Journal of Education and e-Learning Research
ISSN: 2410-9991
Vol. 3, No. 1, 1-8, 2016
http://asianonlinejournals.com/index.php/JEELR

Ghanaian Teacher Trainees' Conceptual Understanding of Stoichiometry

***Ruby Hanson*[1]**

[1]Department of Chemistry Education, University of Education, Winneba, Ghana

Abstract

Chemical stoichiometry is a conceptual framework that encompasses other concepts such as the mole, writing of chemical equations in word and representative form, balancing of equations and the equilibrium concept. The underlying concepts enable students to understand relationships among entities of matter and required amounts for use when necessary. Success in this area of chemistry depends mainly on a student's understanding of the concepts of the mole. An interpretive study on trainees' conceptual understanding of chemical stoichiometry was carried out among 78 teacher trainees in their second year of study. The study comprised a combination of quantitative and qualitative interpretation of responses provided by trainees to stoichiometric questions. The interpretation indicated that their learning of stoichiometry was basically through the use of picket fence (factor label), undefined strategies and algorithm. The trainees were found to have more persistent problems with conceptual interpretation as they were not able to fully translate word problems into mathematical equations regardless their algorithmic underpinnings. Neither did they understand fully, the law of conservation of matter. Qualitative findings were found to be consistent with quantitative outputs.

Keywords: Chemical change, Conceptual understanding, Non-limiting reactant, Percent yield, Stoichiometry, Theoretical yield.

Contents

Citation | Ruby Hanson (2016). Ghanaian Teacher Trainees' Conceptual Understanding of Stoichiometry. Journal of Education and e-Learning Research, 3(1): 1-8.
DOI: 10.20448/journal.509/2016.3.1/509.1.1.8
ISSN | 2410-9991

1. Introduction

Chemical stoichiometry is a broad concept which is applied in many areas of chemistry, especially analytical chemistry, where the quantitative relationships among number of moles of reactants and products are shown by a balanced equation. It enables learners to solve numerical problems on chemical reactions, concentrations, amounts of substances, titrimetry and chemical equilibrium efficiently. These aforementioned related stoichiometric concepts are fundamental in quantitative chemistry. Failure to understand and connect between these concepts creates conceptual problems for students. For example, stoichiometric calculations are necessary to evaluate the results of quantitative analysis like titration. Research has revealed that students often have alternative conceptions about stoichiometry and so resort to the use of formula to solve such related problems. Boujaoude and Barakat (2000) found out in their studies on students' abilities to solve stoichiometric calculations that one's ability to solve numerical problems and conceptual understanding were not related. They Boujaoude and Barakat (2003) also found that students were more successful in solving problems by applying algorithmic statistics than ones that required conceptual understanding. However, students with less conceptual understanding used other incorrect strategies. Voska and Heikkinen (2000) found in their study of strategies which students used to solve their stoichiometric calculations that, for even simple exercises, students avoided the direct calculation of amounts of substances which had to be expressed in moles. This implies that problems on the amount of substance in moles could be problematic for students. There was however no statistical significant correlation between learning approaches and conceptual understanding. Wolfer and Lederman (2000) studied the gap between freshmen students' success in solving computational problems and conceptual ones. They found that students held some incorrect understanding and had weak links between the microscopic and macroscopic levels of chemistry; so that, this weakness led to conceptual problems in their study of stoichiometry. It was also found in another study on stoichiometric calculations that, out of 200 British A 'Level graduates about to enter university, none used the expected method of resolution required for finding out amounts of substances (or moles) contained in given matter (Case and Fraser, 1999).

Other studies have shown that, often teachers accept correct numerical answers without analysing student understanding (Nakhleh and Mitchell, 1993) which according to Antwi (2013) does not help students to build in-depth understanding of concepts. He further asserts that one's ability to solve numerical problems does not mean an understanding of underlying concepts as had been reiterated by Boujaoude and Barakat (2000); Boujaoude and Barakat (2003). Such students hold misunderstandings of the expected basic concepts and their relationships. Sound conceptual understanding is therefore necessary for solving stoichiometric problems more scientifically. Concepts such as chemical bonds, balancing of chemical equations, the mole, concentrations of solutions, limiting reagents, and quantity relationships have to be to understood. Incidentally, misconceptions about stoichiometry and balancing of equations which hamper the understanding of chemical stoichiometry have been reported by Sanger (2005) as well as Voska and Heikkinen (2000). Understanding the idea of limiting reactants or surplus of reactants is one other basic step in determining amounts of and subsequently, mass of products in chemical reactions. Chemical reactions are presented as if all reactants are used up and converted into products. However, this is not the case. Students find it hard to believe that some reactants could limit reactions. If the amounts of reactants are not stoichiometrically equivalent, then one or more reactants might remain, but certainly one of the reactants would be used up. It is quite difficult for students to understand that the used up species would be the limiting reactant. Dahsah and Coll (2007) found that students had alternative frameworks that related the mole ratio to mass ratio. They also found that students rationalise that limiting reagent is the smallest quantity of mass and not the mole in a chemical reaction.

