UNIVERSITY OF EDUCATION, WINNEBA

THE USE OF THE FIRST PRINCIPLE APPROACH TO ENABLE SELECTED S.H.S. STUDENTS DEDUCE THE LIMITING REAGENTS IN CHEMICAL REACTIONS

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STUDENT'S DECLARATION

I, Thomas Obuor, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for any other degree elsewhere.

SIGNATURE:…………………………………………………………..

DATE:…………………………………………………………………

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR:……………………………………………..

SIGNATURE:……………………………………………………………

DATE:……………………………………………………………………

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To the Headmistress, Staff and Students of Sunyani Senior High School, I am only left to say "more is thy due than all can pay".

DEDICATION

This thesis is dedicated to my dear wife, Georgina; and children, Grace, Gloria and Godwin for their love and support.

TABLE OF CONTENTS PAGE

LIST OF TABLES PAGE

LIST OF FIGURES PAGE

ABSTRACT

An action research was conducted by providing an alternative method, first principle approach, to enable students deduce limiting reagents in chemical reactions. Purposive sampling technique was employed to select 50 SHS 2 science students at Sunyani Senior High School in the Brong-Ahafo Region of Ghana for the study. This sampling technique was used because the participants needed to be students who had just completed a course in stoichiometry and chemical equations in chemistry. The instruments used to gather data in this study were questionnaire and tests. The internal consistency of the items on the instruments was verified by examining the coefficient alpha of the various items in the instrument using the scores from the pilot-testing to determine the reliability. The overall reliability coefficient alpha for each of the two (2) test instruments constructed was found to be 0.70. After recording the scores from the pre-intervention and post-intervention tests, the SPSS version 16.0 computer programming for analysing data was used to analyse the scores. Descriptive statistics were used to describe the data in terms of standard deviation, frequencies, percentages and bar charts. The findings of the study indicate that the first principle approach helped the students to deduce the limiting reactants in chemical reactions better than other approaches. This is evident by the fact that 80% of the students scored at least 50% of the marks in the post-intervention test, after they have been introduced to the first principle approach, as against only 14% students scoring at least 50% of the marks in the pre-intervention test. It is recommended that teachers consider the use of this first

principle approach during instruction for the benefit of all students. It is also suggested that further research be done on this topic by other researchers in other places of the country.

CHAPTER ONE

INTRODUCTION

Overview

This chapter deals with the introduction of the study. The areas covered in the introduction include; Background to the Study, Statement of the Problem, The Purpose of the Study, Significance of the Study, Research Questions, Delimitations and Limitations of the study.

1.1 Background to the Study

The limiting reagent concept in reaction stoichiometry problem solving is an area that often poses problems to students. The difficulties that students experience are related to several conceptual issues evidenced in the wider context of stoichiometry problem solving in general (Schmidt, 1997; BouJaoude & Barakat, 2000).

Students‟ understanding or lack of understanding of science concepts, especially chemical concepts they learn in senior high school has been the subject of most studies by science education researchers (Anderson & Renstrom, 1983; Anamuah-Mensah, 1995;

Schmidt, 1997; BouJaoude & Barakat, 2000). The general consensus of these studies has been that, students have misconceptions about chemical concepts.

Chandrasegaran, Treagust, Waldrip and Chandrasegaran (2009) conducted a qualitative case study to investigate the understanding of the limiting reagent concept and the strategies used by five students in Year 11 when solving four reaction stoichiometry problems. Students" written problem-solving strategies were studied using the think-aloud protocol during problem-solving, and retrospective verbalisations after each activity. The study found that, contrary to several findings reported in the research literature, the two high-achieving students in the study tended to rely on the use of a memorised formula to deduce the limiting reagent, by comparing the actual mole ratio of the reactants with the stoichiometric mole ratio. The other three average-achieving students, however, generally deduced the limiting reagent from first principles, using the stoichiometry of the balanced chemical equation. The study concluded that, overall, the students displayed limited confidence during problem-solving to determine the limiting reagent and to perform related computations.

According to Chandrasegaran, *et. al*. (2009), the average-achieving students in their study have demonstrated a preference for the use of reasoning strategies from first principles making use of the balanced chemical equation when solving limiting reagent problems. This preference for the use of first principles by average-achieving students according to Chandrasegaran, *et. al*. (2009) reinforces the need for teachers to consider the use of this strategy during instruction for the benefit of average and lower-achieving students, without totally relying on solving problems in rote fashion.

Worth considering therefore, among the scientific approaches to learning is the use of the first principle approach to enable selected S.H.S. students deduce the limiting reagents in chemical reactions

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1.2 Statement of the Problem

Several studies have been undertaken involving high school as well as college students with the purpose of evaluating their proficiency in stoichiometry problem-solving in general, as well as involving the concept of limiting reagents. Such a trend in research studies is not unexpected as limiting reagent problem-solving is invariably associated with the wider context of reaction stoichiometry problem-solving. The limiting reagent concept in reaction stoichiometry problem solving is an area that often poses problems to students. The difficulties that students experience are related to several conceptual issues evidenced in the wider context of stoichiometry problem-solving in general (Schmidt, 1997; BouJaoude & Barakat, 2000).

Several studies have confirmed the influence of alternative conceptions that are held by students in contributing to the difficulties that they experience when solving stoichiometry problems (Mitchell & Gunstone, 1984; BouJaoude & Barakat, 2000; Dahsan & Coll, 2007). Studies associated with reaction stoichiometry computations by high school students, some of which are referred to in this section, have included the limiting reagent concept as part of the studies. A study by Gauchon and Méheut (2007) investigated the effect of Grade 10 students" preconceptions about the concept of limiting reagent on their understanding of stoichiometry. Depending on the physical state of the reactants, students believed that both reactants in a chemical reaction were completely used up when the reactants were in the same state. On the other hand, only one reactant was thought to have changed completely when a solid was one of the reactants.

In Ghana the situation is not much different. The West African Examination Council"s (W.A.E.C.) Chief Examiner"s Report of November – December 2003 West African Senior Secondary School Certificate Examination (W.A.S.S.S.C.E.) noted among other things that, the overall performance of the candidates in Integrated Science was below expectation. The weaknesses which manifested included the following:

ii inability to balance chemical equations,

iii inability to write chemical symbols correctly,

iiii writing of botanical names wrongly,

iiv inability to apply scientific principles,

iv computational skills were also lacking and

ivi lack of ability to draw correct inferences even when they had described the correct test and expected observations.

The Chief Examiner of November – December 2003 West African Senior Secondary School Certificate Examination (2003) therefore suggested that teachers should arouse the interest of students in science and makes them feel that science is life, and must therefore relate what they study to things around them. He continued that, students" performance in the science examination may be influenced by their misconception or lack of understanding of topics in the Senior High School (SHS) Integrated Science syllabus.

It is in the light of this that it becomes imperative to consider the use of the first principle approach, in an action research, to enable selected S.H.S. students deduce the limiting reagents in chemical reactions.

1.3 The Purpose of the Study

The ultimate purpose of this study is to use the first principle approach in an action research to help selected S.H.S. students deduce the limiting reagent in chemical reactions. Specifically the study sought to:

1. explore the understanding of students on the concept of limiting reagents.
2. find out how students deduce the limiting reagents in chemical reaction problem-solving.
3. introduce the approach of first principle to help students in deducing the limiting reagents in chemical reactions.

1.4 Research Questions

Three research questions were formulated to direct investigations in this study.

1. How do students understand the concept of limiting reagent?
2. What approach do students use to deduce the limiting reagents in chemical reactions?

3. Would the use of first principle approach help the students to deduce the limiting reagents in chemical reactions?

1.5 Significance of the Study

It is hoped that the findings of this study will be useful to all teachers of science and textbook writers to employ the right instructional methodologies in their presentation and treatment of the concept of limiting reagent in chemical reaction so as to minimize as far as possible any lack of understanding or misconception of the concept.

The students who will be the subject of the study will benefit greatly as it will help them to be able to deduce the limiting reagents in chemical reactions. The findings will also benefit all science students since the suggested approaches will provide them with techniques in deducing the limiting reagents in chemical reactions.

The study will be significant to other researchers because it will serve as a documentary reference for future research works.

Finally, the study will be of significance to Stakeholders and Educational Policy Makers because it will provide valuable information that will direct policy, planning and implementation in science educational studies.

1.6 Delimitation

The sample frame forming the students‟ population from which the sample was drawn was the SHS 2 science students of the school. The SHS 2 science students were selected because they had just completed a course in stoichiometry and chemical equation in chemistry which had as one of its sub-topics; “deducing the limiting reactants in chemical reactions” at the end of their study in SHS 1. S.H.S 1 students were not used because they had not treated the topic; “stoichiometry and chemical equation in chemistry”. Also, final year students were not used as the subject for the study because the school administration did not allow them to take part in the study.

The study took place within a period of two (2) months. It could have gone beyond the two (2) months period but due to the fact that the study was time bond, it had to be done within the two (2) months period.

1.7 Limitation

The study being an action research took a period of time to complete. It was appropriate for all the students to continue in the study till the end. However, a student could have decided to opt out of the study and this was going to affect the study. To solve this problem, the students were talked to about the benefits of the study to them and to the study of science in general and were encouraged to remain in the study till the end.

Again, the study was carried out in a senior high school and permission had to be sought from the school authorities. The authorities could have decided to deny the researcher an access to carry out the research. In this light, the researcher went to the Assistant Headmaster of the school and explained the purpose and the benefits of the study to him in order to ease access. The permission to conduct the study was granted.

Also the study could not detect whether the answers that were given by the students in the bio-data section of the questionnaire were true or otherwise. In view of this the students were encouraged to be as sincere as possible.

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

Overview

This chapter deals with the review of the related literature. Literature on students‟ understanding of science concepts, Limiting Reagent Concept Difficulties, Mathematical Concepts and Stoichiometry Problem-Solving, and Reasoning and Algorithmic Strategies in Stoichiometry Problem-Solving are discussed. Also, Understanding the Mole Concept and Interpretation of Chemical Formulae and Equations, The First Principle Approach in Chemistry and the SHS Chemistry Syllabus, are reviewed.

2.1 Students' Understanding of Science Concepts

In recent years, students‟ understanding or lack of understanding of science concepts, especially chemical concepts, they lean in senior high school has been the subject of most studies by science education researchers (Anderson & Renstrom, 1983; Anamuah-Mensah, 1995; Schmidt, 1997; BouJaoude & Barakat, 2000; Murdoch, 2000). The general consensus of these studies has been that, students have misconceptions about chemical concepts. A few studies attempted to provide a list of topics which may be difficult for students at certain levels. Pereira and Pestana (1993) used qualitative analysis of students‟ model to discern the nature of students‟ representations and the presence of any misconception and came out with a list of some topics which pose potential difficult to students at different grade levels. These topics include: the concept of particulate nature of matter, melting, dissolving, cooling, chemical reactions and vaporization.

Rosalind (1981) using the work of Jean Piaget and others on the development of children‟s thinking, has indicated that far from being „tabula rasa‟ of repute, pupils bring to their school learning in science ideas, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. The alternate frameworks, in some cases strongly held and resistant to change and in others flexible and with many internal inconsistencies, have their influence on the effectiveness of formal school science programmes.

A similar investigation done by Osbome and Feyberg (1985) on the nature of children‟s ideas, showed that from young age and prior to any teaching and learning of formal science, children develop meanings for many words used in science teaching and views of the world, which relate to ideas taught in science. The study revealed that these children‟s ideas are usually strongly held, even if not well known to teachers and are often significantly different from the views of scientists. The ideas are sensible and coherent views from the children‟s point of view and they often remain uninfluenced or can be influenced in unanticipated ways by science teaching.

Studies indicate that a similar problem exist with older students. Students‟ and teachers‟ understanding of chemical equilibrium was assessed by Banerjee (1991). The sample consisted of 120 college chemistry students enrolled in the third semester of a four year teacher education course, 42 students in a content methodology course with a one year teacher education programme, 40 secondary level chemistry teachers (possessing BSc.) and

29 secondary level teachers with at least MSc in chemistry. A 21 item test on chemical equilibrium (containing closed and open response items) was developed and administered to all the participants. The data indicated widespread misconceptions among both teachers and students relating to Le Chatelier"s principle, rate and equilibrium, application of equilibrium principles to acid – base and ionic solutions. Group comparisons showed misconceptions to be equally high in both teachers and students. It was speculated that the teachers may have developed their misconceptions during their educational experiences and retained the misconceptions despite their teaching and professional experiences.

Again, how students develop their understanding of the concept of diffusion was the focus of a cross-age study conducted by Westbrook and Marek (1991). The sample consisted of 100 randomly selected students from each of the three grade levels: 7th, 10th and college students enrolled in freshman zoology. All subjects completed a biographical questionnaire, two Piagetian tasks assessing combinational logic and proportional reasoning, and a concept evaluation statement. Understanding diffusion at the concrete, observable level was considered to be a "sound" understanding and an understanding at the molecular, abstract level was considered to be a "complete" understanding. At the end of the study, the researchers found out that none of the 300 students possessed a "complete" or "sound" understanding and there was no apparent relationship between understanding and Piagetian developmental level. Interestingly, 55% of the 7th graders were found to possess misconceptions and over 60% of both 10th graders and college students exhibited misconception as well. The researchers concluded that certain misconceptions about diffusion prevail across grade levels, at the molecular perspective of diffusion and as one proceeds through school does not lead to greater understanding, and students used errant vocabulary when describing diffusion.

In another study of undergraduate students‟ conceptions of phenomena, Sexena (1991) investigated 181 Indian undergraduate students‟ conception of light. The students were administered an eight-item questionnaire, with each item based on at least one of six identified major concepts associated with light (eg. reflection, refraction, shadow). The questions were multiple choices, but students were required to explain the reason for their selected responses. A sample of 5% of the students was interviewed to clarify written responses. Analysis of the questionnaire response and interviews indicated that students had difficulty understanding the process of visibility of an object, shadow formation by an opaque object, action of a filter, and action of a lens in image formation. The study also noted that even many of the students who arrived at correct response were not able to support their responses with acceptable logical reasoning.

