Form four students' misconceptions in electrolysis of molten compounds and aqueous solutions

Anita Yung Li BONG & Tien Tien LEE

Faculty of Science and Mathematics, Sultan Idris Education University, 35900 Tanjong Malim, Perak, MALAYSIA

E-mail: lee.tt@fsmt.upsi.edu.my

Received 16 Jan., 2016
Revised 6 Jun., 2016

Contents

Abstract

The purpose of this study is to identify the Form Four students' misconceptions in the electrolysis of molten compounds and aqueous solutions. The respondents were 60 Form Four students from two secondary schools in Sibu, Sarawak. The two instruments used in this study were an open-ended electrochemistry assessment and interview protocol. This study involved both quantitative and qualitative approaches. For the quantitative design, the percentage of the students' misconception in the open-ended electrochemistry assessment was calculated while for the qualitative design, the factors which contributed to the students' misconceptions were identified through interviews. The result from this study showed that respondents were having misconceptions in identifying the anode and cathode, analysing the reaction in the electrolysis of molten compounds and aqueous solutions, and writing chemical equations. Lack of basic knowledge in electrochemistry, language obstacles, and applying rote learning was identified as factors contributing to the students' misconceptions in learning electrochemistry.

Keywords: misconception, electrolysis, molten compounds, aqueous solutions

Statement of Problem

Electrochemistry is categorized as one of the toughest topics in chemistry for secondary students (Kathryn, 2008; Lee & Osman, 2012; Lee, 2013) and students normally find it hard to master this topic. One of the main reasons for this situation is because this topic requires higher order thinking skills which involve microscopic, macroscopic and also symbolic representation levels (Lee & Osman, 2012; Osman & Lee, 2014).

Electrochemistry is also said to be abstract to students (Huddle, White & Rogers, 2000). The movement of the electron is invisible and some students might not be able to visualize the movement of the electrons. Students need to understand the movement of ions and electrons during the electrolysis process, and only then can they transform the process into chemical formulae and equations (Lee & Osman, 2012; Osman & Lee, 2014).

The subtopics of electrochemistry which are analysing the electrolysis of molten compounds and aqueous solutions were chosen as the topic to be investigated because students normally find it hard to differentiate between these two subtopics (Acar & Tarhan, 2007). Furthermore, according to the Integrated Curriculum of Chemistry for Form Four (Integrated Curriculum Specification Chemistry Form 4, 2005), there are three factors listed that might affect the ions discharged at the anode and cathode. The factors listed in the syllabus are:

1. Reactivity of ions in the electrochemical series
2. Concentration of electrolyte used in electrolysis
3. Reactivity of the electrode

Students might confuse which factors should be taken into consideration when more than one possible half-cell reaction exist (Sanger & Greenbowe, 1997).

Based on previous studies, a few factors contribute to the students' misconceptions in electrochemistry. One of them is language usage, either in the textbook or in the teaching process. The language in electrochemistry is very new to students (Huddle, White & Rogers, 2000). The words and terms used in electrochemistry are not general terms and something that is familiar to students in their daily life (Bakar & Tay, 2010).

In addition, some students tend to memorize the concepts when they could not understand the topics taught by the teachers (Taner, Osman & Sami, 2012). They tend to memorize the examples given in the book and apply what they have memorized without any understanding of the concept.

Lastly, some students tend to have misconceptions when they do not have sufficient basic knowledge in the topic they have learned (Garnett & Treagust, 1990). Their knowledge is not adequate and strong enough to support their explanation in solving the questions.

The understanding of concepts is important as it is the basis of thinking skills (Shamsudin, 1995). However, the process of correcting misconceptions among students still has not received the attention it deserves (Alkhalifa, 2006). Thus, in this study, the students' misconceptions in electrochemistry will be identified in order to help students master this topic better.

Objectives of the Study

The objectives of this study are listed below:

1. To determine the Form Four students' misconception in the electrolysis of molten compounds and aqueous solutions.
2. To identify factors contributing to the students' misconceptions in the electrolysis of molten compounds and aqueous solutions.

Methodology

Research Design

This study was a mixed method design which included both the quantitative and qualitative approach. For the quantitative approach (survey), 60 Form Four students from two secondary schools in Sibu, Sarawak were selected to answer an open-ended electrochemistry assessment. For the qualitative approach (case study), ten students were selected from the 60 students to take part in the interview. The purpose of the interview was to find out the factors which contributed to the students' misconceptions in analysing the electrolysis of molten compounds and aqueous solutions.

Respondents

The respondents of this study consisted of Form Four students from two secondary schools in Sibu, Sarawak who were taking the subject of Chemistry. The two schools were selected from 24 schools in the Sibu district based on the cluster sampling method. All the Form Four students who studied Chemistry from the two schools participated in this study, making the total number of respondents 60 students. After all the respondents had answered the open-ended electrochemistry assessment, ten respondents were selected for the interview using the purposive sampling method. The respondents selected for the interview were those who were having misconceptions in the open ended electrochemistry assessment.

Instrument

Two instruments were used in this study, namely the open-ended electrochemistry assessment and interview protocol.