Case and Fraser (1999) have shown that students have acute difficulties in dealing with the abstract concepts required of them to perform stoichiometric calculations. They also found that first year university students exhibited a lot of mistakes in problem solving due to confusion between different chemical quantities. According to Haider and Al Naqabi (2008) some researchers into the understanding of students' conceptions of stoichiometry have found that students have more success in solving problems which require the application of algorithmic strategies than ones which apply conceptual understanding. Niaz (2001) compared students' performances on conceptual and computational problems of chemical reactions, stoichiometry and equilibrium and reported that students who perform better on problems requiring conceptual understanding also perform significantly better on problems requiring manipulation of data. Cracolice *et al.* (2008) in Gultepe *et al.* (2013) reiterate that there is considerable gap between students' ability to solve algorithmic questions that can be answered by applying a set of procedures to generate response and their comprehension of chemical concepts. Students solve chemistry problems using algorithm which they have less problems with, than they do with the conceptual part (Cracolice *et al.*, 2008). Most of such studies on stoichiometry have been done in the Western world and Asia. For example, Dahsah and Coll (2007); Dahsah and Coll (2008) have researched on stoichiometry in Thailand, Haider and Al Naqabi (2008) in the United Arab Emirates, (Gultepe *et al.*, 2013) in Turkey, (Boujaoude and Barakat, 2003) in Lebanon, (Chiu, 2001) in Taiwan, and Schmidt and Jigneus (2003) in Germany and Sweden. Some of these researchers diagnosed problems by identifying the differences between students'' algorithmic and conceptual understanding. Others studied learning styles that students employed in stoichiometry, while a few researched into students' logical frameworks and use of problem solving techniques. No attempt has been made to study students' understanding of stoichiometry along any of these lines in Ghana and West Africa as a whole. This study will attempt to bridge the knowledge gap and present a baseline data upon which further interpretive studies or otherwise on stoichiometry in other parts of West Africa could be done. Interpretive studies would be employed in this study so as to present novel data gathered from the observation and interpretation of students' behaviours in their natural setting.

1.1. Background to the Study

Students' prior knowledge influences their learning of new concepts. Thus, the single most important factor which influences teaching and learning for concept development is to find out what learners know before an instruction. In the sciences in general, pre-assessments to decipher learners' prior concepts and practical activities are hardly carried out in most Ghanaian schools (Talabi and Hanson, 2004). Science topics are hardly taught as conceptual lessons or from first principle and scaffolded (Antwi, 2013). Antwi noted in his study of physics teacher trainees' experiences with interactive engagement that practical activities were hardly carried out in teacher training institutions, as was observed with chemistry teaching and learning. Learning in most Ghanaian schools is limited to one's ability to learn sets of guiding steps, especially where mathematical expressions and solutions are required. This method, however, does not lead to concept formation. Undergraduate teacher trainees, thus come to university with such weaknesses, as a recently conducted pre-assessment test revealed. According to studies by Schmidt and Jigneus (2003) Swedish students exhibited such weaknesses also but solved their problems by employing logical reasoning, the mole method and proportionality to interpret sentence problems into mathematical equations, which often resulted in the formation of paraconceptions. Interestingly, Dahsah and Coll (2008) found in studies in Bangkok that both teachers and students used formulae to solve similar stoichiometric problems instead of using a more pro-active learner-centred or the constructivist approach. This study, thus, explored Ghanaian teacher trainees' understanding of stoichiometric related problems as well as the types of strategies they employed when they were presented with stoichiometric problems.

1.2. Statement of the Problem

The Researcher observed that some teacher trainees who took her course used unexplainable sets of rules for solving mathematical stoichiometric problems. A report by Kusi (2013) in Hanson and Oppong (2014) asserts that learning of stoichiometry is basically through the use of algorithm in secondary schools in the Kumasi metropolis. In secondary schools in the United Arab Emirates, stoichiometry was identified as one of the six most difficult concepts in chemistry (Haider and Al Naqabi, 2008). For which students used inexplicable methods for solving problems.

1.3. Purpose of the Study

The purpose of this study, therefore, was to observe trainees as they solved stoichiometric problems, assess their solutions, ask them to briefly explain their solutions in an interactive session and attempt to interpret how they understood them. Information gathered from the Researcher's interaction with the trainees was used to answer questions which were proposed to guide the study. Such an interpretive method was employed in order to get to the bottom of how undergraduate teacher trainees understood and interpreted stoichiometric concepts.

1.4. Research Questions

The questions which guided the study were as follows:

1. What conceptions do undergraduate teacher-trainees have about basic chemical stoichiometry, using the interpretive method?
2. What principles do undergraduate teacher trainees apply to solve stoichiometric calculations?
3. What principles do undergraduate teacher trainees apply to solve conceptual stoichiometric problems?

Knowing the answers to these questions would support teachers in knowing where and how to focus their teaching as well as how to assess students' work more efficiently.

1.5. Significance of the Study

Although some cases of conceptual studies from parts of the world have been presented, there will be no attempt to make generalisations about how teacher trainees conceptualise chemical stoichiometry. The outcome of this study would however, be an eye-opener for educators of chemistry to develop positive teaching strategies to enhance their students' understanding of chemical stoichiometry in particular and chemistry in general. It would also enable curriculum developers to know how to sequence topics and where best to situate the topic on stoichiometry in a school syllabus.

2. Method

An interpretive study as used by Akatugba and Wallace (2009) was adopted to design and gather data for analysis. This method allowed the identification, documentation and 'knowing-through' of trainees' interpretation of meanings, beliefs, thoughts and general impressions about the stoichiometric concept. It allowed for an interpretation of the learning situation as fully as possible, as well as the totality of whatever was studied from the trainees' view point or frame of reference (Schwandt, 2000). An unstructured interactive session was also employed to gain an in-depth understanding of trainees' own understanding of stoichiometry.

3. Sample

A total of 78 second year undergraduate teacher trainees participated in the study. These trainees, who were aged between 19-25, and all in the formal or abstract operational level, were purposely chosen as they were the only class that had registered to read CHE 242: Introduction to analytical chemistry, for that semester. The entire class participated fully in the introductory class. Chemical stoichiometry is an important topic in analytical chemistry.

