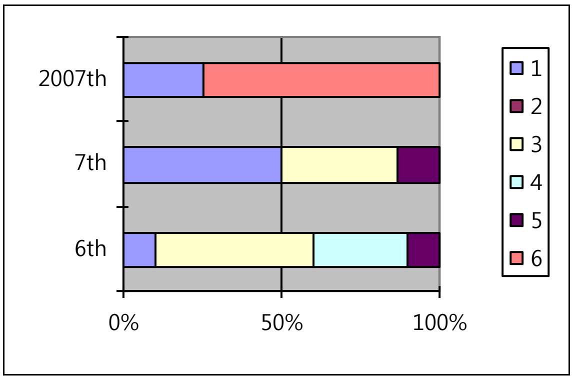


Figure 6. Diagram of change of textbook explanations of ion movement caused by externally applied voltage.

The textbooks published in 6th National Education Curriculum stated that ions are drawn to the electrode with opposite charge. However, there were no specific explanations on why ions are attracted to the oppositely charged electrode, and only one textbook explained that ions were driven by direct current [57].

In 7th National Education Curriculum, more textbooks explained the phenomenon of ions being attracted to the electrodes compared to textbooks from 6th National Education Curriculum. Such textbook descriptions helped students form the concept that ions in solution are attracted to each electrode due to externally applied voltage.
In 2007 amendment of National Education Curriculum, one textbook described the electrochemical phenomenon as, "Cations are driven toward (-) charge and anions are driven toward (+) charge by direct current". Other three textbooks do not contain such descriptions [57].

And then, for comparative analysis the Korean textbook description, we looked at international chemistry textbooks (table 7 and figure 7).

Table 7: Descriptions of ion movement caused by externally applied voltage in international textbook.

Nation	Description
Japan 1	Cation in the aqueous solution is receiving electrons from a cathode electrode connected to the electrode, negative ions in the aqueous solution is a reaction that takes place for taking an electron from the electrode connected to the positive electrode of the battery.
Japan 5	In the negative electrode is a copper ion in the aqueous solution is reduced by getting the former.
Japan 6	Copper is precipitated in the anode. In the positive electrode occurs is chlorine.

Japan 9	In the anode chloride ions in the solution to lose an electron, causing the chlorine gas.
Australia	Positive sodium ions are attracted to this negative electrode and are reduced when electrons from the electrode are donated to the ions, turning them into sodium atoms.
Singapore 1	Cations are negative ions which travel to the cathode. During the electrolysis of dilute aqueous sodium chloride, hydrogen ions will travel to the cathode and form hydrogen gas.
Singapore 2	Sodium in attracted to cathode. Chloride ion attracted to anode.
Singapore 3	cations move to the cathode. Anions move to the anode. Na^+ and H^+ ions are attracted to the cathode. The Cl^- and OH- ions are attracted to the anode.
UK 1	Cathode attracts positive ions. Positive lead ions are drawn to the cathode by electrostatic attraction
UK 2	Cation, attracted to the negative cathode.
UK 3	these are both attracted to the negative cathode.
UK 5	Cations migrate towards the cathode. Anions migrate towards the anode.
Brazile	Migration of ions
Argentina	Concentration, Ion transfer
Germany	Migration of ions

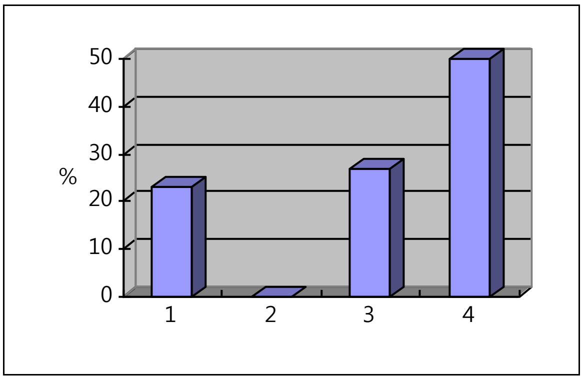


Figure 7. Diagram of international textbook descriptions about the ion movement. Categorization of textbook descriptions of ion movement caused by externally applied voltage. 1) Ion movement due to applied voltage, 2) Ion movement due to concentration polarization, 3) State ion movement without explaining the cause, 4) No relevant explanations