Open-ended Electrochemistry Assessment

An open-ended electrochemistry assessment (Appendix A) consisting of two structured questions was used to identify the students' misconceptions in analysing the electrolysis of molten compounds and aqueous solutions. The questions were developed by referring to the text book (Low, Lim, Eng, Lim & Ahmad, 2005) and previous studies (Acar & Tarhan, 2007; Bakar & Mukhtar, 2011; Bakar & Tay, 2010; Sanger & Greenbowe, 1997). KR-20 value for the open-ended electrochemistry assessment was reported to be 0.816. Table I shows the distribution of questions based on the common misconceptions in electrochemistry.

Table I. Distribution of Questions Based on the Misconceptions in Electrochemistry

Misconceptions	Distribution of Questions	Sample Questions
Identifying Cathode and Anode		
• In the electrolytic cells, the polarity of the terminal of the applied voltages has no effect on the site of the anode and cathode. • The identity of the anode and cathode depends on the physical placement of the half cells. • The anode is negatively charged and because of this it attracts cation. The cathode is positively charged and because of this it attracts anion.	1a), 1b), 1c), 1e(i), 1e(ii), 2a(i), 2a(ii), 2d(i), 2d(ii)	• Does the polarity of batteries affect the position of the anode and cathode in the diagram above? • How would you determine the anode and cathode of the electrode?
Reaction in the Electrolysis of Molten Compounds and Aqueous Solutions		
• The same products are produced in both aqueous and molten situation of electrolysis. • Water does not react during the electrolysis of an aqueous solution. • Metal electrodes only act as an electron carrier during the redox reactions and there will be no changes in the physical structures of the electrodes. • Inert electrodes can be oxidized and reduced. • When two or more oxidation or reduction half reactions are possible, there is no way to determine which reactions	1d), 1g(i), 1g(ii), 2b(i), 2b(ii), 2c), 2e(i), 2e(ii), 2f(i), 2f(ii), 2f(iii), 2g(i)	• If the electrolyte is changed to aqueous potassium iodide, what are the ions involved in the electrolysis process? • Does water take place in this reaction? • Can carbon electrode take place in this electrolysis reaction? Why?

have occurred.		
Writing Chemical Equations • Cannot remember the oxidation state of the ion. • Cannot balance the equation. • Confused on which ions accept electrons and which release electrons.	1f), 2f(iii), 2e(i), 2g(iii)	• Write the half equation for the anode and cathode. • Write the half equations for the reactions at electrode X and electrode Y

Interview Protocol

The purpose of the interview was to assess the students' point of view on why they were having misconceptions in learning electrochemistry. The information collected from the interview was used to identify the sources of misconceptions and this helped to support the findings of the quantitative research.

Procedure

The main objectives of this study are to identify the students' misconceptions and factors contributing to the students' misconceptions in analysing the electrolysis of molten compounds and aqueous solutions. Thus, we constructed an open-ended assessment to identify the students' misconception through their answers in the assessment. On the other hand, the factors which contributed to the students' misconceptions were identified through the interview.

We carried out the open-ended electrochemistry assessment after school hours to avoid disturbing the students' lesson time. Respondents were notified a week before the assessment was given so that they would have ample time to carry out their revision on the topic tested. This was also to ensure that the respondents were well prepared for the assessment.

After answering the questions, the respondents' answers were marked based on the answer scheme. The students' answers were marked as correct if they were able to explain the answers they had given in the assessment questions. If students were unable to explain correctly based on the answers they had given, they were categorized as having misconceptions in the topic tested. Later, the percentage of each misconception was calculated.

For the qualitative design, we applied the purposive sampling method to select students who were having misconceptions in the open-ended electrochemistry assessment to participate in the interview session. The purpose of the interview was to determine the factors which led to the students' misconceptions.

Results and Discussion

The discussion on the misconceptions in the electrolysis of molten compounds and aqueous solutions has been grouped into three categories. The categories are misconceptions in identifying cathode and anode, about the reaction in the electrolysis of molten compounds and aqueous solutions, and lastly in writing the chemical equations. Then, the factors contributing to the students' misconceptions in the electrolysis of molten compound and aqueous solution are discussed.

Identifying Cathode and Anode

The results (Appendix B) showed that three respondents were having misconceptions in identifying the anode and cathode in the electrolytic cell. They assigned the anode to the negative terminal of the battery while the cathode was assigned to the positive terminal of the battery. This finding is parallel with what Acar and Tarhans' found in 2007. In their study, the respondents assigned the anode to the negative terminal because it was negatively charged while the cathode was assigned to the positive terminal because it was positively charged.

Five respondents (8.3%) were having misconceptions in explaining how they assigned the anode and cathode. They gave explanation such as:

- The longer battery is connected to the anode while the shorter one is connected to the cathode.
- The left side is the anode while the right side is the cathode.
- Oxidation occurs at the anode while reduction at the cathode.

The findings of this study are compatible with the findings in Nordin and Chong's study (2010). In their study, they stated that students tend to memorize the position of the anode and cathode drawn by the teacher and in the textbook. The anode is always drawn on the left of the cell notation. Hence, students just memorized the position of the anode and cathode without understanding the concept.