4. Data Collection

A test dubbed Stoichiometric Test to Identify Conception (STIC) was administered to the sample. The test comprised two open-ended questions which focused on concepts required for solving problems in stoichiometry. The first part of each question assessed conceptual understanding, while the second part assessed interpretation of a situational case, relation of stoichiometric concepts and a test of computational skills. The concepts which participants were expected to be conversant with in this study were the mole, molar mass, percent yield, concentration of solutions, limiting reactant, chemical equations and quantity relationships in chemical reactions. These concepts are inter-related so that an adequate understanding in an appreciable number of the associated terms would enable a trainee to build a sound conceptual framework in stoichiometry. The questions were trialled among

15 undergraduate teacher trainees in a comparable situation for construct validity and to ensure the internal consistency of the instrument. The reliability of the test was examined by Cronbach alpha with a result of $\alpha = 0.78$. The test instrument was analysed by two senior chemistry educators. It was necessary to use open-ended questions since they have an inherent diagnostic quality. The interpretation of the outcome was entirely that of the Researcher's.

4.1. Data Analysis and Interpretation Process

Trainees' responses to the Stoichiometric Test to Identify Conception (STIC) were evaluated per item as conceptually correct (CR); partially correct (PC), incorrect (IR) and no response (NR) outcomes. The analysed data is presented in Table 1.

Table-1 Trainees' performance in the STIC (N = 78)

Item	CR	% CR	PC	% PC	IR	% IR	NR	% NR
1a	17	21.79	20	25.64	34	43.59	7	8.97
1b	13	16.66	21	26.92	36	46.18	8	10.26
2a	15	19.23	26	33.33	27	34.64	10	12.82
2b	10	12.82	25	32.05	29	37.18	14	17.95

A response was correct if conceptual understanding and computation were evident. A response was judged partially correct if only part of a question was solved conceptually. An answer that contained wrong relationships and units was marked wrong while a no response label meant that a question was not attempted at all.

The first question required the trainees to demonstrate an understanding of limiting and non-limiting reactants through the correct writing and balancing of a chemical equation and comparing amounts of substances involved. The question was:

1. a) Write a balanced chemical equation for the reaction between calcium carbide (CaC_2) and water to form calcium hydroxide ($Ca(OH)_2$) and ethyne gas (C_2H_2). Identify the limiting and non-limiting reactants and show how much of the non-limiting reagent will be left over after the reaction is complete.

   b) How many grams of NaCl must be added to 375g of water to prepare a 3.75% (m/m) solution of NaCl?

In item 1a) a balanced equation for the reaction was quite critical, while in 1b) computational skills were required. About 52% of the trainees made incorrect and no response options in item one. They reasoned that the limiting reactant was the reactant with the smallest mass while the non-limiting reactant was the reactant with a bigger mass. The second part of question one required a demonstration of computational and concept relational skills. Majority of the trainees used dimensional analysis. In their solutions, units in their denominator of each succeeding term eliminated the units in the numerator of the preceding one until the units of an answer was obtained. Majority of these trainees read physics as their minor subject and must have gained this knowledge from their physics class. A few however, had problems with the characterisation of the nature of matter and how to properly calculate for entities such as a mole or two of an entity.

The second question was:

2. a) When nitrogen monoxide reacts with gaseous oxygen it produces brown gaseous nitrogen dioxide

$$2NO\,(g) + O_2\,(g) \rightarrow 2NO_2\,(g)$$

Consider a mixture of NO and O_2 in a closed container as illustrated below.

NNNNNNNNOOOOOOOOOO

Which of the following would be a true representation of the product mixture?

N_2 O_2 N_2 O_2 N_2 O_2 N_2 O_2 O_2	N_2 NO_2 N_2 NO_2 N_2	NO_2 NO_2 N_2 NO_2 NO_2 N NO_2	N_2 N NO_2 NO_2 NO_2 NO_2

b) A mixture of 80 g of chromium (III) oxide (Cr_2O_3) and 8 g of carbon is used to produce elemental chromium by the reaction

$$Cr_2O_3 + 3C \rightarrow 2\,Cr + 3\,CO$$

i) What is the theoretical yield of chromium that can be obtained from the reaction mixture?

ii) If the actual yield is 21.70g chromium, what is the percent yield for the reaction?

In part A, of item 2, there are 8 nitrogen atoms and 10 oxygen atoms. After the reaction, there would be five NO_2 molecules with three nitrogen atoms remaining in the container. The law of conservation was critical. However, trainees demonstrated an adamancy of reasoning, which prevented them from reflecting on new situations. Non-logical reasoning strategies were attempted.

Analysis of part B of item 2, indicated that trainees could not understand that 'actual yield' is always an experimentally determined number. Neither did they show adequate understanding of what a theoretical yield was. Thus the given equation was of no apparent value to them. This was confirmed in the interactive session. Trainees failed to recognise that the theoretical yield was the maximum amount of product that could be obtained from given amounts of reactants in a chemical reaction that proceeded completely in the number described by its chemical reaction. They also could not show adequate understanding that the 'percent yield' is a ratio of the actual yield to the theoretical yield multiplied by 100. A few (about 42%) showed no understanding of 'percentages' and so divided various values by a 100, instead of multiplying their yield ratios by 100. Two of the trainees had interesting presentations of item 2 part b (2b). These are presented as appendix B.