In Ghana the situation is not much different. The West African Examination Council‟s (W.A.E.C.) Chief Examiner‟s Report of November – December 2003 West African Senior Secondary School Certificate Examination (W.A.S.S.S.C.E.) noted among other things that, the overall performance of the candidates in Integrated Science was below expectation. The weaknesses which manifested included the following:

i. inability to balance chemical equations,

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The West African Examination Council"s (W.A.E.C.) Chief Examiner"s Report of November – December 2003 West African Senior Secondary School Certificate Examination (W.A.S.S.S.C.E.) therefore suggested that teachers should arouse the interest of students in science and makes them feel that science is life, and must therefore relate what they study to things around them. The report continued that, students" performance in the science examination may be influenced by their misconception or lack of understanding of topics in the Senior High School (SHS) Integrated Science syllabus.

The increasing poor performance by Ghanaian students in the WAEC / WASSSCE Integrated Science examination / papers may point to a general lack of understanding of science concepts in the Senior High Schools. Anamuah-Mensah (1995) in his study on what students found difficult in „O"level chemistry has shown that it is possible to identify topics in chemistry which students have difficulty with. He also contended that students" understanding of the topics in the syllabus strongly reflects their actual performance in those topics as indicated by the grades obtained at the GCE „O" level examination.

2.2 Limiting Reagent Concept Difficulties

The limiting reagent concept in reaction stoichiometry problem-solving is an area that often poses problems to students. The difficulties that students experience are related to several conceptual issues evidenced in the wider context of stoichiometry problem solving in general (Schmidt, 1997; BouJaoude & Barakat, 2000). Several studies have confirmed the influence of alternative conceptions that are held by students in contributing to the difficulties that they experience when solving stoichiometry problems (Mitchell & Gunstone, 1984; BouJaoude & Barakat, 2000; Dahsan & Coll, 2007). Studies associated with reaction stoichiometry computations by high school students, some of which are referred to in this section, have included the limiting reagent concept as part of the studies. A study by Gauchon and Méheut (2007) investigated the effect of Grade 10 students" preconceptions about the concept of limiting reagent on their understanding of stoichiometry. Depending on the physical state of the reactants, students believed that both reactants in a chemical reaction were completely used up when the reactants were in the same state. On the other hand, only one reactant was thought to have changed completely when a solid was one of the reactants.

2.3 Mathematical Concepts and Stoichiometry Problem-Solving

One major contributory factor to facilitating stoichiometry problem-solving is the tendency for students to treat exercises on limiting reagents like any other problem in mathematics (as they often do in all chemistry problem solving exercises) with little display of their knowledge and understanding of the chemical principles involved. Students" limited proficiency in the use of the mathematical concepts of proportions, ratios and percentages in reaction stoichiometry is another contributory factor (Bucat & Fensham, 1995). Bucat and Fensham (1995) noted that;

> "Even the simplest computations in chemistry "involve a more complex set of ratios and proportions than most students would have encountered in their mathematical studies of these concepts", and "simple though it seems to an experienced …… chemistry teacher, (a stoichiometry problem) is a minefield far beyond what was regarded as a mastery of these ideas (of ratios and proportions) in mathematics classes". (p. 135).

The importance of these mathematical concepts was echoed by Koch (1995) who reiterated that "the ability to understand and use proportional reasoning is at the heart of stoichiometry" (p. 39). In his study on finding ways of simplifying stoichiometry problems for first year university chemistry students, he noted that for students to be able to solve a variety of stoichiometry problems, they need to have mastery of important concepts such as the mole, molar mass and mole ratio. These findings are supported by a study that investigated the reasoning strategies used by twenty-seven Venezuelan college freshmen during stoichiometry problem-solving (de Astudillo & Niaz, 1996). The students" understandings were found to improve when they conceptualised stoichiometric relations in terms of ratios. The reasoning strategies of the successful students indicated an attempt by them to establish a mass-mole relationship in the solution process.

Findings about issues associated with the use of mathematics in the chemistry classroom are further confirmed by the views of chemistry teachers concerning the difficulties that beginning students of chemistry face in relation to the use of the mole in stoichiometry computations (Dierks, 1985; Furió, Azcona, Guisasola & Ratcliffe, 2000). Added to this difficulty is the lack of mathematical reasoning among students. One cause of this difficulty is the confusion between equations in mathematics and those used in chemistry. While mathematics is concerned mainly with operation on numbers, in chemistry the emphasis is on operating on quantities of substances. Although students‟ problems with handling mathematical relationships are widely acknowledged by chemistry teachers, there is limited reference to research in this area.

A direct consequence of such confusion is the general inability of students to translate textual statements in chemistry into mathematical statements. Dierks (1985) illustrated how a statement likes; "for a given amount of sodium carbonate, twice the amount of hydrochloric acid is needed", is often misrepresented mathematically. Instead of stating $n(HCl) = 2 \times n(Na_2CO_3)$, students incorrectly state $2 \times n(HCl) = n(Na_2CO_3)$. A misrepresentation of this nature is analogous to the „reversed equation phenomenon‟ in algebra involving the translation of expressions in everyday language to algebraic equations using letters, and vice versa (Nickerson, 1985). For example, in a study cited by Nickerson (1985), students expressed the statement; „There are six times as many students (S) as professors (P)‟ algebraically by the equation $6S = P$ (instead of $S = 6P$).

An extensive study (in terms of students‟ participation) involving reaction stoichiometry problem-solving strategies of senior high school students, Schmidt (1984) identified five problem-solving strategies that students used when solving the test items. Two of these strategies used by 50 - 60% of successful students were not illustrated by their teachers during instruction, nor were they found in German textbooks. In these two strategies, students used their own words, like „twice as much‟ and „same proportion‟, thereby avoiding mathematical expressions to describe ratios between masses, molar masses and moles of substances. The other three strategies that were less frequently used had been introduced by their teachers during instruction. These strategies involved the use of mathematical relationships, like n(CuS) = n(Cu), m(Cu) = n(Cu) x M(Cu), etc. The results of this study indicated that success in stoichiometry problem-solving was associated with use of comprehensible reasoning strategies. Comparing his studies with others, Schmidt (1984) concluded that students are more likely to use algorithmic strategies when solving more difficult problems, but tended to use reasoning strategies with easier problems.

2.4 Reasoning and Algorithmic Strategies in Stoichiometry Problem-Solving

The common practice of using algorithms when students perform stoichiometric computations is well documented in the science education research literature (Schmidt, 1997; Fach, de Boer & Parchmann, 2007). The over-dependence on the use of algorithmic strategies, without attempts at reasoning out the solution process, was evident in the problem-solving behaviour of 266 high school students in a study using the think-aloud procedure while they were solving problems in reaction stoichiometry (Gabel & Sherwood 1984). In a study conducted by BouJaoude and Barakat (2000), forty Year 11 students were required to provide explanations when solving eight stoichiometry problems. These students successfully solved traditional problems using algorithmic strategies, but lacked conceptual understanding when solving unfamiliar problems. Similar findings have also been documented with introductory college chemistry students (Nurrenbern, 1979; Lythcott, 1990; Nakhleh, 1993; Mason & Crawley, 1994; Niaz, 1995; Cracoline, Deming & Ehlert, 2008). One reason for the over-reliance on algorithmic procedures suggested by researchers was lack of understanding of the chemical concepts that was further supported by their inability to solve transfer problems involving situations different from the ones that were used during instruction (BouJaoude & Barakat, 2000; Bodner & Herron, 2002). In an investigation of Grade 12 Swedish students‟ algorithmic stoichiometry problem-solving strategies Schmidt and Jignéus (2003) interviewed four students in order to obtain in-depth understanding of the problem-solving strategies that they used when solving four stoichiometry problems. The students were required to calculate the mass of an element in a given mass of a binary compound. All the students were found to use non-mathematical strategies to solve the easy problems. When solving more difficult problems, however, most of the students calculated the mass fraction or the percentages of an element in each compound.

2.5 Understanding the Mole Concept and Interpretation of Chemical Formulae and Equations

The idea of the mole as the unit of the amount of a substance is an integral part of stoichiometric computations. However, there is widespread confusion over the meaning of the mole among students and teachers (Novick & Menis, 1976; Gabel & Sherwood, 1984; De Jong, Veal & Van Driel, 2002; Furió, Azcona & Guisasola, 2002). One reason for this confusion is the different definitions that are used in textbooks and the chemistry curriculum in several countries (Dorin, 1987; Smoot, Price & Smith, 1987; Burton, Holman, Pilling & Waddington, 1994).

Students‟ difficulties with "the mole concept" have been known for a long period (Lazonby, Morris & Waddington, 1982). Given that particle ideas are often poor or inconsistent among teenage chemists, difficulties are unsurprising. Dierks (1981) noted that the mole has only been adopted as a unit in chemistry in relatively recent years. He says that “discussion of "the mole problem" began in 1953” (p. 146) and that thereafter chemists spent a number of years agreeing on a definition. The word "mole" acquired three meanings: “an individual unit of mass; a portion of substance; and a number” (p. 150). Chemistry teachers frequently adopt the simplistic standpoint of the mole as a “counting unit”. Nelson (1991) disagreed with this approach on the grounds that in fact the mole is not strictly defined as a number, but rather as: “...the amount of substance corresponding to the number of atoms in 0.012 kg of carbon-12.” (p. 103). Dierks (1981) suggested that problems also arise when the mole concept is introduced to students who are not being prepared to become professional chemists. He reported that early work on students' difficulties centered on the vital connection between chemical formulae / equations and mathematical expressions representing amounts of substance. Dierks (1981) states:-

> It is generally argued ... that pupils need a clear conception of what is meant by amount of substance if they are to work successfully with this concept. This concept can apparently only be developed when amount of substance is interpreted as a numerical quantity. (p. 152)

Adopting the Ausubelian argument that "meaningful learning occurs when new information is linked with existing concepts" (p. 153), Dierks (1981) advocated beginning to teach the mole as a "number". This contrasts directly with Nelson (1991) who suggested strongly that the mole should be taught as an “amount”, suggesting use of the term “chemical amount” rather than “amount of substance”. This difference may be at the centre of problems associated with the mole - in teaching this concept, we may use “amount of substance” and “number of particles” synonymously, contributing unwittingly to students‟ difficulties by never really explaining what we mean in either case.

BouJaoude and Barakat (2000) made three suggestions about teaching the mole. They developed a stoichiometry test and carried out unstructured interviews with forty 16-17 year olds revealing misunderstandings about molar quantities, limiting reagent, conservation of matter, molar volume of gases at STP and coefficients in a chemical equation. The authors suggest that teachers should help students develop clear relationships between these ideas before numerical problems are presented. They point out that teachers should also analyse students‟‟ approaches to problem solving, suggesting that this will prevent students from continuing to use incorrect strategies. A third suggestion points to use of problems which stimulate thinking, rather than application of an algorithm. In this study, these authors found this helped to build students‟‟ problem-solving abilities.

Also, several studies have documented inadequacies in high school students‟‟ understanding and interpretation of the significance of chemical formulae and equations. In particular, students appear to have limited understanding of the significance of coefficients and subscripts in chemical equations, as well as about the conservation of mass in relation to chemical formulae (Duncan & Johnstone, 1973; Schmidt, 1984; Mulford & Robinson, 2002; Sanger, 2005).

A chemical equation is a shorthand description of the chemical change that occurs during a chemical reaction. Once chemical equations have been introduced in a course of study, it is often assumed that students understand this representational system. The chemical equation is a language of chemistry, one that chemists and chemical educators use constantly. Many of the difficulties in learning chemistry for students may well relate to this problem (Mulfold, 1996). After its introduction, and often a brief one that is focused on the balancing of equations and not usually on what they represent, educators use chemical equations to explain much of the rest of chemistry. This can be seen in everything from phase changes and thermodynamics to chemical equilibrium. If students do not understand the language used by the instructor, how can they be expected to understand what is said?

An equation, which represents equal number of atoms of all similar elements on both sides of a chemical equation, is called a balanced equation. In balancing equations, it is important to understand the difference between a coefficient of a formula and a subscript in a formula. The coefficients in a balanced chemical equation can be interpreted both as the relative number of molecules, moles or formula units involved in the reaction. And subscripts on the other hand indicate the relative number of atoms in a chemical formula. Subscripts should never be changed in balancing an equation, because changing subscript changes the identity of the substance. In contrast, changing a coefficient in a formula changes only the amount and not the identity of the substance and hence can be manipulated in balancing chemical equations. Balancing equation go further than word equation. It gives the formula of the reactants and products and shows the relative number of particles of each of the reactant and the products. Notice that the atoms have been reorganized. It is also important to recognize that in a chemical reaction, atoms are neither created nor destroyed. In other words, there must be the same number of each type of atom on the product side and on the reactant side of the arrow. Thus, a chemical equation should obey the law of conservation of mass. That means a chemical equation should be balanced. The study of the quantitative nature of chemical formulas and chemical reactions is called stoichiometry. Equations and stoichiometry are essential tools in chemistry, and they deserve critical study of how students conceive these concepts.

Eylon *et al* (1982, as cited in Gabel, Samuel & Hunn, 1987) found that when students are given a chemical formula for a relatively simple molecule, 35 percent of the high school chemistry students were unable to represent it correctly using circles representing atoms. These students had an additive view of chemical reactions rather than an interactive one. Eylon *et al* (1982, as cited in Gabel *et al*, 1987) also found that many students perceive a chemical formula as representing one unit of a substance rather than a collection of molecules. In a similar research, Yarroch (1985) found that of the 14 high school students whom he interviewed, only half were able to represent the correct linkages of atoms in molecules successfully. Although the unsuccessful students were able to draw diagrams with the correct number of particles, they seemed unable to use the information contained in the coefficients and subscripts to construct the individual molecules. For example, in the equation, $N_2 + 3H_2 \rightarrow 2NH_3$, students represented $3H_2$ as O O O O O O O rather than OO OO OO. Students were able to use formulas in equations and even balance equations correctly without understanding the meaning of the formula in terms of particles that the symbols represent.