Watanabe [65-67] remarked that in an experiment of electrolyzing an aqueous solution of 0.1 M H_2SO_4, ions near the electrode surfaces moved toward oppositely charged electrodes when certain amount of voltage was applied (3.0V), but their displacement was only of a short distance within the electrical double layer. Also, the movement only takes place for hundredth of a second (0.03 seconds) due to electrostatic repulsion of same charged ions. Ions move toward the electrode surfaces to fill in for imbalance in concentration caused by redox reactions occurring at each electrode surface. During this time, not only ions with the opposite charge but also ions with the same charge move toward the electrode experiencing concentration shortage.

Textbook describing electrolysis as movement of oppositely charged ions toward electrodes due to applied voltage may beget a misconception, and such description is not really helpful in truly understanding electrolysis. Textbooks to be newly published should remove or moderate use of such description.

And then, we look at textbook explanations on ion movement for balancing concentration imbalance at the electrode surface.

In 6^{th} revision of National Education Curriculum, there were five textbooks describing a similar concept in chapter on electrochemical cells. The description says, “Accumulated electric charge at each electrode interferes with the flow of current in electrochemical cells. However, if there exists K^+ or NO_3^- in the solution, they quickly move to neutralize the accumulated charge, rapidly carrying on the reaction”. It explains not only that ions in the solution move in order to rid of concentration imbalance, but also that ion movement is necessary in order to sustain the chemical reaction. Three other chemistry textbooks also stated about the concentration polarization at each electrode as result of electrolysis, but they did not cover the part on ions moving to neutralize the polarization.

In textbooks from 7th revision of National Education Curriculum, concentration polarization at electrode surfaces was covered in four textbooks, but all of them covered the topic in chapter on electrochemical cells and not in chapter on electrolysis.

A redox reaction occurs in electrolysis, and it causes concentration difference between ions near the electrode surfaces. To fill in for the concentration imbalance, ions distant from the electrode surfaces are drawn toward the electrode. If such ion movements do not occur, electrode reaction will only happen for a very short period of time no matter how strong of a voltage is applied [65-67]. Park, Jin-Hee *et al.* [22] also said ion movement driven by concentration difference is very important in sustaining electrode reactions in electrochemical cells. This is why a salt bridge is necessary in cell reactions.

When each side of electrodes is applied with voltage, it only means the electric circuit is initiated by the electric wire between electrodes and by the electric flow near each electrode in the solution. It does not mean the electric circuit is complete because there is no charged substance flowing within the solution yet. Once the ions in the solution move toward each electrode due to the concentration difference, electric current starts flowing within the solution, and thus completes the electric circuit in the electrolysis. This is an important concept in electrochemistry necessary for understanding sustainability of an electrolytic reaction [65-67].

CONCLUSION AND PROPOSALS

This study investigated the conceptions for university student major in science education about electrolysis by a questionnaire and interview.

From this result, it revealed that much of students could not explain electrolysis as an oxidation-reduction reaction or chemical reaction, but they defined it as a separation or decomposition of ions and electrolytes. Also, they thought that ions in the solution could be migrate to the electrode by applied electrical voltage and it maintains the electrolysis phenomena. Also, they showed little understanding about charge disproportion which was induced by oxidation-reduction reaction and a relationship between the migration of ions and overall reaction.

When external voltage is applied through an external electric circuit connected by metal, students thought the circuit of electrochemical cell was complete, albeit there were no movements of ions in the aqueous solution, which is necessary for completing the electric circuit. This is similar to college students not being able to recognize the role of salt bridge in Daniel cell acting as a closed circuit as investigated by Park *et al.* [19-22].

Looking at chemistry textbooks from different revisions of national education curriculum showed that some textbooks contained errors in scientific explanation and lacked use of scientific terms. Such textbook blunders contribute to the formation of student's misconceptions.

Looking at current electrochemical researches on electrolysis, textbook examples of breaking or separating a compound into elemental atoms or ions are limited to fractional portion of application studies such as electroplating. On the other hand, many researches are broadly taking place to study redox reactivity and electric reactivity of reactants in neutral substances such as biological substance and organic compounds [62-64].

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