Another seven respondents (11.7%) were having the misconception that the polarity of batteries does not affect the position of the anode and cathode in the electrolytic cells. This matched the findings of Özkaya, Üce and Sahin whom in their study in 2003 discovered that their respondents also misconceived that the polarity of batteries has no effect on the position of the anode and cathode in the electrolytic cell.

Reaction in the Electrolysis of Molten Compounds

In question 1(e)(i), respondents were asked to state the ions which moved to electrode X and electrode Y and give their explanations in question 1(e)(ii). These questions were created to test students' understanding of the electrolysis of molten compounds. In the situation for the electrolysis of molten potassium iodide, potassium ions (K^+ ions) were selectively discharged at the cathode (electrode Y) while iodide ions (I^- ions) were selectively discharged at the anode (electrode X). A total of 11 respondents were having misconceptions about this question where they gave the answers below:

- Electrode X : potassium ions (K^+ ions), hydroxide ions (OH^- ions)
- Electrode Y : iodide ions (I^- ions), hydrogen ions (H^+ ions)

The result of our study is supported by Bakar and Mukhtar's (2011) findings in their study whereby their respondents were having problems in identifying the ions which were selectively discharged at the anode and cathode during the electrolysis of molten silver bromide.

A total of six respondents (10.0%) were having misconceptions in answering question 1(e)(ii). Three of them explained that potassium ions (K^+ ions) were selectively discharged at the anode while iodide ions (I^- ions) were selectively discharged at the cathode because potassium ions (K^+ ions) and iodide ions (I^- ions) were the only ions present in the electrolysis process. Another three respondents stated that hydroxide ions (OH^- ions) and hydrogen ions (H^+ ions) were present in the solution; thus, the ions were attracted to the anode and cathode due to their lower position in the electrochemical series. This showed that these respondents were having misconceptions by involving water molecules in the electrolysis of molten compounds.

To ensure that the students can differentiate between molten compounds and aqueous solutions, we created question 1(g)(i) whereby the electrolysis of molten potassium iodide was replaced with aqueous potassium iodide. A total of 11 respondents (18.3%) were having misconceptions in answering this question and we found that this result is similar to the findings of Acar and Tarhan (2007). They discovered that students cannot identify products formed in the electrolysis of both aqueous and molten situation of salt. From the 11 respondents who were having misconceptions, seven respondents stated that only potassium ions (K^+ ions) and iodide ions (I^- ions) were present in the aqueous solutions. The result is parallel with the findings of Sanger and Greenbowe's study (1997). In their study, they interviewed students to find out whether water was involved in the electrolysis of aqueous solution. A particular student said "*The water shouldn't do anything, so there may be a little reaction, but it's not going to be measurable. Water will not enter into the equation*". Another two respondents stated that oxygen was the ions involved in this reaction. In fact, hydroxide ions (OH^- ions) were present in this electrolysis and it formed oxygen as the end product. Thus, oxygen cannot be considered as the ions involved in this electrolysis. Another two respondents were having misconceptions in writing the chemical symbol, whereby one of them wrote potassium ions as sodium ions (Na^+ ions) and iodide ions as I^{2-} ions. In Bakar and Mukhtar's study (2011), they discovered that students cannot remember the chemical symbol and oxidation states of ions and this finding is parallel with the result of this study.

Question 1(g)(ii) asked the respondents to select which ions were selectively discharged to the anode and cathode. In this question, hydroxide ions were selectively discharged to the anode while hydrogen ions were selectively discharged to the cathode. A total of 15 respondents (25.0%) were having misconceptions in selecting the ions which were selectively discharged at the anode and cathode. They gave answers such as:

- Anode: hydrogen ions (H^+ ions), iodide ions (I^- ions)
- Cathode: hydroxide ions (OH^- ions), potassium ions (K^+ ions)

The result of this study is compatible with Sanger and Greenbowe's study (1997) whereby their respondents were having difficulties in identifying which ions were selectively discharged at the anode and cathode when there were more than two ions or more possible oxidation or reduction of half reactions.

In Malaysia's Form Four Chemistry syllabus, all electrolyses of molten compounds are carried out by using inert electrodes such as carbon electrodes and platinum electrodes. Students are taught that carbon or platinum electrodes are suitable to be used in the electrolysis of molten compounds because they are inert and do not take place in reaction. In this study, a total of 15 respondents (25.0%) were having misconceptions in that they answered that carbon electrodes took place in the reaction of electrolysis because of some of the reasons below:

- Carbon can electrolyze the compound.
- Carbon can conduct electricity.
- Carbon electrode is a universal electrode.
- Carbon is an active electrode.
- Carbon ions can move freely.

Acar and Tarhan (2007) in their study also revealed similar finding in that their students were also having misconceptions in explaining why carbon electrodes cannot take place in the reaction of electrolysis. However, the finding of their research was different than that of this study. Their respondents answered that inert electrodes can take place in the process of electrolysis because they can be oxidized or reduced.

Reaction in the Electrolysis of Aqueous Solutions

Question 2(c) asked respondents "Does water take place in the electrolysis of aqueous copper (II) chloride solution?" Nine respondents (15.0%) were found to have misconceptions in that they answered water was not involved in this electrolysis. The result of this finding is compatible with Sanger and Greenbowe's study (1997). In their study, the interviewed respondents said that water will not be included in the equation for the electrolysis of aqueous solution.