Another researcher (Nakhleh, 1992) concluded that many students perceive the balancing of equations as a strictly algorithmic (plug-and-chug). Further, Yarroch (1985) illustrated students‟ lack of understanding of the purpose of coefficients and subscripts in formulas and balanced equations of the reaction between nitrogen and hydrogen as follows:

$$\mathbf{N_2 \quad + \quad 3H_2 \quad \rightarrow \quad 2NH_3}$$

□□ OOOOOO □□OOOOOO

Ben-Zvi, Eylon and Silberstein (1987) concluded that balancing and interpreting equations for students is a difficult task. As an example, they performed a task analysis on the combustion of hydrogen, as represented by the equation $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ Ben-Zvi *et al* (1987) argued that in order to appropriately interpret such equation the learner should understand many things such as, the structure and physical state of the reactants and products, the dynamic nature of the particle interactions, the quantitative relationships among the particles, and the large numbers of particles involved. Further they also note that some students seem to have an additive model of reaction: compounds are viewed as being formed by simply sticking fragments together, rather than as being created by the breaking and reforming of bond. Still on a similar research conducted by Sawery (1990) on stoichiometry revealed that only about 10 percent out of 323 students could answer conceptual questions.

Understanding the mole, chemical equations and formulae has a significant bearing on students‟ ability to perform stoichiometric computations in chemistry.

2.6 The First Principle Approach in Chemistry

One method that can be used in deducing the limiting reagent in a chemical reaction is by the use of the first principle approach using the stoichiometry of the balanced chemical equation. For example, if 1 mol of A reacted with 2 mol of B, **x** mol of A would require 2**x** mol of B. If 2**x** mol of B were not available in the question, then B was the limiting reagent and A was the reagent in excess. However, if say, 3**x** mol of B was available, this was more than sufficient; then A was the limiting reagent. This method does not involve computing the actual mole ratio (AMR) and the stoichiometric mole ratio (SMR). For example;

Consider the following reaction:

$Pb^{2+}_{(aq)} \quad + \quad 2I^{-}_{(aq)} \quad \rightarrow \quad PbI_{2(s)}$

If a solution containing 0.03 mol of Pb^{2+} is added to a solution containing 0.05 mol of I^- to produce the precipitate of lead(II) iodide, $PbI_{2(s)}$, deduce the limiting reagent.

In using the first principle approach to deduce the limiting reagent in the problem above, consider the balanced chemical equation. From the balanced chemical equation in the problem above, it may be deduced that 1 mol of Pb^{2+} ions reacts with 2 mol of I^- ions. Therefore, the 0.03 mol of Pb^{2+} ions present will require 0.06 mol of I^- ions, which is more than the 0.05 mol that is available. Hence, the iodide ion, I^- is the limiting reagent in this case. This is the first principle approach.

2.7 Review of the SHS Chemistry Syllabus

2.7.1 Rationale for teaching chemistry

According to the Ghana Education Service (GES) teaching syllabus for chemistry (MOE, 2010), chemistry is concerned with the study of matter and its changes. As such, it is about us humans and everything around us. Chemistry keeps living things alive through the numerous changes that take place in their bodies. Around us for example, there is chemistry in food, clothing, medicine, shelter and in our transportation system. There is chemistry in outer space. Household items like soap, plastics, books, radio, TV, video and computers would not exist without chemistry. Chemistry enables us to understand, explain, control and prevent phenomena like bush fires, industrial pollution, corrosion of metals and the depletion of the ozone layer. Chemistry is therefore a subject of vital importance.

2.7.2 General aims

The 2010 GES chemistry teaching syllabus (MOE, 2010) is intended to:

i. create awareness of the interrelationship between chemistry and the other disciplines or careers.

ii. help students with provide knowledge, understanding and appreciation of the scientific methods, their potential and limitations.

iii. create awareness in students that chemical reactions and their applications have significant implications for society and the environment.

iv. develop students‟ ability to relate chemistry in school to the chemistry in modern and traditional industries or real world situations.

v. help students use facts, patterns, concepts and principles to solve personal, social and environmental problems.

vi. help students use appropriate numeric, symbolic, nomenclature and graphic modes of representation and appropriate units of measurement (eg. SI units).

vii. help students produce, analyse, interpret and evaluate qualitative data; solve problems involving quantitative data; identify sources of error and suggest improvements to reduce the likelihood of error.

viii. help students apply knowledge and understanding of safe laboratory practices and procedures when planning investigations by correctly interpreting hazard symbols;

by using appropriate techniques for handling, maintaining and storing laboratory materials and by using appropriate personal protection equipment.

ix. develop the ability of students to communicate ideas, plans, procedures, results, and conclusions of investigations orally, in writing, and/or in electronic presentations, using appropriate language and a variety of formats (eg. data, tables, laboratory reports, presentations, debates, models).

x. make the subject interesting and motivating through designing hand-on activities for students to enhance their understanding of the subject.

xi. train students to use their theoretical ideas to design experiments to solve practical chemistry problems.

xii. encourage investigative approach to the teaching and learning of chemistry and make chemistry lessons, problem solving in nature.

2.7.3 Scope of content

The 2010 GES chemistry teaching syllabus (MOE, 2010) builds upon the science learnt at the Junior High School level, and is designed to offer at the Senior High School level, the chemistry required to promote an understanding of the chemical processes taking place all around us. The syllabus is also designed to provide enough chemistry to students who:

i. will end their study of chemistry at the SHS level,

ii. require knowledge of chemistry in their vocational studies,

iii. wish to continue their studies at tertiary institutions.

In providing a course based on this syllabus, a wide range of activities including projects have been suggested, in the syllabus, to bring out the initiative and creativity of both the teacher and the student.

2.7.4 Pre-requisite skills

According to the 2010 GES chemistry teaching syllabus (MOE, 2010), the learning of the SHS chemistry requires of students:

(A). Proficiency in English language and a high level of achievement in JHS Integrated Science.

(B). Mathematical Knowledge in the following areas, is also required to facilitate the learning of the subject:

i. arithmetical and algebraic addition, subtraction, multiplication, division, including fraction.

ii. indices, reciprocals, standard forms, decimals, significant figures and approximations.

iii. variations, simple proportions and ratios.

iv. squares, square roots and other roots.

v. logarithms and antilogarithms to base 10.

vi. averages including weighted averages.

vii. algebraic equations: linear, quadratic, simultaneous linear equations and their solutions.

viii. graph drawing and their interpretations.

ix. equation of a straight line, slopes and intercepts.

x. familiarization with the following shapes: triangles, squares, rectangles, circles, cubes, spheres, pyramids and other two and three-dimensional structures.

xi. basic calculus.

xii. use of the internet and search engines.

xiii. knowledge in food and nutrition such as carbohydrates, fats and oils and proteins.

2.7.5 Organization of the syllabus

The syllabus has been structured to cover the three years of the SHS programme. Each year‟s work consists of a number of sections with each section comprising a number of units.

2.7.6 The topic: "Limiting reagent" in the syllabus

The 2010 GES chemistry teaching syllabus (MOE, 2010) suggests that the topic: "Limiting reagent" is taught in SHS 1 under section 4 of the broad topic: "Conservation of matter and stoichiometry". Specifically, the limiting reagent concept is treated under unit 3 of the section 4 of SHS 1 with the heading: "Stoichiometry and Chemical Equations".

According to the syllabus, at the end of the lesson on stoichiometry and chemical equations, students should be able to determine limiting and excess reagents in a chemical reaction.

Under the teaching and learning activities column of the syllabus, it is recommended that teachers help students to determine the limiting and excess reagents in chemical reactions by comparing the available moles of each reactant („actual mole ratio", AMR) to the moles required for complete reaction („stoichiometric mole ratio", SMR) using the mole ratio. No mention is made in the syllabus about the use of first principle approach in deducing the limiting reagent in chemical reactions. Meanwhile, according to Chandrasegaran, *et al*. (2009), the average-achieving students in their study demonstrated a preference for the use of reasoning strategies from first principles making use of the balanced chemical equation when solving limiting reagent problems. This preference for the use of first principles by average-achieving students, according to Chandrasegaran, *et al*. (2009), reinforced the need for teachers to consider the use of this strategy during instruction for the benefit of average and lower-achieving students, without totally relying on solving problems in rote fashion. It is in the light of this that the researcher focused on the topic; "The use of the first principle approach to enable selected S.H.S. students deduce the limiting reagents in chemical reactions".

CHAPTER THREE

METHODOLOGY

Overview

This chapter deals primarily with the method used in carrying out the study. It has been divided into ten distinct sections under the following sub-headings: Research Design, Population, Sample and Sampling Procedure, Research Instruments, Pilot Testing of Instrument, Reliability of the Instrument, Validity of the Instrument, Data Collection Procedure, Implementation of Intervention Design and Data Analysis

3.1 Research Design

The design of a study is the basic plan for a piece of empirical research (Johnson & Christensen, 2008). Among the ideas that are included in a design are the strategy, who and what will be studied, and the tools and procedures to be used for collecting and analysing empirical materials (Punch, 2006).

The study is an action research. According to Stringer (1996), an action research is focused on solving specific problems that local practitioners face in their schools and communities. This is emphasised by Johnson and Christensen (2008) who state that;

> action research is based on the idea that having the "research attitude" is helpful in dealing with complex and changing environment; this attitude involves continuously identifying new problems that one wants to work on and trying new actions to see what improves the situation. (p. 12)

From the foregoing, it can be seen that action research thoroughly integrates theory and research with practice. This study being an action research was appropriate since the study was focused more on local practice and local solution.

The research design for this study was made up of five phases. The first phase addressed the design of the instruments. In implementing the first phase, a questionnaire and two sets of test items were constructed for students. The tests were pilot-tested and feedbacks obtained from the pilot-test were used to refine the test items and the refined tests administered to the subjects of the study later. The second phase of the study was the pre-intervention activities. This involved the interaction of the researcher with the students who formed the subject of the study to explain to them what the study was about. It also included the administration of the pre-intervention test and the marking of the tests.

The third phase was the implementation of the intervention. This involved defining and explaining the term “limiting reactants” as it occurs in chemical reactions to the subject of the study. This was followed by using the “first principle approach” in teaching to help the students deduce the limiting reactants in chemical reactions. After this, the students who formed the subject of the study took part in exercise by using the first principle approach to deduce limiting reactants in chemical reactions. The fourth phase of the study was post-intervention activities. This included the administration of the post-intervention test. The tests were collected and marked at the end of its administration. The firth and the final phase of the study involved the data analysis. A flow chart, Figure 3.1 shows the order in which the research was conducted.

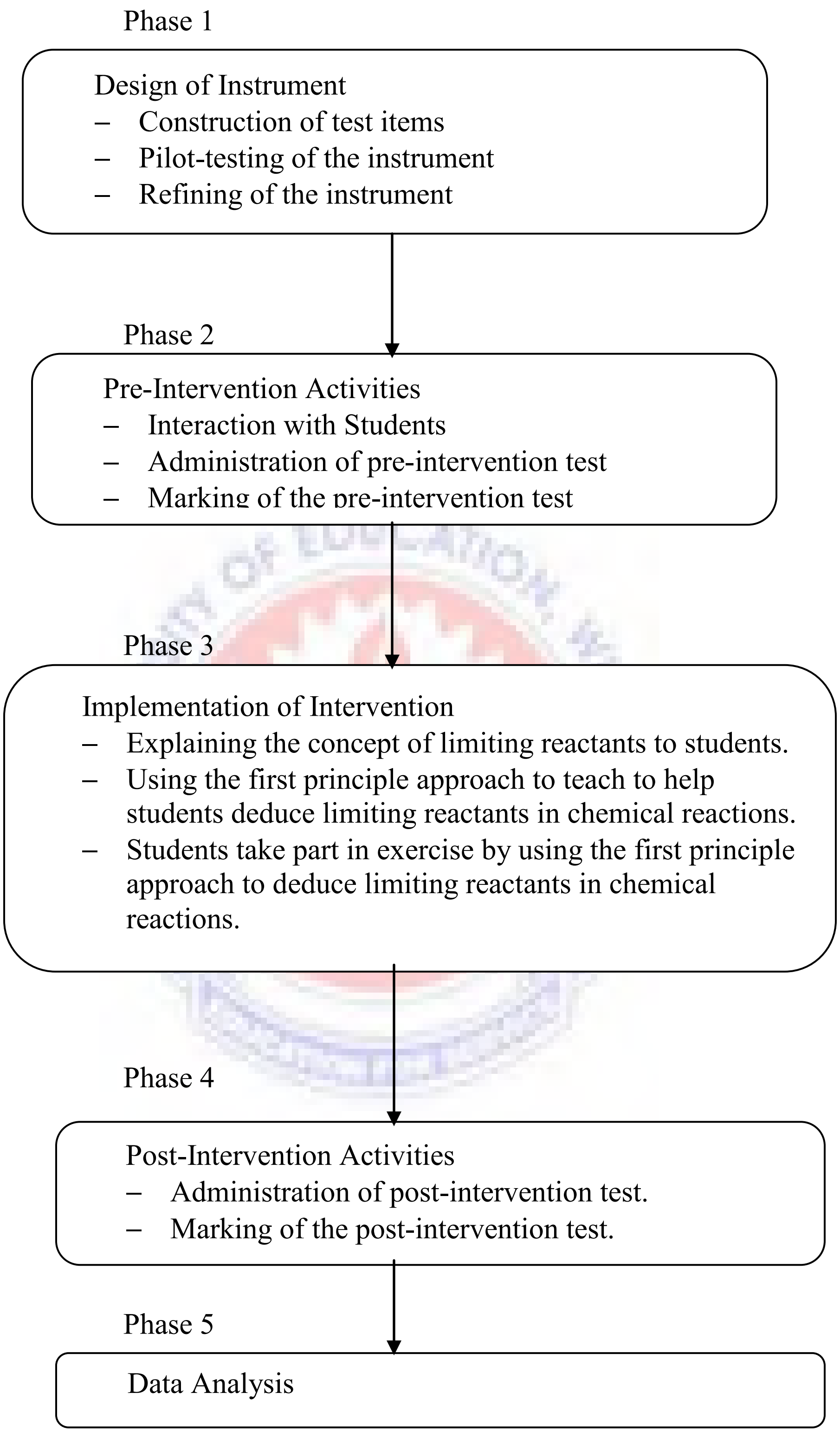

Figure 1: A flow chart of the design of the research

3.2 Population

Johnson and Christensen (2008) define a population as the set of all elements. They continue that, "it is the large group to which a researcher wants to generalize his or her sample results" (p. 224). In other words, it is the total group the researcher is interested in learning more about. This group is sometimes referred to as the target population.