Some of the trainees' pooled wrong responses from their written work and interaction were:

- The mole ratio expression 1:1 was popularly and indiscriminately used

- The assertion that molar mass of a reactant determines the mass of product instead of the amount of reactant given in the problem
- Diverse products with incorrect formula were produced
- Wrong expressions of reaction equations ad formulas
- The use of molar mass for amount of substance
- Units for molar mass expressed in moles
- Errors in the calculation of molar masses

Some of the trainees' partial responses

- 1:1 mole ratio; errors in stoichiometric amounts of the substances which react or are produced
- Failure to identify substances which are present in excess of the stoichiometric amounts
- The yield of the reaction is established from the relative amount of a reactant which has reacted, even in cases when the particular reactant is present in excess of the stoichiometric amounts
- Misunderstanding of the significance of coefficients in mathematical equations
- Interchanging mole ratio with mass ratio (Mole ratio depicts stoichiometric relationships and gives the amounts of reacting species with respect to reactants and their relationships with resulting products).
- Unfamiliarity with scientific language and the ability to translate meaningful sentences into equations or mathematical expressions and vice versa.
- A limiting reagent was defined as the least amount of reactant present in terms of mass and sometimes, the reactant present in excess; which led to difficulties in working out the least amount of substance.
- Quantity relationship in chemical reactions

5. Discussion

Most of the identified problems could be attributed to the inherent abstract nature of the topic which might have led to diverse abstractions on the part of students. From Table 1, an average of 17.63 % demonstrated an apparent correct response to the two items in the STIC, while 29.46% gave partially correct responses. In all less than 50% appeared to have in-depth understanding of the procedures and concepts required for studying chemical stoichiometry at the tertiary level, which is quite unfortunate. This is because very basic secondary school questions were used for the STIC, yet an average of 52.2.90 % made incorrect and wrong responses as indicated earlier. A whopping 40.40% made incorrect responses while 12.50 % did not attempt some of the STIC items at all. These observations indicate that quantitatively more than half of the trainees have carried over alternative concepts and weak mathematical skills from their high schools to the university. Often times, teachers are not aware of these inherent problems, unless a conscious effort is made by the teacher to find them out (Hanson, 2014). Teachers are incidentally limited by curriculum, with respect to encouraging conceptual thinking as observed by other researchers (Gultepe *et al.*, 2013). This is because in their view, carrying out diagnostic assessments limits the actual time available for teaching (Hanson and Oppong, 2014). Thus, they hardly make efforts to identify students' conceptual misunderstandings before they introduce new topics. Diagnostic assessments are nevertheless the best thing to do, for the purposes of authentic concept building in the sciences. For example, in this study, when trainees were to find out how much of the non-limiting reagent would be left, over 40% could not rationalise what was expected of them due to poor interpretation and conception. Misconceptions or alternative conceptions lead to errors which will be repeated as often time as possible as long as students' misunderstandings are not identified and addressed accordingly. These, called 'systematic errors' by Kousathana and Tsaparlis (2002) were also identified by Locaylocay (2006) in other topics in chemistry education. Such errors present conceptual difficulties to students in their understanding. Students' level of conceptual understanding has a significant effect on their ability to identify examples quickly and clearly and to solve problems with understanding. Their representation ability and success at using correct mole ratio are important for solving stoichiometric problems. Trainees in this study were found to use algorithmic methods, which confirm the assertion that this is true for students who have not sufficiently grasped the chemistry behind a problem. Quite a number of them (an average of about 10) failed to attempt an answer to the questions. This could be due to lack of confidence and incompetence in dealing with such problems, as was observed with item 2b. From appendix B, the second trainee solved the problem in a haphazard 'hip-hop' manner until he arrived at the expected answer. The first was more methodical. Some trainees demonstrated a memoristic 'fixedness' of reasoning and this hindered them from reflecting on new situations (Niaz, 2001). Their general performance in stoichiometric principles was positively correlated with their understanding of the mole, representational skills and mathematical accuracy. Trainees had difficulties in dealing with abstract situations, as noted by Case and Fraser (1999). In Schmidt and Jigneus (2003) study, students used a non-mathematical strategy to solve easy questions but relied on unacceptable formula when faced with complex problems. They hardly show and logical reasoning in their analysis. Teachers often accept numerical answers without examining students' conceptual understanding about related concepts (Dahsah and Coll, 2007) and presume that they have an understanding about underlying concepts. This was not the case in this study as the processes adopted for the trainees' solutions were rather assessed. A critical study of trainees' presentations in appendix B suggests that the trainees might have been exposed to varying teaching methods in secondary schools. Instructional method could have been a determining factor for the both the quantitative and qualitative results. This is because different teachers taught these trainees in high school and so teacher-effect would exert some influence. These teachers could have their own conceptual deficiencies. This was however not assessed in this study. About 64% of all students who were able to balance equations correctly and used them to interpret stoichiometric coefficients appropriately made success with their stoichiometric solutions. It was observed that trainees had difficulties when the stoichiometric proportions were not 1:1 but otherwise.

The informal interactive session, which lasted for twenty minutes, affirmed some of the interpretations which the researcher had assigned to observations made on the trainees' answer sheets. They demonstrated a lack of understanding of mole ratios, inability to interpret word problems, relationship issues and poor mathematical computations. They admitted to not hearing about some important terms like 'limiting reactant' and 'percentage yield'. Majority of them attested to having heard about the law of conservation of mass in their lower secondary years but had forgotten what it was all about and its application. These issues pointed to the fact that some kind of diagnostic assessment was indeed necessary before the introduction of any new topic which would have to be followed by remediation if the need arose, to enable learners to build more authentic scientific concepts. Again, the readiness of learners would have to be taken into consideration with the introduction of new concepts (Gooding and Metz, 2011) so that the formation of alternative concepts would be avoided.