Question 2(b)(i) asked the respondents to list out the ions present in the aqueous copper (II) chloride solution. The ions which were supposed to be present in the electrolysis of aqueous copper (II) chloride solution are copper (II) ions (Cu^{2+} ions), chloride ions (Cl^- ions), hydrogen ions (H^+ ions) and hydroxide ions (OH^- ions). About 26.7% of the respondents, namely 16 of them, were having misconceptions in listing out the ions present in the aqueous copper (II) chloride solutions. Out of these 16 respondents, nine of them listed copper (II) ions (Cu^{2+} ions) and chloride ions (Cl^- ions) were the only ions present in the electrolysis of aqueous copper (II) chloride solution. They did not include water in the electrolysis of aqueous copper (II) chloride solution. This finding is supported by the findings of Acar and Tarhan's (2007) study, whereby their students also stated the same ions were produced in both the aqueous and molten situation of salt electrolysis. Another seven respondents (11.7%) in our study gave the wrong chemical symbol for the ions present in copper (II) chloride solution. Copper ion was written as Ca^{2+} ions in this study. This finding is similar to that of Bakar and Tay's study (2010) in which their respondents could not remember the correct symbol for the chemical ions.

Question 2(b)(ii) requested the respondents to state the sources of ions in copper (II) chloride solutions. A total of 36 respondents (60.0%) gave incomplete answers. Out of these, five of them (8.3%) listed the sources for copper (II) ions (Cu^{2+} ions) and chlorides ions (Cl^- ions) only and another three respondents (5.0%) listed sources for water only. 28 of the respondents (46.7%) stated that ions came from the copper (II) chloride solution without classifying where each ion came from.

Question 2(d)(i) requested the respondents to list out the ions that were moved to the anode and cathode for electrolysis of aqueous copper (II) chloride solution. Two respondents (3.3%) were having misconceptions with this question. One respondent wrote copper (II) ions (Cu^{2+} ions) which were the cations discharged at the anode. This respondent was confused with the concept of the anode attracting the anions and cathode attracting the cations. This finding is parallel with Acar and Tarhan's (2007) findings, whereby their respondents stated that the cathode attracts anions because it was positively charged. The other respondent was having misconceptions by giving the wrong chemical symbol. The respondent wrote chloride ions (Cl^- ions) as I^- ions and this finding is similar to Bakar and Tay's study (2010). In their study, their respondents could not remember the correct chemical symbol for the ions present in the electrolyte.

Question 2(d)(ii) requested the students to explain how they identified which ions were moved to the anode and cathode. Four respondents (6.7%) were having misconceptions with this question. Two of them stated that copper (II) ions which were the cations are attracted to the anode because the ions were positively charged. Another two respondents answered that chloride ions which were the anions are attracted to the cathode because the ions were negatively charged. The finding is compatible with Bakar and Mustafa's study in 2010 whereby they stated their respondents were having difficulties in analysing which ions were selectively discharged at the anode and cathode during the electrolysis process.

Question 2(e)(ii) required the respondents to explain how they chose which ions were selectively discharged at the anode and cathode. A total of 20 respondents (33.3%) were having misconception with this question whereby 18 of them answered chloride ions (Cl^- ions) were discharged at the anode due to the higher concentration in the solutions. Based on the answers given, respondents were having problem in identifying the concentrated electrolyte in the electrolysis of an aqueous compound. Another two answered that hydrogen ions (H^+ ions) were selectively discharged at the cathode instead of copper (II) ions (Cu^{2+} ions) because they misconceived that hydrogen ions are placed in the lower position of the electrochemical series as compared to the copper ions. This clearly showed that they did not understand the electrochemical series. This finding matches the findings of Bakar and Mustafa (2010). In their study, their students had difficulties in analysing which ions were selectively discharged at the anode and cathode because the students were unable to determine the position of ions in the electrochemical series.

Using Concentrated Electrolyte in Electrolysis of Aqueous Solution

In question 2(f)(i), we replaced the electrolyte with a more concentrated copper (II) chloride solution, then asked the respondents to predict the observations at the anode of the electrolytic cell. The correct scientific answer should be that green gas is released at the anode and there is a pungent smell. Ten respondents (16.7%) were found to have misconceptions by giving their observations as follows:

- Brown solid is deposited (6 respondents)
- Anode is covered by brown solid (1 respondent)
- Colourless gas is produced (2 respondents)
- Water level rises (1 respondent)

Question 2(f)(ii) required the respondents to give explanations based on their observations. Nine respondents (15.0%) were found to be having misconceptions when they gave explanations such as:

- The solution is diluted so hydroxide is discharged (1 respondent)
- Hydrogen is produced (2 respondents)
- Hydroxide ions are discharged (1 respondent)
- Copper is selected because there are more copper ions in the solution (4 respondents)
- Copper atom is converted into copper ions (1 respondent)

Lee and Osman (2012) found that the respondents in their study were having misconceptions in solving questions which involved the use of concentrated electrolyte in the electrolysis of concentrated copper (II) chloride solution. In their study, they found that only 7.9% of their respondents could explain correctly why chlorine gas was formed at the anode during electrolysis of concentrated copper (II) chloride solution.