The sample frame forming the students" population from which the sample was drawn was the SHS 2 science students of Sunyani Senior High School in the Brong-Ahafo Region of Ghana. The SHS 2 science students were selected because they had just completed a course in stoichiometry and chemical equation in chemistry which had as one of its sub-topics; "deducing the limiting reactants in chemical reactions" at the end of their study in SHS 1.

3.3 Sample and Sampling Procedure

A sample is a set of elements taken from a larger population according to certain rules (Johnson & Christensen, 2008). According to Johnson and Christensen (2008), sampling is the process of drawing a sample from a population. This implies that, when we sample, we study the characteristics of a subset (the sample) selected from a larger group (the population) in order to understand the characteristics of the larger group (the population). A sample is always smaller than a population, and it is often much smaller.

Purposive sampling technique was employed in this study. This sampling technique was used because the participants needed to be of certain characteristics. In this case, students who had just completed a course in stoichiometry and chemical equations in chemistry were needed. SHS 2 science students offering elective chemistry were the people who had these characteristics. Sunyani Senior High School has two streams of science classes (science 1 and science 2) in SHS 2. The SHS 2 science 1 class had a population of 42 students (consisting of 36 boys and 8 girls) whiles the SHS 2 science 2 class had a population of 44 students (consisting of 36 boys and 8 girls). The study was an action research and only one class was needed for the study. The SHS 2 science 1 class was chosen because it is the first on the list. However, the eight (8) girls in the SHS 2 science 2 class were asked to join the SHS 2 science 1 class for the purpose of this study. The eight (8) girls from the SHS 2 science 2 class were asked to join in the study in order to get a round figure of 50 and also to increase the number of girls in the study. All the 42 students in the SHS 2 science 1 class and the eight (8) girls in the SHS 2 science 2 class agreed to take part in the study after the purpose and the benefits of the study had been explained to them. The distribution of male and female students in the study is as shown in Table 1.

Table 1: Sex of participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	31	62.0	62.0	62.0
	Female	19	38.0	38.0	100.0
	Total	50	100.0	100.0	

The ages of the students ranged from 16 years to 19 years. Out of the students who took part in the study, 10 were 16 years old, 24 were 17 years old, 14 were 18 years old and two (2) were 19 years old. The distribution of the ages of the students is shown in Table 2.

Table 2: Age of participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	16 years	10	20.0	20.0	20.0
	17 years	24	48.0	48.0	68.0
	18 years	14	28.0	28.0	96.0
	19 years	2	4.0	4.0	100.0
	Total	50	100.0	100.0	

3.4 Research Instruments

The instruments used to gather data in this study were questionnaire and tests. A questionnaire according to Patton (2002) is a self-report data-collection instrument that each research participant fills out as part of a research study. In this study, questionnaire was used to gather the bio-data of the participants. This data included the name of the school, age, form and sex. See appendix A for the questionnaire. Questionnaire was used for the bio-data collection because of its convenience of enabling respondents‟ consistency and uniformity to questions they answer. Again, with questionnaire, less time is required to collect data and confidentiality is also assured.

Cohen, Swerdlik and Philips (1996) define testing as “the process of measuring… variables by means of devices or procedures designed to obtain a sample of behavoiur” (p. 6). Two sets of test items were constructed for this study. These were the pre-intervention test and the post-intervention test. The pre-intervention test consisted of ten (10) sets of question items on stoichiometry and chemical equations as it occurs in the GES (2010) teaching syllabus for SHS chemistry (MOE, 2010). The test items were specifically on “deducing limiting reagent in chemical reactions”. The question items as seen in appendix B was used to gather information about the understanding of students on the concept of limiting reagent in chemical reaction.

The post-intervention test also consisted of ten (10) sets of items on stoichiometry and chemical equations as it occurs in the GES (2010) teaching syllabus for SHS chemistry (MOE, 2010). The post-intervention test items were similar to the pre-intervention test items. The post-intervention test items as seen in appendix C were used to find out about the effectiveness of using the approach of first principle in deducing the limiting reagents in chemical reactions.

3.5 Pilot-Testing the Instrument

Pilot-testing is a small scale test administered before conducting an actual study. Its purpose is to reveal defects in the research instrument (Cohen *et al*, 1996). According to Patton (2002), it is highly desirable to pilot-test a test in order to revise the items based on the results of the pilot test. This enables the researcher to determine whether the instrument items posses the desired qualities of measurement and descriminability. This is emphasised by Johnson and Christensen (2008) who state that a pilot-testing of instrument can reveal ambiguities, poorly worded questions, questions that are not understood, and to check how long it takes participants to complete the test under circumstances similar to those of the actual research study. Johnson and Christensen (2008) add that pilot-testing should be conducted with a minimum of five (5) to ten (10) people. The pilot-testing of the instrument for this study was conducted using ten (10) SHS 2 science 2 students of Sunyani Senior High School. The ten (10) SHS 2 science 2 students were used for the pilot-testing because they had similar features with the main participant of the study. The students for the pilot-testing had completed a course in stoichiometry and chemical equation in chemistry just as the participants in the main study and they were taught by the same teacher who taught the participants in the main study. Through the pilot-testing, it was revealed that the $1^1/_2$ hours initially allocated to complete the ten (10) item questions each in the pre-intervention test and the post-intervention test was not enough to complete the questions. The duration for completing the pre- and post-intervention tests was adjusted to 2 hours for each. The researcher administered the pilot-testing himself. Ambiguous and poorly worded questions were refined using the results from the pilot-test to ensure reliability.

3.6 Reliability of the Instruments

Reliability refers to the consistency or stability of a set of scores. It is often defined as the degree of stability or consistency of a measure (Aron, Aron & Coups, 2004). That means that, the reliability of a score is how much you would get the same results if you were to give the same score again to the same person under the same circumstances. According to Johnson and Christensen (2008), reliability is determined by the methods of repeated forms (test-retest), internal consistency, interscorer and equivalent forms.

After obtaining the scores from the pilot-testing of the instrument, the internal consistency of the items on the instrument was verified by examining the coefficient alpha of the various items in the instrument. Coefficient alpha provides an estimate of the reliability of a homogeneous test or an estimate of the reliability of each dimension in a multidimensional test (Aron, *et al*, 2004). The Statistical Package for Social Sciences (SPSS, version 16.0) computer soft ware was used for the analysis of the items on the instruments. The overall reliability coefficient alpha for each of the two (2) test instruments was found to be 0.70. This results showed that the items in the instruments had a good internal consistency and therefore capable of measuring what they were purported to measure. This is so, because according to Johnson and Christensen (2008), as a popular rule, the size of coefficient alpha should generally be, at a minimum, greater than or equal to 0.70 (≥ 0.70) for research purposes and somewhat greater than that value (e.g. ≥ 0.90) for clinical testing purposes.

3.7 Validity of the Instruments

Validity is the extent to which a test measures what is needed for a particular purpose. Validity is defined by Johnson and Christensen (2008) as “the accuracy of inferences, interpretations, or actions made on the basis of test scores” (p. 150). Patton (2002) also refers to validity as the appropriateness, correctness, meaningfulness, and usefulness of the specific references researchers make based on the data they collect. In short, it can be said that, a valid instrument is one that measures what it was designed to measures. Therefore what is important in validity is to make sure that a test is measuring what it is intended to measure for the particular people in a particular context and that the interpretations made on the basis of the test scores are correct. According to Patton (2002), validity is the most important idea to consider when preparing or selecting an instrument for use.

According to Johnson and Christensen (2008) one method for obtaining validity evidence of an instrument is to study the construct to measure, examine the test content, and make a decision whether the test content adequately represents the construct. This is usually done by experts according to Johnson and Christensen (2008). Another method for obtaining validity evidence of an instrument according to Johnson and Christensen (2008) is to relate the test scores to a known criterion by collecting concurrent and/or predictive evidence.

Great effort was made to ensure that the questionnaire and the test items covered all the research questions posed in this study. This was done by cross checking to see whether the test items can really answer the research questions. Also the supervisor, two chemistry teachers at Sunyani Senior High School and colleagues in the Science Department of the University of Education, Winneba were served with copies of the questionnaire and the test items to examine and determine whether the items covered all the research questions adequately. Suggestions received from them were used to refine and sharpen the content of the questionnaire and the test items, making them more relevant and valid for the purpose of the study.

3.8 Data Collection Procedure

The researcher sought permission from the Assistant Headmaster (Academic) of the school to carry out an action research using the SHS 2 science students of the school which was granted. Since the researcher is a teacher in the school, there was no need for an introductory letter to the school authorities. The researcher met the group of fifty (50) science students who served as subject of the study on a Saturday (in order not to interfere with their normal classes) and gave them orientation on the purpose and benefits of the study. The researcher again briefed the students on how the various items were to be responded to. The students‟ questions and concerns were clarified to enable them understand issues and provide the appropriate responses.

The researcher personally administered the questionnaire (see appendix A for the questionnaire) and the test items to the students in a classroom. In the administering the items, the questionnaire, gathering information about their bio-data, was given to the students first. Five (5) minutes was allowed for the students to complete the questionnaire. They were, however, not rushed. After collecting the questionnaire on the bio-data, the students were administered the pre-intervention test. They were given two (2) hours to complete the test items. Once again, they were not rushed. Those who could not complete within the two (2) hours were allowed extra time. All the questionnaires and the pre-intervention test items were administered and collected by the researcher on the same day in the classroom. None of the questionnaires and the test items was missing. The responses of the students on the pre-intervention test were marked over 100 and the scores recorded. See appendix D for the marking scheme of the pre-intervention test.

The researcher met the group of fifty (50) science students who formed the subjects of the study in two weeks time to carry out the intervention activity. All the fifty (50) students were present for the intervention activity. The intervention activity consisted of four parts and was carried out in four consecutive days. After the intervention activity, the students were discharged to re-appear in two (2) weeks time for the post-intervention test to be administered. The researcher and all the fifty (50) students met after two (2) weeks of the intervention activity, in a classroom in the school. The researcher, once again, personally administered the post-intervention test items to the students. They were allowed two (2) hours to answer the test items. However, students who could not answer all the test items within two (2) hours were allowed extra time to complete the task. The post-intervention test items were administered and collected by the researcher the same day and none was found missing. The responses of the students on the post-intervention test were marked over 100 and the scores recorded. See appendix E for the marking scheme of the post-intervention test.

3.9 Implementation of the Intervention Design

This aspect of the research outlines the various practical activities that were carried out to achieve the aims and objectives of the research work. This include orientation, explaining the concept of limiting reagent, using the first principle approach to teach the concept of deducing the limiting reagent and using class exercise to build up students" confidence. The four aspects of the intervention activity were carried out in four consecutive days.

3.9.1 Orientation

The researcher met the group of fifty (50) SHS 2 science students who formed the subjects of the study on day one of the intervention activity and gave them orientation on the purpose and the benefits of the study. They were also told what the study entails, how long the study will take and the need for them to remain in the study to the end. They were also briefed on the difficulties students find in deducing the limiting reagent in chemical reactions and how the use of the first principle approach will help them and students in general in overcoming these difficulties.

3.9.2 Explaining the concept of limiting reagent

Students were taken through the discussion of the concept of limiting reagent as it occurs in chemical reactions on the second day of the intervention activity. The concept of limiting reagent in chemical reactions was explained to students as occurring in a situation when we carry out reactions with **limited** amount of one reactant and an excess amount of the other. In this case the reactant that is completely consumed in the chemical reaction limits the amount of product(s) formed and is called the limiting reactant or limiting reagent. The combustion of octane (C_8H_{18}) in excess amount of oxygen gas (O_2) was used as an illustrative example to help students understand the concept of limiting reagent in chemical reactions. (See appendix F for details on explaining the concept of limiting reagent.)

3.9.3 Using the first principle approach to deduce limiting reagent in a chemical reaction.

The researcher illustrated the use of the first principle approach to deduce the limiting reagent in a chemical reaction to the students after explaining the concept of limiting reagent on the second day of the intervention activity. A reaction involving 0.150 mol of LiOH and 0.080 mol of CO_2 to produce Li_2CO_3 and H_2O was used as the first illustrative example. This illustrative example demanded indicating which of the two (2) reactants, LiOH and CO_2, is the limiting reactant and also calculating the moles of Li_2CO_3 that can be produced. This approach requires the writing of a balanced chemical equation for the reaction and making the assumption that; “all of one of the reactant is used up in the reaction”. This assumption is made on the basis that, reactions whose reactants are not in stoichiometric proportions would always have one reactant being used up and another being in excess. With this assumption, one then finds how much of the other reactant(s) would be needed if all of the other reactant is used up. If the moles of this reactant needed is more than the moles available, then this reactant is the limiting reactant and if less than the actual moles available, then this reactant is the reactant in excess. Also the amount of product(s) produced is/are always dependent on the limiting reactant. The researcher went through a second illustrative example with students on how to use the first principle approach to deduce the limiting reactant in chemical reaction. See appendix F for details on how to use the first principle approach to deduce the limiting reactant in a chemical reaction.

3.9.4 Use of class exercise to build up students' confidence

At the end of the lesson on how to use the first principle approach to deduce limiting reactants in chemical reactions, the researcher met the subject of the study on the third day of the intervention activity and class exercise was given to the students to use the knowledge gained to deduce the limiting reactants in some chemical reactions. The researcher went round to inspect the students doing the class exercise. The exercises were marked and corrections made for the students. The researcher went through the class exercise with students. This helped build up their confidence in the use of the first principle approach to deduce limiting reactants in chemical reactions. See appendix F for the details on the class exercise.

3.10 Data Analysis

Data analysis is the process of simplifying data in order to make it comprehensible (Cohen *et al*, 1996). Therefore in data analysis, any statistical techniques, both descriptive and inferential used should be described. This study, being a qualitative study required a descriptive statistics for analysis of the data.