6. Conclusion

Majority of the trainees in this study had conceptual interpretative problems in understanding that one's ability to comprehend and translate worded problems into representational form correctly was important in setting up correct relationships also. It appeared that about 50% of the trainees were operating at a concrete operational level and thus had difficulty interpreting abstract situations into concrete representations. In all, fifteen alternative conceptions were realised from the study.

7. Implication

Teachers must pay attention to all concepts associated with chemical stoichiometry before the start of the topic. They should move emphasis away from teaching the use of complex algorithms to strategies that require concept formation and higher cognitive skills, but in a step-wise manner.

8. Recommendation

When teaching stoichiometric concepts, teachers should teach the mole and related terms concepts until students clearly understand them, before engaging them in the solution of numerical problems. Again, new terms and basic computational skills should be taught gradually and applied in varying contexts. They must ensure that students can understand and interpret abstract events into concrete representations. Even with the best instructions, students could still develop misconceptions, so teachers should continue to monitor their students' understanding and correct any identified misconceptions. The adoption of conceptual change pedagogy would provide useful insight into students' thinking and enable misconceptions to be overcome.

9. Acknowledgement

I wish to acknowledge second year trainees in the 2014/15 year group who availed themselves for this interpretive study, especially two of them who allowed their scripts to be copied.

References

Akatugba, A.H. and J. Wallace, 2009. An integrative perspective on students proportional reasoning in high school physics in a West African context. International Journal of Science Education, 31(11): 1473-1493.

Antwi, V., 2013. Interactive teaching of mechanics in a Ghanaian university context. Amersfoort: Drukkerij Wilco.

Boujaoude, S. and H. Barakat, 2000. Secondary school students difficulties with stoichiometry. School Science Review, 81(296): 91-98.

Boujaoude, S. and H. Barakat, 2003. Students problem solving strategies in stoichiometry and their relationships to conceptual understanding ans learning approaches. Electronic Journal of Science Education, 7(3): 23-29.

Case, J.M. and D. Fraser, 1999. An investigation into chemical engineering students understanding of the mole and the use of concrete activities to promote conceptual change. International Journal of Science Education, 21(12): 1237-1249.

Chiu, M.H., 2001. Exploring mental models and causes of high school students misconceptionsin acids-bases, particle theory and chemical equilibrium. Proceedings of National Science Council, ROC, 11 (1): 20-38.

Cracolice, M.S., J.C. Deming and B. Ehlert, 2008. Concept learning versus problem solving: A cognitive difference. Journal of Chemical Education, 85(6): 873-878.

Dahsah, C. and R.K. Coll, 2007. Thai grade 10 and 11 students conceptual understanding and ability to solve stoichiometric problems. Research in Science and Technological Education, 25(2): 227-241.

Dahsah, C. and R.K. Coll, 2008. Thai grade 10 and 11 students understanding of stoichiometry and related concepts. International Journal of Science and Mathematics Education, 6(4): 573-600.

Gooding, J. and B. Metz, 2011. From misconceptions to conceptual change. Science Teacher, 78(4): 34-37.

Gultepe, N., A.Y. Celik and Z. Kailic, 2013. Exploring effects of high school students mathematical processing skills and conceptual understanding of chemical concepts on algorithmic problem solving. Australian Journal of Teacher Education, 38(10): 106-122.

Haider, A.H. and C.A.K. Al Naqabi, 2008. Emirati high school students understandings of stoichiometry and the influence of metacognition on their understanding. Research in Science and Technological Education, 26(2): 215-237.

Hanson, R., 2014. Undergraduate chemistry teacher-trainees understanding of stoichiometry- a case study in the university of education, Winneba. Winneba: Faculty of Science Education, University of Education, Winneba.

Hanson, R. and E.K. Oppong, 2014. Ghanaian high school chemistry studnets conceptual understanding of stoichiometry and their translations of problems. Journal of Science Education and Research, 1(1): 1-8.

Kousathana, M. and G.T. Tsaparlis, 2002. Students errors in solving numerical chemical equilibrium problems. Chemistry Education: Research and Practice in Europe, 3(1): 5-17.

Kusi, D., 2013. Improving the performance of students in titrimetry through cooperative learning in senior high schools within Kumasi metropolitan area. Winneba: University of Education, Winneba.

Locaylocay, J.R., 2006. Changes in college students conceptions of chemical equilibrium. Amsterdam: Vrije Universiteit Printers.

Nakhleh, M.B. and R.C. Mitchell, 1993. Concept learning versus problem solving. Journal of Chemical Education, 70(3): 190-192.

Niaz, M., 2001. Response to contradiction: Conflict resolution strategies used by students in solving problems of chemical equilibrium. Journal of Science Education and Technology, 10(2): 205-211.

Sanger, M.J., 2005. Evaluating students conceptual understanding of balanced equations and stoichiometric ratios using a particulate drawing. Journal of Chemical Education, 82(1): 131-134.

Schmidt, H.J. and C. Jigneus, 2003. Students'strategies in solving algorithmic stoichiometry problems. Chemistry Education: Research and Practice, 4(3): 305-317.

Schwandt, T.A., 2000. Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructionism, in handbook of qualitative research. N. K. Denzin and Y. S. Lincoln, Eds. 2nd Edn., Thousand Oaks, CA: Sage Publications. pp: 189-213.

Talabi, J.K. and R. Hanson, 2004. A comparative evaluation of the science resource centres of Ghana and Nigeria. Ghana Journal of Education and Teaching, 1(3): 59-63.
Voska, K. and H. Heikkinen, 2000. Identification and analysis of student conceptions used to solve chemical equilibrium problems. Journal of Research in Science Teaching, 37(2): 160-176.
Wolfer, A. and N. Lederman, 2000. Introducing college chemistry students understanding of stoichiometry: Connections between conceptual and computational understandings and instructions. Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Appendix

Appendix-A.