Using Active Electrode in Electrolysis of Aqueous Solution

In question 2(g), we replaced the carbon electrodes with copper electrodes and asked the respondents about the physical appearance of the two electrodes at the end of the electrolysis. Four respondents (6.7%) were having misconceptions whereby two of them stated the anode becomes thicker while the cathode becomes thinner and another two of them stated there are no changes on the electrodes. The finding is compatible with Acar and Tarhan's study (2007) whereby they stated that their respondents answered that metal electrodes only act as an electron carrier and there will be no physical changes in the electrodes' physical structures.

Out of the 43 respondents who were able to give correct observations for question 2(g)(i), only 12 respondents (20.0%) were able to give correct scientific explanations for their observation in questions 2(g)(ii). Five respondents (8.3%) were having misconceptions whereby they gave answers such as:

- Copper ions are deionized at the cathode
- Copper electrode at the cathode is dissolved in the solution
- Anode loses electrons, cathode gains

Writing Chemical Equation

The topic of electrolysis involves many chemical equations to represent the reactions that took place. In this study, it was found that many students were having misconceptions in writing the chemical equations. In question 2(e)(i), respondents were required to write a balanced equation for the reaction of hydroxide ions (OH^- ions) at the anode. Instead of writing the correct balanced equation, the respondents wrote $2OH^- \rightarrow O_2 + H_2O + 2e^-$ to represent the process at the anode. The chemical equation written was not balanced; the correct balanced equation should be $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$. Similarly, this is supported by the findings of Bakar and Tay (2010) who stated that their respondents could not write balanced chemical equations because they were weak in mathematics.

Additionally, some of the respondents were having misconceptions by writing the wrong oxidation states of elements. As an example, for the equation in question 2(g)(iii), one of the respondents wrote the equation $Cu \rightarrow Cu^{+} + e^{-}$ because of his misconception. The balanced equation should be $Cu \rightarrow Cu^{2+} + 2e^{-}$, where one copper atom was oxidized to produce one copper (II) ions and two electrons. This respondent gave the wrong oxidation state for copper (II) ions (Cu^{2+} ions). This finding is supported by Bakar and Mukhtar's finding (2011) whereby in their study, their respondents could not remember the oxidation states of ion. According to Bakar and Mukhtar, when students cannot remember the oxidation states of an ion they will have problems in writing the correct chemical equation.

In addition, there were also four respondents who remembered the wrong chemical symbols. Three of them wrote copper (II) ions (Cu^{2+} ions) as Ca^{2+} ions in question 2(d)(i) and one of them wrote potassium ions (K^{+} ions) as Na^{+} ions in question 1(f). This finding is parallel with Bakar and Mukhtar's finding (2011) whereby their respondents could not write the correct chemical symbol for lead (II) ions.

Furthermore, we found that the respondents could not write proper chemical equations. In question 1(g)(ii), the equation was written as $Cu^{2+} + 2e^{-} = Cu$. The respondents replaced the arrow in the equation with an equal sign.

Factors Contributing to Students' Misconceptions in the Electrolysis of the Molten Compounds and Aqueous Solutions

An interview was conducted to find out the reasons contributing to the students' misconception. The findings of the interview showed that the lack of basic knowledge in the topic of electrochemistry resulted in the respondents not being able to proceed in solving the questions in the open-ended electrochemistry assessment. We discovered that many of the students did not have the habit of doing revision after learning a new concept in the topic of electrochemistry. Some of the respondents were able to answer the question in the interview after they did their revision. Bakar and Mukhtar (2011) also found that students who lacked basic knowledge were unable to write out the correct chemical symbol for the ions present in the electrolyte.

In addition, there were three respondents who were having language problems in studying electrochemistry. This was the reason which contributed to the students' misconceptions in answering the questions. Only one student tried to search for the meaning of words when she could not understand the language in the text book.

Language obstacles contributed to students' misconceptions in this study. According to Eilks and Hofstein (2013), the linguistic ability of students affects their ability to learn Chemistry. Hence, students who have a problem in understanding the terms will influence their learning in electrochemistry (Bakar & Mukhtar, 2011).

We also discovered that three students in this study applied rote learning whereby they memorized the concepts in electrochemistry without understanding the concepts in this topic. They tend to write anything that they could remember in answering the open-ended electrochemistry assessment given and this caused misconceptions. The interview results correspond to those of Bakar and Tay's study (2010) whereby their respondents also applied rote learning in electrochemistry and this contributed to their respondents' misconceptions. In their study, they discovered that students were able to list out the electrolyte and non-electrolyte compounds but failed to give an explanation for their answers.

Conclusion and Implication of study

Table II concludes all the students' misconceptions which were discovered in this study.