After recording the scores from the pre-intervention and post-intervention tests, the SPSS version 16.0 computer programming for analysing data was used to analysed the scores. The descriptive statistics was used to describe the data in terms of mean, standard deviation, frequency, percentage and bar chart. The results were then summarised as the major findings of the study. The discussions were done according to the major findings identified in the study and were used to answer the research questions.

CHAPTER FOUR

RESULTS AND DISCUSSION

Overview

In this chapter, the results of the study and the analysis done on them to answer the research questions are presented. The presentations of the results and the analysis were done according to the research questions. The results are summarised in Tables 3 to 5 and Figures 2 to 4.

Research question one: **How do students understand the concept of limiting reagent?** `

This research question attempted to find out about the general understanding of the students on the concept of limiting reagents in chemical reactions. The question 1 in the pre-intervention test required students to explain, in their own words, the term limiting reagent as it occurs in a chemical reaction. A student was deemed to have an understanding of the concept of limiting reagent if he or she was able to give correct explanation to the concept of limiting reagent as it occurs in a chemical reaction. Students" responses to this question 1 in the pre-test was marked and grouped into "correct explanation" and "wrong explanation". Students with "correct explanations" are those who have understanding of the concept of limiting reagent as it occurs in a chemical reaction and those with "wrong explanations" are those who lack understanding of the concept. The result, as analysed by the SPSS version 16.0 computer programming for analysing data, is shown in Table 3 and Figure 2.

Table 3: Students' understanding of "Limiting reagent"

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Correct explanation	41	82.0	82.0	82.0
	Wrong explanation	9	18.0	18.0	100.0
	Total	50	100.0	100.0	

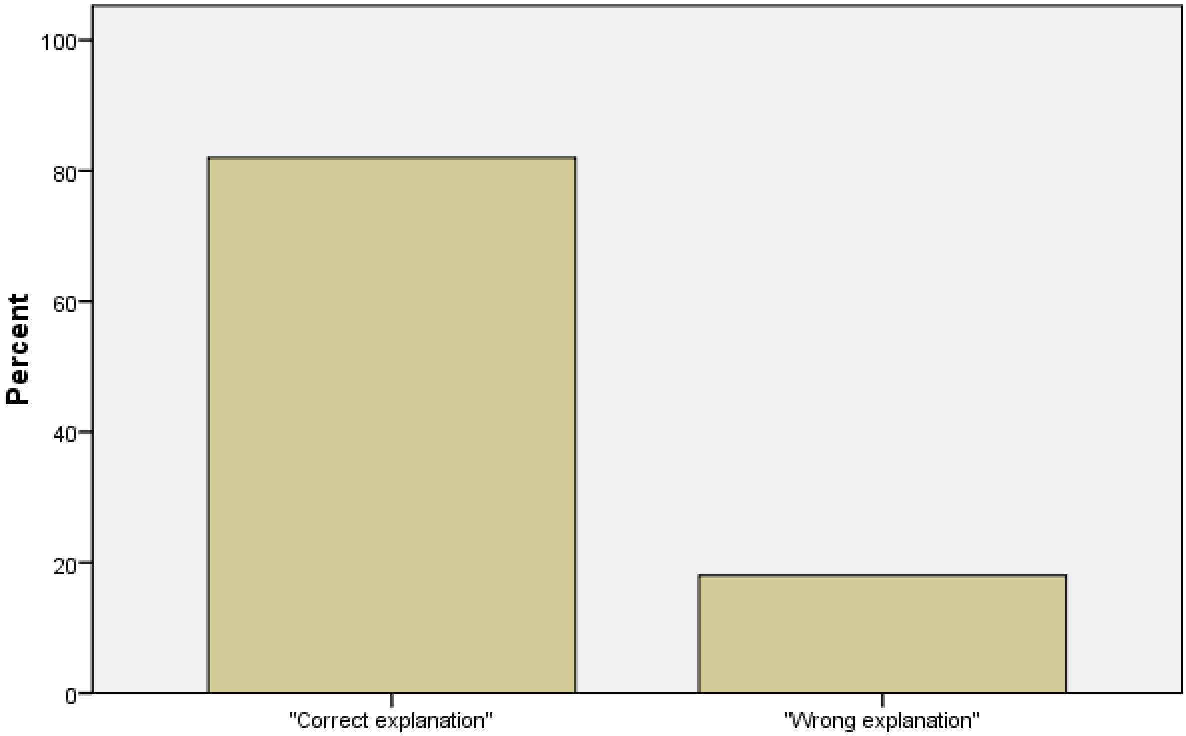

Figure 2: **Students' understanding o "Limiting reagent"**

The results from Table 3 and Figure 2 show that 82% of the students had a good understanding of the concept of limiting reagent as it occurs in a chemical reaction. Some of the students‟ correct explanations, picked at random, are summarised below.

Student 1: *The limiting reagent is the substance that is in shortage to complete the chemical reaction fully.*

Student 2: *The limiting reagent is the substance that is in short supply. It is the reactant which is fully used up in a reaction.*

Student 3: *The limiting reagent is the substance that is used to completion and limits the reaction from producing more of the product.*

Student 4: *Not enough of one (reactant) is available to react with all of the other (reactant).*

Student 5: *The limiting reagent is one reactant that does not have enough mass to fully react with all of another reactant.*

As evidenced from the above statements, these students conveyed at least a satisfactory understanding of what the concept meant. Phrases such as „short supply‟ and „used to completion‟ conveyed the perception of the limiting reagent as a reactant that was completely used up during a chemical reaction. This results shows that lots of the students understood the concept of limiting reagent when it was taught by their class teacher. This finding is in sharp contrast with a study by Gauchon and Méheut (2007) who investigated the effect of Grade 10 students‟ preconceptions about the concept of limiting reagent on their understanding of stoichiometry. According to Gauchon and Méheut (2007), depending on the physical state of the reactants, students believed that both reactants in a chemical reaction were completely used up when the reactants were in the same state. On the other hand, only one reactant was thought to have changed completely when a solid was one of the reactants.

It can also be seen from Table 3 and Figure 2 that 18% of the total students gave wrong explanations to the term limiting reagent. These students lacked the understanding of the concept of limiting reagent. These students are in the minority as compared to the 82% who had understood the concept of limiting reagent.

Research question two: **What approach do students use to deduce the limiting reagents in chemical reaction?**

This research question attempts to find out about the strategies used by students in determining the limiting reagents in chemical reactions. This was determined by analysing the various approaches the students used during the pre-intervention test to deduce the limiting reagents in chemical reactions. From the analysis of the students‟ pre-intervention test responses, two strategies were identified as those used by the students. These are the strategies of; “deducing limiting reagent by comparing „actual mole ratio‟ (AMR) and „stoichiometric mole ratio‟ (SMR)” and “deducing limiting reagent from first principle approach”.

The first strategy involved comparing the „actual mole ratio‟ (AMR) with the „stoichiometric mole ratio‟ (SMR). In order to determine the limiting reagent, students had to reason how the numerator or the denominator of the AMR had to change so that it was equal to the SMR, and from there deduce the limiting reagent (which was the reagent that was in short supply).

The second method also involved deducing the limiting reagent from first principles using the stoichiometry of the balanced chemical equation. This method does not involve computing the actual mole ratio (AMR) and the stoichiometric mole ratio (SMR).

The preferences by students of these two approaches in deducing limiting reagents in chemical reactions, as analysed from their pre-intervention test responses, using the SPSS version 16.0 computer programming, are indicated in Table 4 and Figure 3.

Table 4: Strategies used by students to deduce limiting reagents in chemical reactions

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Deduced limiting reagent by comparing AMR and SMR.	46	92.0	92.0	92.0
	Deduced limiting reagent from first principle approach.	4	8.0	8.0	100.0
	Total	50	100.0	100.0	

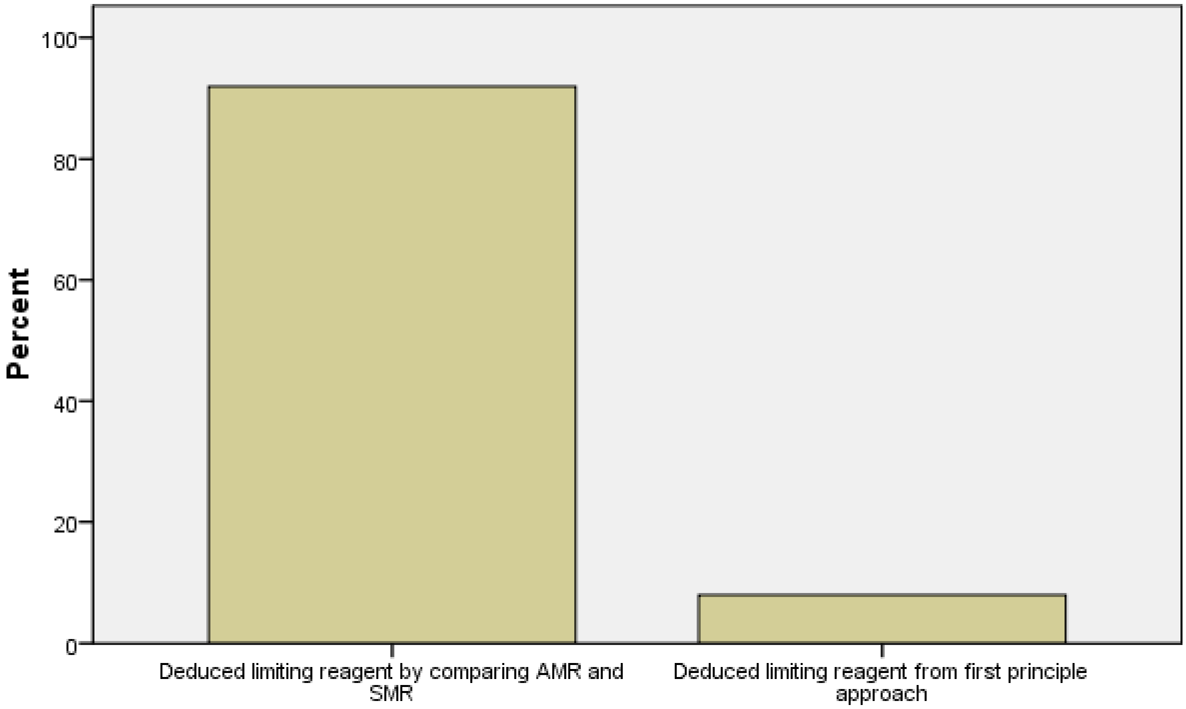

Figure 3: Strategies used by students to deduce limiting reagents in chemical reactions

It can be seen from Table 4 and Figure 3 that the students preferred to deduce the limiting reagent by comparing the „actual mole ratio‟ (AMR) and the „stoichiometric mole ratio‟ (SMR). This is evidenced by the fact that 46 students representing 92% used the approach of „comparing AMR and SMR‟ as against only four (4) students representing eight percent (8%) who used the „first principle approach‟ in their deduction of limiting reagent in chemical reaction problems presented to them in the pre-intervention test. This finding from this study is not unexpected because the approach of „comparing AMR and SMR‟ is the strategy that has been described in the GES (2010) SHS chemistry syllabus to be used by teachers in helping students deduce limiting reagents in chemical reactions. No mention has been made in the syllabus about the use of „first principle approach‟ in deducing the limiting reagent in chemical reactions. Again, the approach of „comparing AMR and SMR‟ was the strategy that was used during classroom instruction by the class teacher.

This finding is also in support of the finding by Chandrasegaran, *et al.* (2009), who conducted a qualitative case study to investigate the understanding of the limiting reagent concept and the strategies used by five students in Year 11 when solving four reaction stoichiometry problems. Students‟ written problem-solving strategies were studied using the think-aloud protocol during problem-solving, and retrospective verbalisations after each activity. The study found that, contrary to several findings reported in the research literature, the two high-achieving students in the study tended to rely on the use of a memorised formula to deduce the limiting reagent, by comparing the actual mole ratio of the reactants with the stoichiometric mole ratio.

The few students, eight percent (8%), who used the „first principle approach‟ in their deduction of limiting reagents in chemical reaction problems presented to them in the pre-intervention test might have come across them in some textbooks on their own.

Research question three: **Would the use of first principle approach help the students to deduce the limiting reagents in chemical reactions?**

This research question sought to find out whether the first principle approach was able to help students in determining the limiting reagents in chemical reactions or otherwise. In other words this research question seeks to determine whether students are able to deduce limiting reagents in chemical reactions better after they have been introduced to the approach of first principle. This was done by comparing the scores of students in the pre-intervention test to the scores in the post intervention test. In the pre-intervention test, students used the strategy of comparing the „actual mole ratio" (AMR) with the „stoichiometric mole ratio" (SMR) to deduce the limiting reagent in chemical reaction. In the post-intervention test students deduced the limiting reagent in chemical reaction from the first principle approach using the stoichiometry of the balanced chemical equation. The result, as analysed by the SPSS version 16.0 computer programming for analysing data, is shown in Table 5 and Figure 4.