1. a) $Ca + C \rightarrow CaC + C_2H_2$
   b) 100g of solution – 2.75g NaCl = 97.25g H_2O
   97.25g of water contains 2.75g of NaCl
   Thus, 375g of water will contain = 375g H_2O x 2.75g NaCl/ 97.25g H_2O
   = 1031.25g NaCl/ 97.25
   = 10.6g NaCl

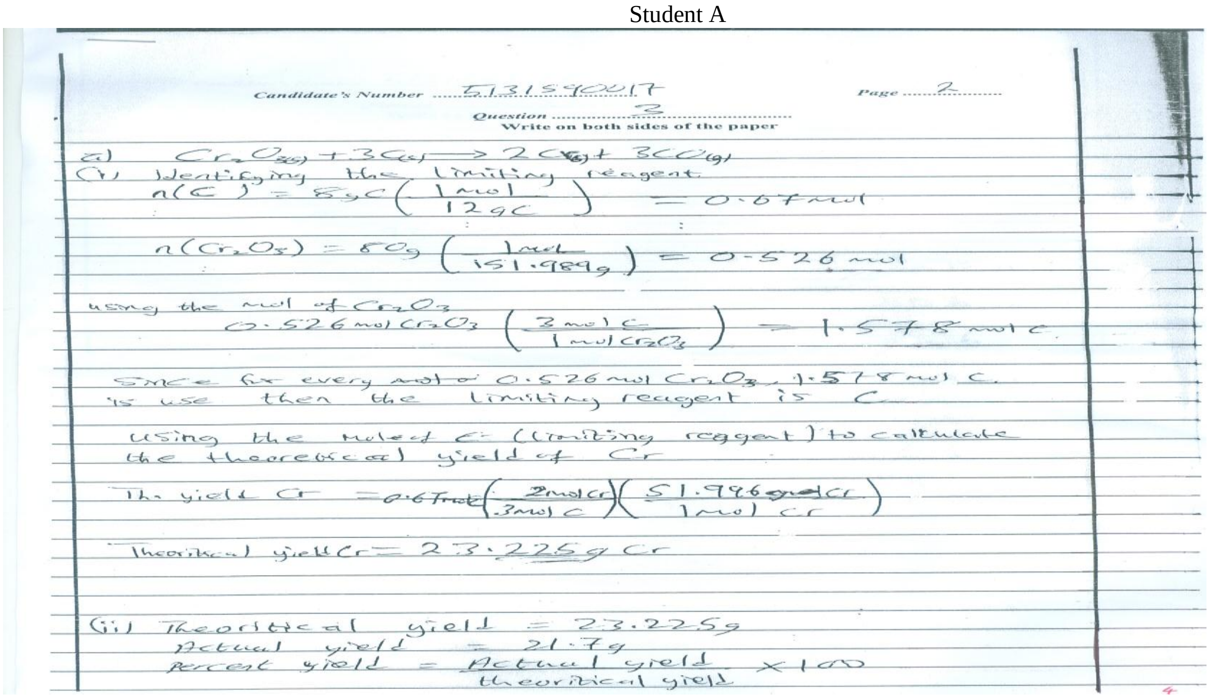
2. a) The answer is as indicated in the diagram

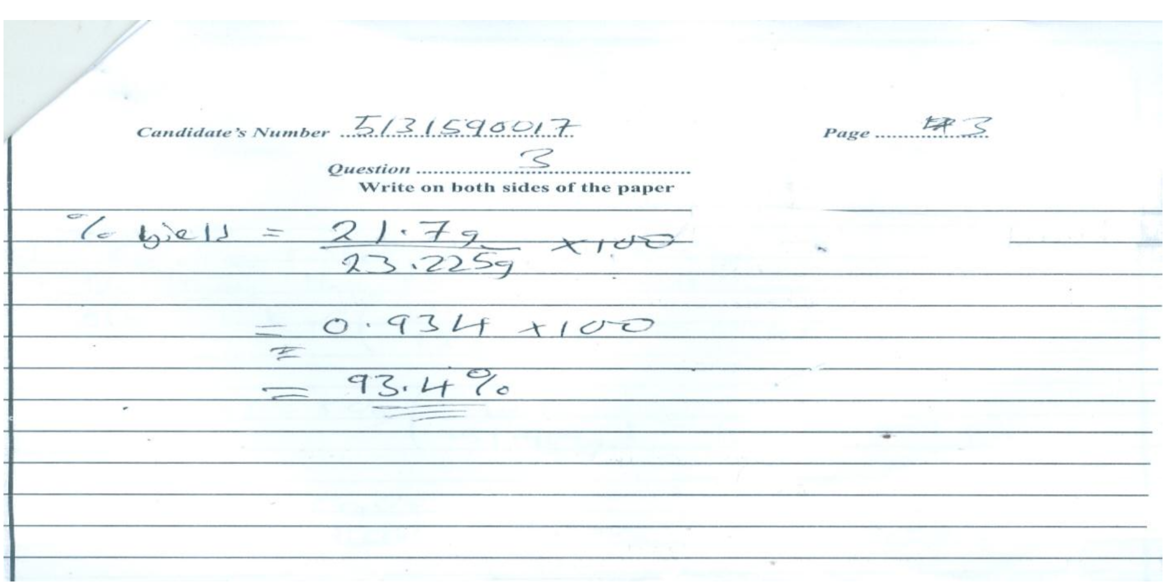
   NO_2 NO_2 NO_2 NO_2 NO_2 N N N

   b A mix of 80g of chromium (III) oxide (Cr_2O_3) and 8g of carbon (C) is used to produce elemental chromium (Cr) by the reaction:
   $Cr_2O_3 + 3C \rightarrow 2Cr + 3CO$
   i) What is the theoretical yield of chromium that can be obtained from the reaction mixture?
   ii) If the actual yield is 21.7g, what would be the percent yield for the reaction?
   Answers are indicated on trainees' scripts