Table II. Misconceptions of Form Four Students in the Electrolysis of the Molten Compounds and Aqueous Solutions

Concepts in Electrolysis of Molten Compounds and Aqueous Solutions	**Misconceptions**
Identifying the Anode and Cathode	• Longer battery is connected to the anode while the shorter battery to the cathode. • Identify the anode and cathode based on the position of the electrodes (left terminal is anode, right terminal is cathode)
Reaction in the Electrolysis of the Molten Compounds and Aqueous Solutions	• Carbon electrode takes place in electrolysis of molten compounds. • Anions move to the cathode while cations move to the anode of the electrolytic cell during the electrolysis process. • Water is involved in electrolysis of molten compounds. • Not able to select which ions move to the anode and cathode. • Concentrated electrolyte does not affect the process

	of electrolysis. • Reactive electrodes do not experience any changes in physical appearance during electrolysis.
Writing Chemical Equations	• Wrong chemical symbols • Cannot balance the equation • Wrong oxidation states for element

In short, the findings from the interview showed that the reasons which contributed to the students' misconceptions are lacking basic knowledge, having language obstacles and applying rote learning in the study of electrochemistry.

The findings of this study are very useful for the schools where this study was conducted. The results of the study reflected directly on the students' understanding of the topic of the electrolysis in the molten compounds and aqueous solution. This study will be able to serve as a guideline for the teachers to look in depth into the students' problems in mastering the topic of electrochemistry.

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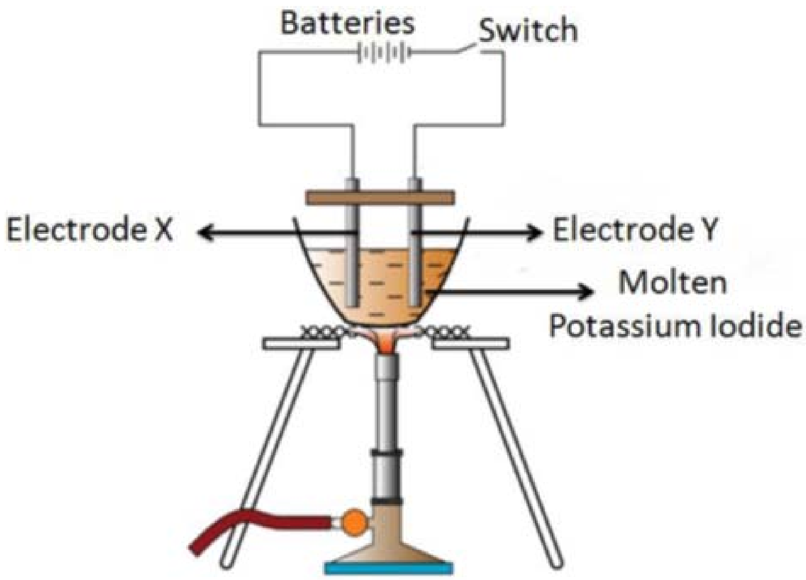
Appendix

Appendix A: open-ended electrochemistry assessment

Question 1

A compound is electrolyzed using carbon electrodes as shown in figure below:



a) Identify which electrode is anode and cathode?

Anode: ________________________________

Cathode: ________________________________

b) How would you determine anode and cathode of electrode?

Anode:

____

Cathode:

____

c) Does polarity of batteries affect the position of anode and cathode in the diagram above?

____

d) Can carbon electrode take place in this electrolysis reaction? Why?

____

e) i) Which ions move to electrode X and Y during the electrolysis process?

Electrode X: ____

Electrode Y: ____

ii) Explain your answer in e (i).

Electrode X

____

Electrode Y

____

f) Write the half equation for anode and cathode.

Anode: ____

Cathode: ____

g) i) If the electrolyte is changed to aqueous potassium iodide, what are the ions involved in electrolysis process?

____

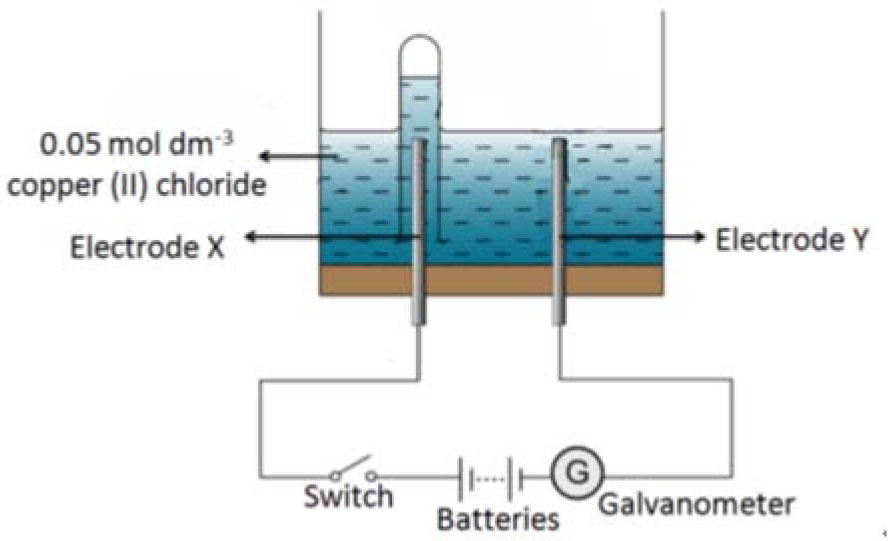
ii) What ion is selectively discharged to anode and cathode?