Table 5: Comparison of scores of students in the pre- and post-intervention tests

MARKS	**PRE-INTERVENTION TEST**		**POST-INTERVENTION TEST**	
(%)	FREQUENCY	%	FREQUENCY	%
0 – 10	0	0	0	0
11 – 20	1	2	0	0
21 – 30	13	26	3	6
31 – 40	24	48	7	14
41 – 50	5	10	10	20
51 – 60	4	8	7	14
61 – 70	2	4	9	18
71 – 80	1	2	9	18
81 – 90	0	0	5	10
91 – 100	0	0	0	0
TOTAL	**50**	**100**	**50**	**100**

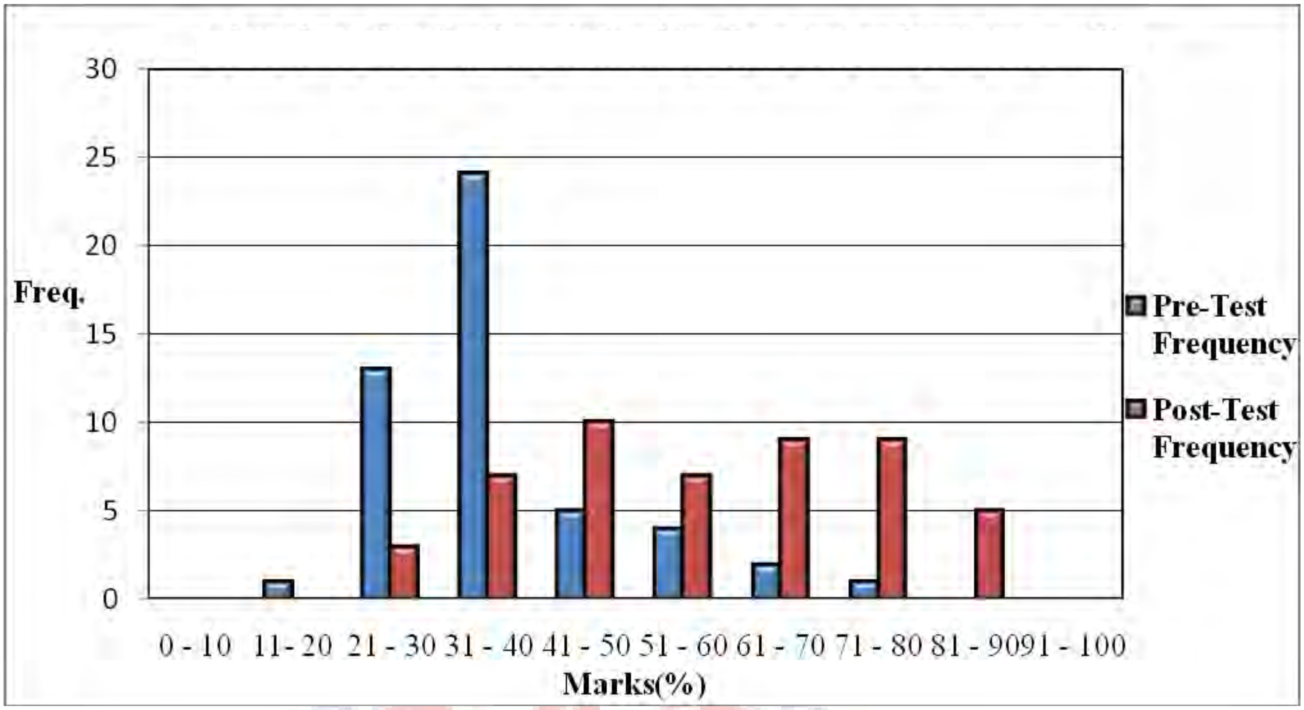

Figure 4: A bar chart showing the relationship of the Pre-Test and Post-Test scores

A careful study of Table 5 and Figure 4 shows that, in general students‟ performance in the post-intervention test, based on the first principle approach, was better than their performance in the pre-intervention test, based on comparing the „actual mole ratio‟ (AMR) and the „stoichiometric mole ratio‟ (SMR). From Table 5 it can be seen that one student, representing 2% got the lowest mark of 11-20% in the pre-intervention test whereas no student got below 21% in the post-intervention test. Again, it can be seen from Table 5 and Figure 4 that five (5) students, representing 10% of the students scored the highest mark of 81-90% in the post-intervention test as against no student scoring 81-90% in the pre-intervention test. It also be deduced from Table 5 and Figure 4 that 80% of the students scored at least 50% marks in the post-intervention test as against only 14% students scoring at least 50% marks in the pre-intervention test. From the foregoing, it can be concluded that the first principle approach helped the students to deduce the limiting reactants in chemical reactions better than the other approaches. This finding is in support of the finding by Chandrasegaran, *et. al*. (2009) that, the average-achieving students in their study demonstrated a preference for the use of reasoning strategies from first principles making use of the balanced chemical equation when solving limiting reagent problems. This preference for the use of first principles by average-achieving students according to Chandrasegaran, *et. al*. (2009) reinforces the need for teachers to consider the use of this strategy during instruction for the benefit of average and lower-achieving students, without totally relying on solving problems in rote fashion.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview

This chapter summarises the findings that has been established in this study on "providing an alternative method, first principle approach, in deducing the limiting reagent in chemical reactions", conclusions drawn, recommendations and suggestions given by the researcher for future research in this area.

5.1 Summary of the Major Findings

The findings from the study indicated that students were able to state correctly that the limiting reagent is the reactant that is completely used up in a chemical reaction. This is an indication that the students had a good understanding of the concept of limiting reagent as it occurs in a chemical reaction .This is evident by the fact that 82% of the students in the study were able to give correct explanations to the meaning of the concept of limiting reagent in the pre-intervention test. Phrases such as „short supply‟ and „used to completion‟ used by the students in the explanations conveyed the perception of the limiting reagent as a reactant that was completely used up during a chemical reaction. The results showed that lots of the students understood the concept of limiting reagent when it was taught by their class teacher.

Again, from the analysis of the students‟ pre-intervention test responses, two strategies were identified to be used by the students in deducing the limiting reagent in chemical reactions. These were the strategies of; "deducing limiting reagent by comparing

„actual mole ratio‟ (AMR) and „stoichiometric mole ratio‟ (SMR)" and "deducing limiting reagent from first principle approach".

The first strategy involved comparing the „actual mole ratio‟ (AMR) with the „stoichiometric mole ratio‟ (SMR). In order to determine the limiting reagents, students had to reason how the numerator or the denominator of the AMR had to change so that is was equal to the SMR, and from there deduce the limiting reagent (which was the reagent that was in short supply). The second method also involved deducing the limiting reagent from first principles using the stoichiometry of the balanced chemical equation. This method does not involve computing the actual mole ratio (AMR) and the stoichiometric mole ratio (SMR).

The findings of the study indicate that 46 students representing 92% used the approach of „comparing AMR and SMR‟ as against only four (4) students representing eight percent (8%) who used the „first principle approach‟ in their deduction of limiting reagent in chemical reaction problems presented to them in the pre-intervention test. This finding from this study is not unexpected because the approach of „comparing AMR and SMR‟ is the strategy that has been described in the GES (2010) SHS chemistry syllabus to be used by teachers in helping students deduce limiting reagents in chemical reactions.

Finally, it can be concluded that the alternative method, first principle approach, helped the students to deduce the limiting reactants in chemical reactions better than the other approaches. This is evident by the fact that 80% of the students scored at least 50% marks in the post-intervention test, after they have been introduced to the first principle approach, as against only 14% students scoring at least 50% marks in the pre-intervention test, when they used the approach of „comparing AMR and SMR‟. This finding is in support of the finding by Chandrasegaran, *et. al*. (2009) that, the average-achieving students in their study demonstrated a preference for the use of reasoning strategies from first principles making use of the balanced chemical equation when solving limiting reagent problems.

5.2 Conclusion

This study was meant to use an alternative method (first principle approach) to enable fifty (50) selected S.H.S. 2 students of Sunyani Senior School deduce the limiting reagents in chemical reactions. Students‟ performance in the pre-intervention test on deducing limiting reagents in chemical reactions, using the approach of „comparing AMR and SMR‟, was found to be very low. The study intervened by using the first principle approach to teach the students to deduce the limiting reagents in chemical reactions. Students‟ performance in the post-intervention test on deducing limiting reagent in chemical reactions improved significantly after they have been introduced to the first principle approach. It can therefore be concluded that the first principle approach helped the students to deduce the limiting reactants in chemical reactions better than the approach of „comparing AMR and SMR‟.

5.3 Recommendations

In the light of the foregoing discussion, the following recommendations are worth considering;

The students in this study have demonstrated a preference for the use of reasoning strategies from first principles making use of the balanced chemical equations when solving limiting reagent problems, as they performed better when they were introduced to the first principle approach. This preference for the use of first principles by the students reinforces the need for teachers to consider the use of this strategy during instruction for the benefit of all students, without totally relying on solving problems in rote fashion. If they feel more confident with the use of algorithmic strategies or memorised formulae, students should be made aware of the reasons for doing so.

It is also necessary for teachers to engage students in a variety of approaches; for example, considering changes at the submicroscopic level using particle diagrams, so that students" conceptual understanding of limiting reagent concepts can be further enhanced.

In addition, textbook writers should also consider including this alternative strategy when explaining the determination of limiting reagents in problem-solving. The Curriculum Research and Development Division (CRDD) of the Ministry of Education should also consider including the first principle approach as one of the approaches to be used to help students deduce the limiting reagents in chemical reactions.

It is also suggested that further research be done on this topic by other researchers in other places of the country. This is because only one Senior High School in the Brong Ahafo region of Ghana was used and this may not be the true reflection in the entire country.

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APPENDIX A: BIO-DATA

SUNYANI SENIOR HIGH SCHOOL

DEPARTMENT OF SCIENCE

SUBJECT: CHEMISTRY

This test is to collect information on "Using the first principle approach to help students deduce the limiting reagents in chemical reactions". It will be appreciated if you answer the following questions. You must note that this study is only a research and the marks you obtain will not be recorded by your teachers. However, you must note that you will benefit greatly for taking part in this exercise as it will provide you with an approach in deducing the limiting reagents in chemical reactions. Thank you for accepting to take part in this exercise. All answers will be treated confidential.

SECTION A: BIO DATA

INSTRUCTION: Please fill where necessary and tick were necessary.

School:……………………………………………………………………………………

Age:………………………

Form: SHS 1 ☐ SHS 2 ☐ SHS 3 ☐

Sex: Male ☐ Female ☐

APPENDIX B: PRE-INTERVENTION TEST

SUNYANI SENIOR HIGH SCHOOL

DEPARTMENT OF SCIENCE

SUBJECT: CHEMISTRY

SECTION B: PRE-INTERVENTION TEST

DURATION: 2 Hours

INSTRUCTION: Answer all questions

1. In your own words explain the term ***limiting reagent*** as it occurs in a chemical reaction.
2. Consider the following reaction: $2Al + 6HBr \rightarrow 2AlBr_3 + 3H_2$
   a. When 3.22 moles of Al reacts with 4.96 moles of HBr, how many moles of H_2 are formed?
   b. What is the limiting reactant?
   c. For the reactant in excess, how many moles are left over at the end of the reaction?
3. Consider the following reaction: $3Si + 2N_2 \rightarrow Si_3N_4$
   a. When 21.44 moles of Si reacts with 17.62 moles of N_2, how many moles of Si_3N_4 are formed?
   b. What is the limiting reactant?

c. For the reactant in excess, how many moles are left over at the end of the reaction?

4. Consider the following reaction: $2CuCl_2 + 4KI \rightarrow 2CuI + 4KCl + I_2$

a. When 0.56 moles of $CuCl_2$ reacts with 0.64 moles of KI, how many moles of I_2 are formed?

b. What is the limiting reactant?

c. For the reactant in excess, how many moles are left over at the end of the reaction?

5. Consider the following reaction: $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$

a. When 26.62 moles of FeS_2 reacts with 5.44 moles of O_2, how many moles of SO_2 are formed?

b. What is the limiting reactant?

c. For the reactant in excess, how many moles are left over at the end of the reaction?

6. 100 cm^3 of a solution containing 0.003 mol dm^{-3} of lead(II) trioxonitrate(V), $[Pb(NO_3)_2]$, is added to 100 cm^3 of a solution containing 0.200 mol dm^{-3} of potassium iodide, KI.

The unbalanced ionic equation for the precipitation reaction that occurs is given below.

$Pb^{2+}_{(aq)} + I^{-}_{(aq)} \rightarrow PbI_{2(s)}$.

Determine:

a. the limiting reagent;

b. the number of moles of excess reagent;

c. the maximum number of moles of lead(II) iodide, PbI_2, that can be obtained.

7. A mixture of 8.00 g of hydrogen gas (H_2) and 96.0 g of oxygen gas (O_2) was sparked in a closed vessel, when water was produced according to the chemical equation

$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$.

Determine:

a. the limiting reagent;

b. the mass of excess reagent;

c. The mass of water produced. [A_r (H) = 1.0; A_r (O) = 16.0]

8. Ozone (O_3) reacts with nitric oxide (NO) discharged from jet planes to form oxygen gas and nitrogen dioxide. 0.740 g of ozone reacts with 0.670 g of nitric oxide. Determine the identity and quantity of the reactant supplied in excess.

[A_r (N) = 14.0; A_r (O) = 16.0]

9. How many grams of IF_5 would be produced using 44.01 grams of I_2O_5 and 101.0 grams of BrF_3 in the equation: $6I_2O_5 + 20BrF_3 \rightarrow 12IF_5 + 15O_2 + 10Br_2$?

[Mr(I_2O_5) = 333.795, Mr(BrF_3) = 136.898, M(IF_5) = 221.89]

10. Suppose 316.0 g aluminum sulphide reacts with 493.0 g of water. What mass of the excess reactant remains? [Mr(Al_2S_3) = 150.159, Mr(H_2O) = 18.015]

The unbalanced equation is: $Al_2S_3 + H_2O \rightarrow Al(OH)_3 + H_2S$

APPENDIX C: POST-INTERVENTION TEST

SUNYANI SENIOR HIGH SCHOOL

DEPARTMENT OF SCIENCE

SUBJECT: CHEMISTRY

SECTION C: POST-INTERVENTION TEST

DURATION: 2 Hours

INSTRUCTION: Answer all questions

1. Explain the term ***limiting reagent*** as it occurs in a chemical reaction.

2. Zinc and sulphur react to form zinc sulphide according to the equation:

   $Zn + S \rightarrow ZnS$

   If 25.0 g of zinc and 30.0 g of sulphur are reacted,

   a) Which chemical is the limiting reactant?

   b) How many grams of ZnS will be formed?

   c) How many grams of the excess reactant will remain after the reaction is over?