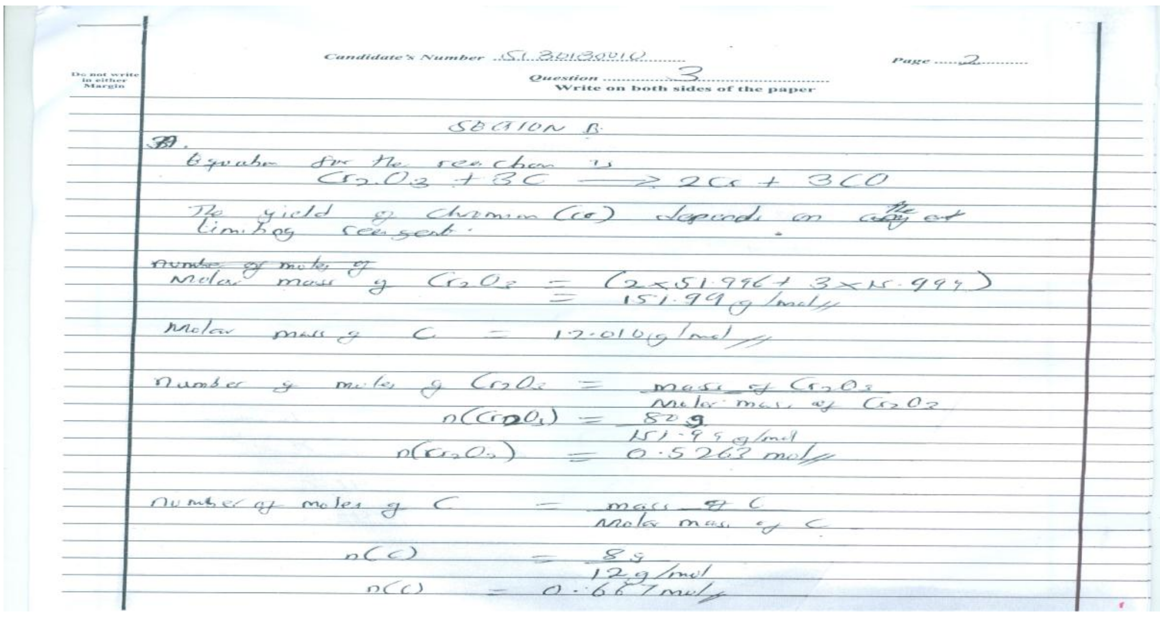
Appendix-B.

Student A


Candidate's Number 5131590017 Page 2
Question 3
Write on both sides of the paper
a) $Cr_2O_{3(s)} + 3C_{(s)} \rightarrow 2Cr_{(s)} + 3CO_{(g)}$
(i) Identifying the limiting reagent
n(C) = 8gC (1 mol / 12gC) = 0.67 mol
$n(Cr_2O_3)$ = 80g (1mol / 151.989g) = 0.526 mol
using the mol of Cr_2O_3
0.526 mol Cr_2O_3 (3 mol C / 1 mol Cr_2O_3) = 1.578 mol C
Since for every mol of 0.526 mol Cr_2O_3, 1.578 mol C is use then the limiting reagent is C
using the mole of C (limiting reagent) to calculate the theoretical yield of Cr
The yield Cr = 0.67mol C (2mol Cr / 3mol C)(51.996g mol Cr / 1mol Cr)
Theoretical yield Cr = 23.225g Cr
(ii) Theoretical yield = 23.225g
Actual yield = 21.7g
Percent yield = Actual yield / theoretical yield x100


Candidate's Number 5131590017 Page 3
Question 3
Write on both sides of the paper
% yield = 21.7g / 23.225g x100
= 0.934 x100
= 93.4%

Student B



Candidate's Number 5120130010 Page 2

Question 3

Write on both sides of the paper

SECTION B

Equation for the reaction is
$Cr_2O_3 + 3C \rightarrow 2Cr + 3CO$

The yield of Chromium (Cr) depends on the amount of limiting reagent.