Anode: ____

Cathode: ____

Question 2

0.05 mol dm^{-3} copper (II) chloride solution is electrolyzed by using carbon electrodes as shown in the diagram below.



a) i) Which electrode is anode and which is cathode?

Anode: ________________________________

Cathode: ________________________________

ii) Based on your answer in a (i), how do you assign anode and cathode for electrode X and Y?

Anode: ________________________________

Cathode: ________________________________

b) i) What ions are present in the electrolysis process above?

____

ii) What are the sources for the ions you have listed in b (i)?

____

c) Does water takes place in this reaction?

____

d) i) Which ions move to anode and cathode?

Anode:

____

Cathode:

____

ii) Explain how you identify the ions which move to anode and cathode.

Anode: ____

Cathode: ____

e) i) Write the half equations for reactions at electrode X and electrode Y

Anode:

____

Cathode:

____

ii) Explain how do you choose which ions are selectively discharged at anode and cathode based on the half equation you have written in e (i).

Anode:

____

Cathode:

____

f) i) If 0.05 mol dm^{-3} of copper (II) chloride solution is replaced with 2 mol dm^{-3} of copper (II) chloride solution, predict what will be observed at anode.

____

ii) Explain your answer.

____

iii) Write a half equation for the observation in f (i).

____

g) i) If both of the carbon electrodes are replaced with 2 copper electrodes, what can you observe on physical appearances of the 2 copper electrodes after the electrolysis process?

____

ii) Explain your answer.

____

iii) Write half equation for anode and cathode to support your answer in g (i) and g (ii).

Anode: ____

Cathode: ____

Appendix B

Percentage of misconceptions occurring among the respondents for each question in the test

Item no.	Question	Scientific answers	Misconceptions	Percentage (%)
1 (a)	Identify anode and cathode.	Anode: Electrode X Cathode: Electrode Y	Anode: Electrode Y Cathode: Electrode X	5.0
1 (b)	How to identify anode and cathode?	Positive terminals of batteries is connected to anode while negative terminals to cathode.	• Longer battery to anode, shorter to cathode. • Left is anode, right is cathode. • Oxidation anode, reduction cathode	8.3
1 (c)	Does polarity of batteries affect the position of anode and cathode in diagram?	Yes	No	11.7
1 (d)	Can carbon electrode take place in this electrolysis reaction? Why?	No. It is inert.	• Carbon electrode can electrolyze compound. • Carbon electrode can conduct electricity. • Carbon electrode is universal electrode. • Cheap and good conductor. • Stable electrode • Active electrode • Carbon ions can move freely • Only carbon electrode react in molten	25.0
1 (e) (i)	Ions move to electrode X and Y during the electrolysis	Electrode X: I^- ions Electrode Y: K^+ ions	• Electrode X: K^+ ions	18.3

	process.		Electrode Y: I^- ions • Electrode X: OH^- ions Electrode Y: H^+ ions	
1 (e) (ii)	Explain your answer in e (i).	• Anions, I^- ions are negatively charged and they are attracted to anode whereby the positive ends of batteries is attached. • Cations, K^+ ions are positively charged and they are attracted to cathode whereby the negative end of batteries.	• K^+ ions and I^- ions are the only ions present • OH^- ion is in lower position then I^- ion in electrochemical series. • H^+ ion is lower position then K^+ ion in electrochemical series.	10.0
1 (f)	Write the half equation for anode and cathode.	• Anode: $2I^-$ (aq) $\rightarrow I_2(g) + 2e^-$ • Cathode: K^+ (aq) $+ e^- \rightarrow K(s)$	• Anode: K^+ (aq) + $e^- \rightarrow K(s)$ • Cathode: $2I^-$ (aq) $\rightarrow I_2(g) + 2e^-$ • Anode: $4OH^-$ (aq) $\rightarrow O_2(g) + 2H_2O(l) + 4e^-$ • Cathode: $2H^+ + 2e^- \rightarrow H_2$ • Potassium ion is written as Na^+ ion. • Wrong equation $I^- \rightarrow I_2 + 2e^-$ $K^+ + e^- = K$	25.0
1 (g) (i)	If the electrolyte is changed to aqueous potassium iodide, what are the ions involved in electrolysis process?	K^+ ions, H^+ ions, I^- ions, OH^- ions	• Only K^+ ions, I^- ions. • Oxygen • Wrong chemical symbol Potassium ions written as Na^+ions Iodide ions written as I_2^- ions	18.3