   [Zn = 65.74, S = 32.065]

3. If 2.35 moles of H_2 gas react with 5.33 mol of N_2 gas to make ammonia gas (NH_3) according to the equation, $3H_{2(g)} + N_{2(g)} \rightarrow 2NH_{3(g)}$;

a) Which chemical is the limiting reactant?

b) How many moles of the excess reactant will remain after the reaction is over?

c) How many grams of NH_3 can you make? [M(NH_3) = 17.04 g/mol]

4. Consider the reaction: $2Al + 3 I_2 \rightarrow 2AlI_3$

Determine the limiting reagent if one starts with:

a) 1.20 mol Al and 2.40 mol iodine.

b) 1.20 g Al and 2.40 g iodine [Al = 26.98 g mol^{-1}, I_2 = 253.8 g mol^{-1}]

5. 15.00 g aluminum sulphide and 10.00 g water react until the limiting reagent is used up.

Here is the balanced equation for the reaction: $Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2S$

a) Which is the limiting reagent?

b) What is the maximum mass of H_2S which can be formed from these reagents?

c) How much excess reagent remains after the reaction is complete?

[M(Al_2S_3) = 150 g mol^{-1}, M(H_2O) = 18 g mol^{-1}, M(H_2S) = 34 g mol^{-1}]

6. If there is 35.0 grams of C_6H_{10} and 45.0 grams of O_2, how many grams of the excess reagent will remain after the reaction ceases? $2C_6H_{10} + 17O_2 \rightarrow 12CO_2 + 10H_2O$

   [M(C_6H_{10}) = 82.145 g/mol, M(O_2) = 31.998 g/mol]

7. Based on the balanced equation: $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$;

   a) determine the limiting reactant and

   b) calculate the number of excess reagent units remaining when 28 C_4H_8 molecules and 228 O_2 molecules react?

8. For the combustion of sucrose: $C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O$ there are 10.0g of sucrose and 10.0 g of oxygen reacting. Which is the limiting reagent?

   [M($C_{12}H_{22}O_{11}$) = 342.2948 g/mol, M(O_2) = 31.9988 g/mol]

9. The reaction of 4.25 g of Cl_2 with 2.20 g of P_4 produces 4.28 g of PCl_5.

   What is the percent yield? Equation: $10Cl_2 + P_4 \rightarrow 4PCl_5$

   [M(Cl_2) = 70.906 g/mol, M(P_4) = 123.896 g/mol, M(PCl_5.) = 208.239 g/mol]

10. How many grams of PF_5 can be formed from 9.46 g of PF_3 and 9.42 g of XeF_4 in the following reaction? $2PF_3 + XeF_4 \rightarrow 2PF_5 + Xe$

    [M(PF_3) = 87.968 g/mol, M(XeF_4) = 207.282 g/mol, M(PF_5) = 125.964 g/mol]

APPENDIX D:

MARKING SCHEME FOR THE PRE-INTERVENTION TEST

1. The limiting reagent is the reactant that is completely used up in a chemical reaction.

[8 marks]

2. Balanced equation: $2Al + 6HBr \rightarrow 2AlBr_3 + 3H_2$

Mole ratio: 2 : 6 : 2 : 3

× If all Al reacts: 3.22mol + $^6/_2$ x 3.22

= 9.66mol

✓ If all HBr reacts: $^2/_6$ x 4.96 + 4.96mol → $^2/_6$ x 4.96 + $^3/_6$ x 4.96

= 1.65mol = 1.65mol = 2.48mol

a) Moles of H_2 formed = 2.48

b) The limiting reactant is HBr (because it was completely used up).

c) Al was in excess.

Moles of Al left over at the end of the reaction = (3.22 – 1.65) moles = 1.57 moles

[10 marks]

3. Balanced equation: $3Si + 2N_2 \rightarrow Si_3N_4$

Mole ratio: 3 : 2 : 1

✓ If Si reacts: 21.44mol + $^2/^3$ x 21.44 → $^1/_3$ x 21.44

= 14.29 mol = 7.147 mol

a) Moles of Si_3N_4 formed = 7.147

b) The limiting reactant is Si (because it was completely used up).

c) N_2 was in excess.

Moles of N_2 left over at the end of the reaction = (17.62 – 14.29) = 3.33 moles

[10 marks]

4. Balanced equation: $2CuCl_2 + 4KI \rightarrow 2CuI + 4KCl + I_2$

Mole ratio: 2 : 4 : 2 : 4 : 1

× If all $CuCl_2$ reacts: 0.56 mol + $^{4}/_{2}$ x 0.56
= 1.12 mol

✓ If all KI reacts: $^{2}/_{4}$ x 0.64 + 0.64 mol → 0.32 mol + 0.64 mol + ¼ x 0.64
= 0.32 mol = 0.16 mol

a) Moles I_2 formed = 0.16 mol

b) The limiting reactant is KI (because it was completely used up).

c) $CuCl_2$ was in excess.

Moles of $CuCl_2$ left over at the end of the reaction = (0.56 – 0.32) = 0.24 mol

[10 marks]

5. Balanced equation: $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$

Mole ratio: 4 : 11 : 2 + 8

× If all FeS_2 reacts: 26.62 mol + $^{11}/_{4}$ x 26.62
= 73.21 mol

✓ If all O_2 reacts: $^{4}/_{11}$ x 5.44 + 5.44mol → $^{2}/_{11}$ x 5.44 + $^{8}/_{11}$ x 5.44
= 1.98 mol = 0.989 mol

a) Moles of SO_2 formed = 3.96 mol

b) The limiting reactant is O_2 (because it was completely used up).

c) FeS_2 was in excess.

Moles of FeS2 left over at the end of the reaction = (26.62 – 1.98) = 24.64 moles

[10 marks]

6. Moles of $Pb(NO_3)_2$ and KI should be calculated first.

Moles, n = C x V

Volume of $Pb(NO_3)_2$, V = 100 cm^3 = 0.1 dm^3

Conc. of $Pb(NO_3)_2$, C = 0.003 mol dm^3

Volume of KI, V = 100 cm^3 = 0.1dm^3

Conc. of KI, C = 0.200 mol dm^3

∴ Moles of $Pb(NO_3)_2$ = 0.003 moldm^{-3} x 0.1 dm^3 = 0.0003 mol

Moles of KI = 0.200 mol dm^{-3} x 0.1dm^3 = 0.0200 mol

Balanced ionic equation:	Pb^{2+}	+	$2I^-$	→	PbI_2
Mole ratio:	1	:	2	:	1
✓ If all $Pb(NO_3)_2$ reacts:	0.0003mol	+	2 x 0.0003 = 0.0006mol	→	0.0003mol

a) The limiting reagent is $Pb(NO_3)_2$ (because it was completely used up).

b) The excess reagent is KI.

The moles of KI that was in excess = (0.0200 – 0.0006) = 0.0194 mol.

c) The maximum number of moles of PbI_2 that can be obtained = 0.0003 mol.

[10 marks]

7. Calculate for the moles of H_2 and O_2 from their given masses first.

Moles, n = m / M

Mass of H_2, m = 8.00g

Molar mass of H_2, M = 2(1) = 2 $gmol^{-1}$

Mass of O_2, m = 96.0g

Moles of H_2, n = 8.00g / 2$gmol^{-1}$ = 4 mol

Molar mass of O_2, n = 96.0g / 32$gmol^{-1}$ = 3 mol

	Balanced equation:	$2H_2$	+	O_2	→	$2H_2O$
	Mole ratio:	2	:	1	:	2
✓	If all H_2 reacts:	4	+	½ x 4	→	4 mol
				= 2 mol		

a) The limiting reagent is H_2 (because it was completely used up).

b) O_2 is the excess reagent.

Moles of O_2 in excess = (3 – 2) mol = 1 mol

Mass, m = n x M

∴ Mass of O_2 in excess, m = 1 mol x 32 $gmol^{-1}$ = 32 g

c) Moles of H_2O produced, n = 4 moles

Molar mass of H_2O, M = 2(1) + 16 = 18 $gmol^{-1}$

Mass, m = n x M

∴ Mass of H_2O produced = 4 mol x 18 gmol-1 = 72 g

[12 marks]

8. Calculate the moles of O_3 and NO from their given masses.

Moles, n = m / M

Mass of O_3, m = 0.740 g

Molar mass of O_3, M = 3(16) = 48 $gmol^{-1}$

Mass of NO, m = 0.670 g

Molar mass of NO, M = 14 + 16 = 30 $gmol^{-1}$

∴ Moles of O_3, n = 0.740 g / 48 $gmol^{-1}$ = 0.0154 mol

Moles of NO, n = 0.670 g / 30 $gmol^{-1}$ = 0.0223 mol

Balanced equation:	O_3	+	NO	→	O_2	+	NO_2
Mole ratio:	1	:	1	:	1	:	1
✓ If all O_3 reacts:	0.0154 mol	+	0.0154 mol				

∴ The reactant supplied in excess is NO.

Moles of NO in excess = 0.0223 – 0.0154 = 0.0069 mol

Mass of NO in excess, m = 0.0069 mol x 30 gmol-1 = 0.207 g

[10 marks]

9. Calculate the moles of I_2O_5 and BrF_3 from their given masses.

Moles, n = m / M

Mass of I_2O_5, m = 44.01 g

Molar mass of I_2O_5, M = 333.795 $gmol^{-1}$

Mass of BrF_3, m = 101.0g

Molar of BrF_3, M = 136.898 $gmol^{-1}$

∴ Moles of I_2O_5, n = 44.01 g / 333.795 $gmol^{-1}$ = 0.132 mol

Moles of BrF_3, n = 101.0g / 135.898 $gmol^{-1}$ = 0.738 mol

Balanced equation:	$6I_2O_5$	+	$20BrF_3$	→	$12IF_5$	+	$15O_2$	+	$10Br_2$
Mole ratio:	6	:	20	:	12	:	15	:	10
✓ If all I_2O_5 reacts:	0.132 mol	+	$^{20}/_{6}$ x 0.132	→	$^{12}/_{6}$ x 0.132				
			= 0.44		= 0.264				

∴ Moles of IF_5, n = 0.264 mol

Molar mass of IF_5, M = 221.89 $gmol^{-1}$

Mass, m = n x M

∴ Mass of IF_5, m = 0.264 mol x 221.89 $gmol^{-1}$ = 58.58 g

[10 marks]

10. Calculate the moles of Al_2S3 and H_2O from their given masses.

Moles, n = m / M

Mass of Al_2S_3, m = 316.0 g

Molar mass of Al_2S_3, M = 150.159 $gmol^{-1}$

Mass of H_2O, m = 493.0 g

Molar mass of H_2O, M = 18.015 $gmol^{-1}$

∴ Moles of Al_2S_3, n = 316.0g / 150.156 $gmol^{-1}$ = 2.104 mol

Moles of H_2O, n = 493.0 g / 18.015 $gmol^{-1}$ = 27.47 mol

Balanced equation: $Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2S$

Mole ratio: 1 : 6 : 2 : 3

✓ If all Al_2S_3 reacts: 2.104 mol + 6 x 2.104

Al_2S_3 is the limiting reactant and H_2O is the reactant in excess.

Moles of H_2O in excess, n = (27.47 – 12.624) mol = 14.846 mol

Mass, m = n x M

∴ Mass of H_2O in excess, m = 14.846 mol x 18.015 $gmol^{-1}$ = 267.5 g (4 sig. fig)

[10 marks]

APPENDIX E:

MARKING SCHEME FOR THE POST-INTERVENTION TEST

1. Limiting reagent is the reactant that is completely used up in a chemical reaction.

[8 marks]

2. Calculate the moles of Zn and S from their given masses.

Moles, n = m / M

Mass of Zn, m = 25.0 g

Molar mass of Zn, M = 65.74 gmol^{-1}

Mass of S, m = 30.0 g

Molar mass of S, M = 32.065 gmol^{-1}

∴ Moles of Zn, n = 25.0 g / 65.74 gmol^{-1} = 0.380 mol

Moles of S, n = 30.0g / 32.065 gmol^{-1} = 0.936 mol

Balanced equation: $Zn + S \rightarrow ZnS$

Mole ratio: 1 : 1 : 1

✓ If all Zn reacts: 0.38 mol + 0.38 mol → 0.38 mol

a) The limiting reagent is Zn (because it was completely used up).

b) Moles of ZnS formed, n = 0.38 mol

Molar mass of ZnS, M = 65.74 + 32.065 = 97.805 gmol^{-1}

Mass of ZnS formed, m = 0.38 mol x 97.805 gmol^{-1} = 37.1659 g

c) S is the reactant in excess.

Moles of S in excess = (0.936 – 0.38) = 0,556 mol

Mass, m = n x M

$\therefore$ Mass of S in excess, m = 0.556 mol x 32.065 $gmol^{-1}$ = 17.83 g [12 marks]

3. Balanced equation: $3H_2 \quad + \quad N_2 \quad \rightarrow \quad 2NH_3$

Mole ratio: 3 : 1 : 2

✓ If all H_2 reacts: 2.25mol + $^{1}/_{3}$ x 2.35 $\rightarrow$ $^{2}/_{3}$ x 2.35

= 0.783 mol = 1.57 mol

a) The limiting reagent is H_2 (because it was completely used up).

b) N_2 is the reactant in excess.

Moles of N_2 that remain after the reaction is over = (5.33 – 0.783) = 4.547 mol

c) Moles of NH_3 produced, n = 1.57 mol

Molar mass of NH_3, M = 17.04 $gmol^{-1}$

Mass, m = n x M

$\therefore$ Mass of NH_3 formed, m = 1.57 mol x 17.04 $gmol^{-1}$ = 26.75 g (4 sig. fig.)

[10 marks]

4. Balanced equation: $2Al \quad + \quad 3I_2 \quad \rightarrow \quad 2AlI_3$

Mole ratio: 2 : 3 : 2

✓ If all Al reacts: 1.20 mol + $^{3}/_{2}$ x 1.20 $\rightarrow$ 1.20 mol

= 1.80 mol

a) The limiting reagent is Al (because it was completely used up).

b) Calculate the moles of Al and I_2 from their given masses.

Moles, n = m / M

Mass of Al, m = 1.20 g

Molar mass of Al, M = 26.98 $gmol^{-1}$

Mass of I_2, m = 2.40 g

Molar mass of I_2, M = 253.8 $gmol^{-1}$

$\therefore$ Moles of Al, n = 1.20g / 26.98 $gmol^{-1}$ = 0.0445 mol

Moles of I_2, n = 2.40 g / 253.8 $gmol^{-1}$ = 9.46 mol

Balanced equation: $2Al \quad + \quad 3I_2 \quad \rightarrow \quad 2AlI_3$

Mole ratio: 2 : 3 : 2

✓ If all Al reacts: 0.0445 mol + 3/2 x 0.0445

= 0.0668 mol

The limiting reagent is Al (because it was completely used up).