Molar mass of Cr_2O_3 = (2×51.996 + 3×15.999)
= 151.99 g/mol

Molar mass of C = 12.016 g/mol

Number of moles of Cr_2O_3 = mass of Cr_2O_3 / Molar mass of Cr_2O_3

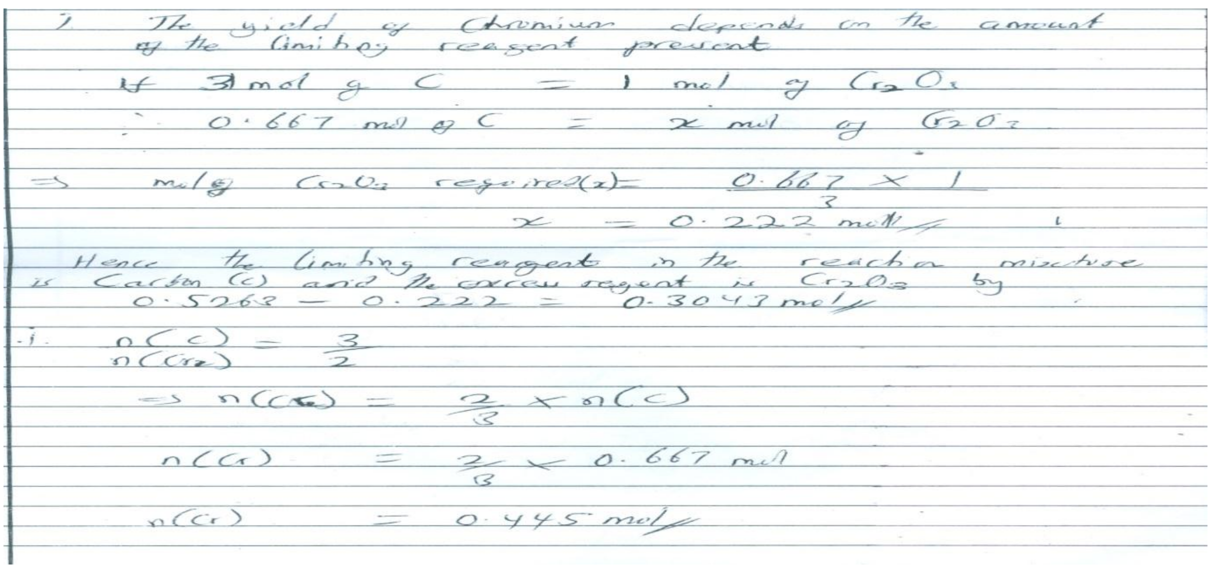
n(Cr_2O_3) = 80 g / 151.99 g/mol

n(Cr_2O_3) = 0.5263 mol

Number of moles of C = mass of C / Molar mass of C

n(C) = 8 g / 12 g/mol

n(C) = 0.667 mol



i. The yield of Chromium depends on the amount of the limiting reagent present

If 3 mol of C = 1 mol of Cr_2O_3

∴ 0.667 mol of C = x mol of Cr_2O_3

⇒ mol of Cr_2O_3 required (x) = 0.667 × 1 / 3

x = 0.222 mol

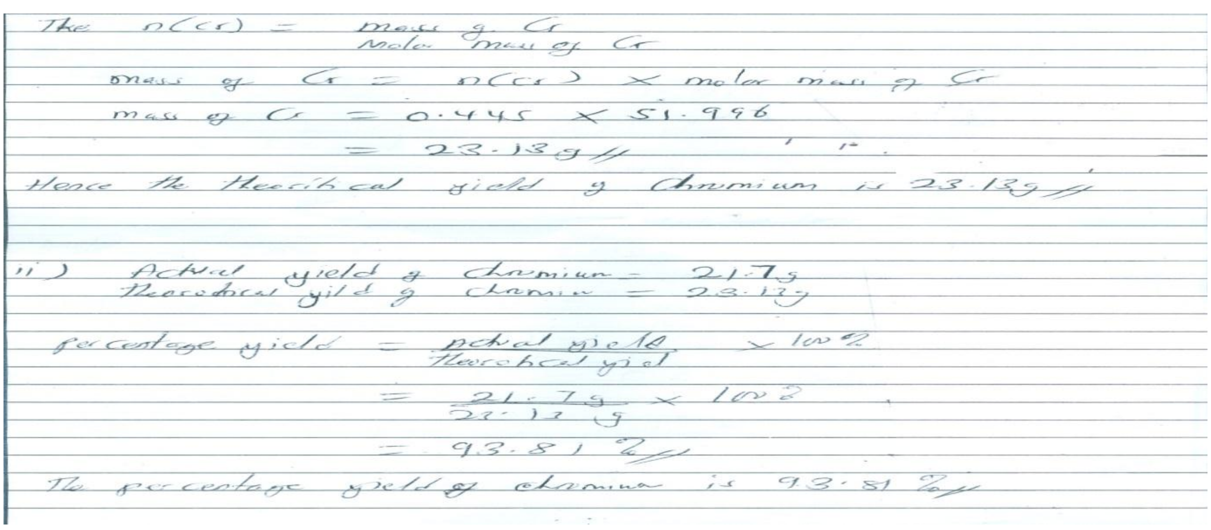
Hence the limiting reagent in the reaction mixture is Carbon (C) and the excess reagent is Cr_2O_3 by 0.5263 − 0.222 = 0.3043 mol

i. n(C) / n(Cr) = 3/2

⇒ n(Cr) = 2/3 × n(C)

n(Cr) = 2/3 × 0.667 mol

n(Cr) = 0.445 mol



The n(Cr) = mass of Cr / Molar mass of Cr

mass of Cr = n(Cr) × molar mass of Cr

mass of Cr = 0.445 × 51.996

= 23.13 g

Hence the theoretical yield of Chromium is 23.13 g

ii) Actual yield of chromium = 21.7 g
Theoretical yield of chromium = 23.13 g

percentage yield = actual yield / theoretical yield × 100%

= 21.7 g / 23.13 g × 100%

= 93.81 %

The percentage yield of chromium is 93.81 %

Follow up question

Silver and silver-plated objects tarnish in the presence of hydrogen sulphide.

$4\,Ag + 2H_2S + O_2 \rightarrow 2Ag_2S + 2H_2O$

If 25g of Ag, 5g of H2S and 4g of O2 are in a reaction mixture, which could be the limiting reactant for tarnish formation?

Solution

Moles of product of each reactant were worked out. Water was chosen as the target product.

25g of Ag yielded 0.11585 moles of H_2O; 5g H_2S yielded 0.1466 moles H_2O, while 4g of O_2 yielded 0.25 moles of H_2O. Ag was found to be the limiting reactant as it produced the least amount of H_2O.