1 (g) (ii)	Which ion is selectively discharged to anode and cathode?	• Anode: OH^- ions • Cathode: H^+ ions	• Anode: H^+ ions Cathode: OH^- ions • Anode: I^- ions Cathode: K^+ ions • Anode: I^- ions Cathode: H^+ ions	25.0
2 (a) (i)	Identify anode and cathode.	Anode: Electrode X Cathode: Electrode Y	Anode: Electrode Y Cathode: Electrode X	5.0
2 (a) (ii)	How to identify anode and cathode?	Positive terminals of batteries is connected to anode while negative terminals to cathode.	• Longer battery to anode, shorter to cathode. • Anode at right, cathode at left.	5.0
2 (b) (i)	What ions are present in the electrolysis process above?	Cu^{2+} ions, H^+ ions, Cl^- ions, OH^- ions	• Cu^{2+} ions, Cl^- ions only • Cu^{2+} ions, OH^- ions only • Wrong chemical symbol Copper ions written as Ca^{2+}	26.7
2 (b) (ii)	What are the sources for the ions you have listed in b (i)?	Copper (II) chloride contributes Cu^{2+} ions and Cl^-ions while water contributes to H^+ and OH^- ions.	Answers not complete, not related or no answers	0.0
2 (c)	Does water take place in this reaction?	Yes	No	15.0
2 (d) (i)	Which ions move to anode and cathode?	• Anode: Cl^- ions , OH^-ions • Cathode: Cu^{2+} ions , H^+ ions	• Anode: Cl^- ions Cathode: Cu^{2+} ions • Wrong chemical symbol Chloride ions written as I^- ions	3.3
2 (d) (ii)	Explain how do you identify the	• Anions, which are OH^- ions and	• Cu^{2+} only attracted to anode because it	6.7

	ions which move to anode and cathode?	Cl^- ions, are negatively charged thus they are attracted to anode. • Cations which are Cu^{2+} ions and H^+ ions are positively charged thus they are attracted to cathode.	is positive charge. • Cl^- ions only attracted to cathode because it is negative charge.	
2 (e) (i)	Write the half equations for reactions at electrode X and electrode Y.	• Anode: $4OH^-$ (aq) → O_2 (g) + $2H_2O$(l) + $4e^-$ • Cathode: Cu^{2+} (aq) + $2e^-$ → Cu (s)	• Anode: $2Cl^-$ (aq) → Cl_2(g) + $2e^-$ Anode: Cu^{2+} (aq) + $2e^-$ → Cu (s) • Cathode: $4OH^-$ (aq) → O_2 (g) + $2H_2O$(l) + $4e^-$ Cathode: $2H^+$ (aq) + $2e^-$ → H_2(s) • Wrong equation $2OH^-$ (aq) → O_2 (g) + H_2(l) + $2e^-$ OH^- (aq) → 2H (g) + $2H_2O$(l) + $4e^-$ Cu^{2+} (aq) + $2e^-$ = Cu (s)	65.0
2 (e) (ii)	Explain how do you choose which ions is selectively discharged at anode and cathode based on the half equation you have written in e (i).	• OH^- ions are selectively discharged at anode due to its lower position in electrochemical series as compared to Cl^- ions. • Cu^{2+} ions are selectively discharged at cathode due to its lower position in electrochemical	• Cl^- ions are selectively discharged at anode due to its higher concentration. • H^+ ions are selectively discharged at cathode due to its lower position in electrochemical series	33.3

		series as compared to H^+ions		
2 (f) (i)	0.05 mol dm^{-3} of copper (II) chloride solution is replaced with 2 mol dm^{-3} of copper (II) chloride solution. Predict what will be observed at anode.	A green gas is released at anode and there is pungent smell.	• Brown solid is deposited • Anode covered by brown solid • Gas bubble produce • Colourless gas produces.	16.7
2 (f) (ii)	Explain why chlorine is selectively discharged.	Cl^- ions is selectively discharged due to higher concentration of Cl^- ions in electrolyte as compared to OH^- ions.	• The solution is dilute. • Copper is selectively discharged. • Hydrogen is produced. • Hydroxide ions is discharged • Copper is selected because there are more copper ions in solution. • Copper atom is concerted to copper ions.	15.0
2 (f) (iii)	Write a half equation for the observation in f (i).	$2Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$	• Wrong equation $Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$ • Incorrect end product $Cu^{2+} (aq) + 2e^- \rightarrow Cu (s)$ $4OH^- (aq) \rightarrow O_2 (g) + 2H_2O(l) + 4e^-$ • Half equation is written as full equation • $2Cl^- + Cu^{2+} \rightarrow Cl_2 + Cu$	23.3

2 (g) (i)	If both of the carbon electrodes are replaced with 2 copper electrodes, what can you observe on physical appearances of the two copper electrodes after the electrolysis process?	• Anode becomes thinner while cathode becomes thicker. • Mass of anode decreases while mass of cathode increases.	• Anode becomes thicker, cathode becomes thinner. • No change.	6.7
2 (g) (ii)	Explain answer in g (i)	Copper anode dissolves to form Cu^{2+} ions while Cu^{2+}ions will be selectively discharged at cathode to form copper metal.	• Anode loses electrons. • Cathode dissolved to release electrons. • Chlorine displaces copper.	8.3
2 (g) (iii)	Write half equation for anode and cathode to support your answer in g (i) and g (ii).	• Anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ • Cathode: $Cu^{2+}+ (aq) + 2e^- \rightarrow Cu (s)$	• Anode: $Cu^{2+} (aq) + 2e^- \rightarrow Cu (s)$ • Cathode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ • Wrong equation $Cu (s) \rightarrow Cu^+ (aq) + e^-$	15.0