[10 marks]

5. Calculate the moles of Al_2S_3 and H_2O from their given masses.

Moles, n = m / M

Mass of Al_2S_3, m = 15.00 g

Molar mass of Al_2S_3, M = 150 $gmol^{-1}$

Mass of H_2O, m = 10.00 g

Molar mass of H_2O, M = 18 $gmol^{-1}$

$\therefore$ Moles of Al_2S_3, n = 15.00 g / 150 $gmol^{-1}$ = 0.100 mol

Moles of H_2O, n = 10.00 g / 18 $gmol^{-1}$ = 0.556 mol

Balanced equation: $Al_2S_3 \quad + \quad 6H_2O \quad \rightarrow 2Al(OH)_3 \quad + \quad 3H_2S$

Mole ratio: 1 : 6 : 2 : 3

× If all Al_2S_3 reacts: 0.100 mol + 6 x 0.100

= 0.600 mol

✓ If all H_2O reacts: $^1/_6$ x 0.556 + 0.556 mol $\rightarrow$ $^2/_6$ x 0.556 + $^3/_6$ x 0.556

= 0.0927mol = 0.185 mol = 0.278mol

a) The limiting reagent is H_2O (because it was completely used up).

b) Moles of H_2S formed, n = 0.278 mol

Molar mass of H_2S, M = 34 $gmol^{-1}$

Mass, m = n x M

∴ Mass of H_2S which can be formed, m = 0.278 mol x 34 $gmol^{-1}$ = 9.452 g

c) Al_2S_3 is the reactant in excess.

Moles of Al_2S_3 in excess = (0.100 – 0.0927) mol = 0.0073 mol

[10 marks]

6. Calculate the moles of C_6H_{10} and O_2 from their given masses.

Moles, n = m / M

Mass of C_6H_{10}, m = 35.00 g

Molar mass of C_6H_{10}, M = 82.145 $gmol^{-1}$

Mass of O_2, m = 45.0 g

Molar mass of O_2, M = 31.998 $gmol^{-1}$

∴ Moles of C_6H_{10}, n = 35.0 g / 82.145 $gmol^{-1}$ = 0.426 mol

Moles of O_2, n = 45.0 g / 31.998 $gmol^{-1}$ = 1.406 mol

Balanced equation: $2C_6H_{10}$ + $17O_2$ → $12CO_2$ + $10H_2O$

Mole ratio: 2 : 17 : 12 : 10

× If all C_6H_{10} reacts: 0.426mol + $^{17}/_{2}$ x 0.426

= 3.621 mol

✓ If all O_2 reacts: $^{2}/_{17}$ x 1.406 + 1.406 mol

= 0.164 mol

∴ O_2 is the limiting reagent and C_6H_{10} is the reagent in excess.

Moles of C_6H_{10} in excess, n = (0.426 – 0.164) mol = 0.262 mol

Mass, m = n x M

∴ Mass of C_6H_{10} in excess, m = 0.262 mol x 82.145 $gmol^{-1}$ = 21.52 g (4 sig. fig.)

[10 marks]

7. Number of entities is proportional to moles since N = n x L.

Balanced equation:	C_4H_8	+	$6O_2$	→	$4CO_2$	+	$4H_2O$
Mole ratio:	1	:	6	:	4	:	4

✓ If all C_4H_8

molecules reacts: 28 molecules + 6 x 28

= 168 molecules

a) The limiting reagent is C_4H_8 since all the molecules are used up.

b) O_2 is the reactant in excess.

Molecules of O_2 remaining at the end of the reaction: = (228 – 168) molecules

= 60 molecules

[10 marks]

8. Calculate the moles of $C_{12}H_{22}O_{11}$ and O_2 from their given masses.

Moles, n = m / M

Mass of sucrose ($C_{12}H_{22}O_{11}$), m = 10.0 g

Molar mass of $C_{12}H_{22}O_{11}$, M = 342.2948 $gmol^{-1}$

Mass of O_2, m = 10.0 g

Molar mass of O_2, M = 31.9988 $gmol^{-1}$

∴ Moles of $C_{12}H_{22}O_{11}$, n = 10.0 g / 342.2948 $gmol^{-1}$ = 0.0292 mol

Moles of O_2, n = 10.0 g / 31.9988 $gmol^{-1}$ = 0.313 mol

Balanced equation: $C_{12}H_{22}O_{11}$ + $12O_2$ → $12CO_2$ + $11H_2O$

Mole ratio: 1 : 12 : 12 : 11

✓ If all $C_{12}H_{22}O_{11}$ reacts: 0.0292mol + 12 x 0.0292

= 0.3504 mol

∴ O_2 is the limiting reagent because it was completely used up in the reaction.

[10 marks]

9. Calculate the moles of Cl_2 and P_4 from their given masses.

Moles, n = m / M

Mass of Cl_2, m = 4.25 g

Molar mass of Cl_2, M = 70.906 $gmol^{-1}$

Mass of P_4, m = 2.20 g

Molar mass of P_4, M = 123.896 $gmol^{-1}$

∴ Moles of Cl_2, n = 4.25 g / 70.906 $gmol^{-1}$ = 0.0599 mol

Moles of P_4, n = 2.20 g / 123.896 $gmol^{-1}$ = 0.01776 mol

Balanced equation: $10Cl_2$ + P_4 → $4PCl_5$

Mole ratio: 10 : 1 : 4

✓ If all Cl_2 reacts: 0.0599mol + $^1/_{10}$ x 0.0599 → $^4/_{10}$ x 0.0599

= 0.00599 mol = 0.02396 mol

∴ Cl_2 is the limiting reagent since it is completely used up and the amount of PCl_5 produced is dependent on the limiting reagent.

Mass, m = n x M

∴ Mass of theoretical yield of PCl_5, m = 0.02396 mol x 208.239 $gmol^{-1}$

= 4.99 g (3 sig. fig.)

Actual yield of PCl_5 = 4.28 g

% yield = $^{\text{Actual yield}} / _{\text{Theoretical yield}}$ x 100 = 4.28 g / 4.99 g x 100 = 85.8%

[10 marks]

10. Calculate the moles of PF_3 and XeF_4 from their given masses.

Moles, n = m / M

Mass of PF_3, m = 9.46 g

Molar mass of PF_3, M = 87.968 $gmol^{-1}$

Mass of XeF_4, m = 9.42 g

Molar mass of XeF_4, M = 207.282 $gmol^{-1}$

∴ Moles of PF_3, n = 9.46 g / 87.968 $gmol^{-1}$ = 0.108 mol

Moles of XeF_4, n = 9.42 g / 207.282 $gmol^{-1}$ = 0.0454 mol

Balanced equation:	$2PF_3$	+	XeF_4	$\rightarrow 2PF_5$	+	Xe
Mole ratio:	2	:	1	: 2	:	1
× If all PF_3 reacts:	0.108mol +		½ x 0.108 = 0.054 mol			
✓ If all XeF_4 reacts:	2 x 0.0454 + = 0.0908 mol		0.0454 mol	$\rightarrow$2 x 0.0454 = 0.0908 mol	+	0.0454mol

∴ XeF_4 is the limiting reactant and the amount of PF_5 formed is dependent on the limiting reactant.

Moles of PF_5 formed, n = 0.0908 mol

Molar mass of PF_5, M = 125.964 $gmol^{-1}$

Mass, m = n x M

∴ Mass of PF_5 formed, m = 0.0908 mol x 125.964 $gmol^{-1}$ = 11.44 g (4 sig. fig.)

APPENDIX F:

INTERVENTION ACTIVITIES

1. Explaining the term “limiting reactants”.

Suppose we carry out a reaction by using numbers of moles of reactants that are in the same ratio as the stoichiometric coefficients in the balanced equation. In this case, we say that the reactants are in **stoichiometric proportions**, and we find that if the reaction goes to completion, the initial reactants are fully consumed. In practice, however, we often carry out reactions with a **limited** amount of one reactant and plentiful amounts of others.

The reactant that is completely consumed in a chemical reaction limits the amount of products formed and is called the **limiting reactant** or **limiting reagent**. (Reagent is a general term for a chemical).

Illustration example:

In the combustion of octane in oxygen shown as;

$$2C_8H1_{8(l)} \quad + \quad 25O_{2(g)} \rightarrow \quad 16CO_{2(g)} \quad + \quad 18H_2O_{(l)}$$

If we allow 2 mol C_8H_{18} to react with 25 mol O_2, the reactants are in stoichiometric proportions. On the other hand, if we allow the 2 mol C_8H_{18} to burn in a plentiful supply of O_2 gas – more than 25 moles – then the C_8H_{18} is the **limiting reactant**. The octane is completely consumed and some unreacted O_2 remains; the O_2 is a reactant present in excess.

2. Using the first principle approach to deduce the limiting reactant in a chemical reaction. Illustration examples:

a) Lithium hydroxide absorbs carbon dioxide to form lithium carbonate and water as shown below:

$$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$$

If a reaction vessel contains 0.150 mol LiOH and 0.080 mol CO_2,

i. which compound is the limiting reactant?

ii. how many moles of Li_2CO_3 can be produced?

<u>Solution</u>

i. Balanced equation: $2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$

Mole ratio: 2 : 1 : 1 : 1

To identify the limiting reactant, we make an assumption that;

Assuming that all the LiOH reacts:

$$\Rightarrow 0.150\text{mol } LiOH + \tfrac{1}{2} \text{ x } 0.150\text{mol } CO_2 \rightarrow \tfrac{1}{2} \text{ x } 0.150\text{mol } LiCO_3 + \tfrac{1}{2} \text{ x } 0.150\text{mol } H_2O$$

$$0.150\text{mol } LiOH + 0.075 \text{ mol } CO_2 \rightarrow 0.075 \text{ mol } LiCO_3 + 0.075 \text{ mol } H_2O$$

Since the 0.075 mol of CO_2 required if all LiOH reacts is less than the 0.080 mol of CO_2 available, the LiOH is the limiting reactant and the CO_2 is the reactant in excess.

ii. The amount of product produced is always dependent on the limiting reactant. Therefore, 0.075 mol of Li_2CO_3 is produced in this reaction.

b) Boron trifluoride (BF_3) reacts with water to produce boric acid (H_3BO_3) and fluoroboric acid (HBF_4) according to the equation:

$$4BF_3 + 3H_2O \rightarrow H_3BO_3 + 3HBF_4$$

If a reaction vessel contains 0.496 mol BF_3 and 0.313 mol H_2O,

i. which compound is the limiting reactant?

ii. For the reactant in excess, how many moles are left over at the end of the reaction?

iii. How many moles of HBF_4 can be produced?

Solution

Balanced equation: $4BF_3 + 3H_2O \rightarrow H_3BO_3 + 3HBF_4$

Mole ratio: 4 : 3 : 1 : 3

× If all BF_3 reacts: 0.496mol + ¾ x 0.496 = 0.372 mol

This is not possible because the 0.372 mol of H_2O required if all BF_3 reacts is not available.

✓ If all H_2O reacts: $^{4}/_{3}$ x 0.313 = 0.417 mol + 0.313mol → $^{1}/_{3}$ x 0.313 = 0.104 mol + 0.313mol

i. H_2O is the limiting reactant because it was completely used up in the reaction and limited the amounts of products formed.

ii. BF_3 is the reactant in excess.

Moles of BF_3 left at the end of the reaction = (0.496 – 0.419) mol = 0.077 mol

iii. Moles of HBF_4 produced = 0.313 mol

3. Exercise

a) Magnesium nitride (Mg_3N_2) can be formed by the reaction of magnesium metal (Mg) with nitrogen gas (N_2) according to the equation:

$$3Mg_{(s)} \quad + \quad N_{2(g)} \quad \rightarrow \quad Mg_3N_{2(s)}$$

If 35.0 g of magnesium reacted with 15.0 g of nitrogen,

i. what is the limiting reactant?

ii. how many moles of the excess reactant remains after the reaction?

iii. how many grams of magnesium nitride is formed at the end of the reaction?

[Mr(Mg) = 24.305, Mr(N_2) = 28.013, Mr(Mg_3N_2) = 100.93]

Solution

Calculate the moles of Mg and N_2 from their given masses.

Moles, n = m / M

Mass of Mg, m = 35.0 g

Molar mass of Mg, M = 24.305 $gmol^{-1}$

Mass of N_2, m = 15.0 g

Molar mass of N_2, M = 28.013 $gmol^{-1}$

∴ Moles of Mg, n = 35.0 g / 24.013 $gmol^{-1}$ = 1.44 mol

Moles of N_2, n = 15.0 g / 28.013 $gmol^{-1}$ = 0.535 mol

Balanced equation:	$3Mg_{(s)}$	+	$N_{2(g)}$	→	$Mg_3N_{2(s)}$
Mole ratio:	3	:	1	:	1
✓ If all Mg reacts:	1.44 mol	+	$^1/_3$ x 1.44	→	$^1/_3$ x 1.44
			= 0.48 mol		= 0.48 mol

i. Mg is the limiting reactant because it was completely used up in the reaction.

ii. N_2 is the reactant in excess because the 0.535 mol available is more than the 0.48 mol required if all the Mg reacts.

Moles of N_2 that remain after the reaction: (0.535 – 0.48) mol = 0.055 mol

Molar mass of N_2, M = 28.013 $gmol^{-1}$

Mass, m = n x M

$\therefore$ Mass of N_2 that remain after the reaction = 0.055 mol x 28.013 $gmol^{-1}$

= 1.541 g

iii. Moles of Mg_3N_2 produced, n = 0.48 mol

Molar mass of Mg_3N_2, M = 100.93 $gmol^{-1}$

Mass, m = n x M

$\therefore$ Mass of Mg_3N_2 produced, m = 0.48 mol x 100.93 $gmol^{-1}$ = 48.45 g

TABLE OF CONTENTS PAGE