**TÜRK FEN EĞİTİMİ DERGİSİ**
**Yıl 5, Sayı 2, Ağustos 2008**

**Journal of**
**TURKISH SCIENCE EDUCATION**
**Volume 5, Issue 2, August 2008**

http://www.tused.org

# The Modified GRASS Model: An Alternate Path to Solve Complex Stoichiometric Problems

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**Received:** 10.05.2008 **Revised:** 05.07.2008 **Accepted:** 15.07.2008

*The original language of article is English (v.5, n.2, August 2008, pp.11-25)*

## ABSTRACT

A major stumbling block to students' success in solving complex stoichiometric problems is that learners store information in a compartmentalized way and cannot transfer what is learned in one context to another context. To address this concern, chemistry educators developed problem-solving models as pedagogical aids to improve student performance. Unfortunately, most of the problem-solving models have deficiencies in that they are not teachable and their applications to complex problems face some hindrances. This paper reports the modifications carried out on the GRASS model so as to make it teachable to the learners and how it can be applied in solving complex stoichiometric problems.

**Keywords**: Knowledge Construction, Problem-Solving Instruction, Problem- Solving Models, Stoichiometry.

## INTRODUCTION

Stoichiometry as a topic in chemistry involves problem solving where students are given the amount of one substance in a chemical reaction and are required to calculate the amount of another substance necessary to react completely with the given substance, or the amount of substances produced in the chemical reaction. As noted by BouJaoude and Barakat (2003), stoichiometry is one of the most basic, central, yet abstract topics in chemistry. It appears in every senior secondary school chemistry textbook and take up a good part of the chemistry curriculum. Stoichiometry is essential for understanding quantitative and qualitative aspects of chemical reactions as well as for solving many types of problems in senior secondary school chemistry.

Among the various factors that influence students' performance in solving stoichiometric problems is the complexity of the problem (Okanlawon, 2005). A science problem can be judged as simple or complex based on certain criteria, such as: (i) the number of sub-problems that have to be solved to reach the final solution; (ii) the number of formulae, laws and principles that must be applied to solve the problem (Taconis, Ferguson-Hessler, & Broekkamp, 2001). Using the above criteria a complex stoichiometric problem can be defined as a problem that consists of many sub-problems.

Also, they can be viewed as problems that are based on two or more concepts and may require several cycles of interpreting, representing, planning, execution and evaluation. As considered by Bunce, Gabel, and Samuel (1991), this type of problems are also known as combination problems. These complex stoichiometric problems require stringing together many steps using conceptually organized knowledge. This type of knowledge helps a problem solver to (i) interpret the information given in the problem statement (ii) identify the entity to be calculated (iii) build a representation of the problem situation and to plan a possible pathway to a solution. Learners who learn primarily by rote lack conceptual understanding and hence they fail to develop knowledge integration which is required in solving complex stoichiometric problems. The fact that complex stoichiometric problems require at least two concepts when solving them calls for retrieval of information (prerequisite knowledge) from long-term memory. According to Anderson (1991), information in memory is a network of multi-relational connections; and elaborateness or richness of interrelationships between concepts influences its accessibility in problem-solving (Chi and Koeske, 1983). Prerequisite knowledge such as: (i) the mass-mole relationship ($n = m/M$) (ii) the solution formula ($c = n/v$) (iii) the molar volume ($V_m = v/n$) (iv) the density formula ($D = m/v$) (v) the universal gas law ($P_1V_1/T_1 = P_2V_2/T_2$) and (vi) Dalton's law of additive pressures ($P_T = P_1 + P_2 + \ldots$) are to be retrieved from the existing cognitive structure depending on the type of stoichiometric problem at hand.

Solving stoichiometric problems is difficult for the students (Bello, 1990; Eniayeju, 1990; Goering-Boone & Rayner-Canham, 2001) because of their poor understanding of stoichiometric principles (Olmsted, 1999). Conceptual difficulties become more evident when attempting to solve complex stoichiometric problems. In addition, stoichiometric problems take on different forms (e.g., mole -to – mole problems, gram - to – gram problems, gas volume - to – gas volume problems) to the extent that they cannot be solved by employing only algorithms. Algorithmic problem- solving requires applications of pre-existing procedures where learning and problem solving may not occur (Shuell, 1990). Meaningful problem-solving, on the other hand, requires the use of algorithms as well as conceptual knowledge in developing the correct solution pathways (Schmidt, 1997). One body of research findings highlights the importance of conceptual understanding for successful problem solving and qualitative thinking in chemistry and suggests that students' inadequate and incorrect conceptual knowledge impedes successful problems-solving in stoichiometry (Harmon, 1993; BouJaonde, 1994; Niaz, 1995), while other studies have demonstrated an over-reliance on using algorithms to solve problems (Lythcott, 1990; Pickering, 1990; Sawrey, 1990; Nakhleh, 1993; Nakhleh & Mitchell, 1993).

In Nigeria the issue of stoichiometry is being introduced in the first and second year of Senior Secondary School; and students at these levels of schooling do not possess enough problem-solving skills. Moreover, they also know less about the underlying chemical concepts, such as the particle theory or the chemical equation. Many authors agree that stoichiometry concepts are difficult to grasp by students and therefore, they are discouraged (e.g. Schmidt and Jigneus, 2003). A lack of understanding of stoichiometry concepts hinders understanding of subsequent topics and leads to even more reliance on memorized techniques. Worrisome as this situation is, there is need to develop problem-solving models to serve as pedagogical tools for the teaching and learning of stoichiometry. A problem-solving model is conceived as a conceptual model that is an external representation created by teachers or scientists for facilitating the comprehension or the teaching of systems or states of affairs in the world (Greca & Moreire, 2000). Norman (1983) also considered conceptual models as external representations that are shared by a given community, and have their coherence with the scientific knowledge of that community.

In an attempt to improve chemistry students' performance in solving sotichiometric problems, chemistry educators (Gizara, 1981; Bunce & Heikkinen, 1986; Goering-Boone & Rayner-Canham, 2001; Ault, 2001; McCalla, 2003) developed different problem-solving models. Many shortcomings of these models have been identified by chemistry educators (Herron and Greenbowe, 1986; Herron, 1996; Bodner, 2003). For instance, one major criticism that was raised against the GRASS model is that detail pedagogical information has not been provided concerning how teachers should guide their students in planning and execution of solution of a given stoichiometric problem when applying the model.

In order for a model to be regarded as an effective pedagogical aid, it must be "teachable", it must be a model that can be easily transformed into accessible form for students. In addition, the GRASS model met some drawbacks when applied to high-demanding problems (complex problems). In spite of these shortcomings, it is hoped that the GRASS model can be modified into practically more effective pedagogical aid. The GRASS model which has been developed by Goering-Boone and Rayner-Canham (2001) consists of five stages, namely, Given, Required, Analysis, Solution, and Statements.

Specifically, the primary aim of this paper was to modify the GRASS model in order to make it pedagogically more effective. This work also aimed at using the modified GRASS model in solving complex stoichiometric problems.

## 1- The GRASS Model

The GRASS model which has been developed by Goering – Boone and Rayner-Canham (2001) consists of five elements: Given, Required, Analysis, Solution, and Statement. Each element is important, but both the Analysis and Solution segments are the distinguishing features of this model. The Given and Required seems as mere formality in the problem-solving process but they provide a very concise summary of the problem statement; hence they are useful for providing structure for students. The advantage of carrying out those two stages lies in the fact that it enables problem solvers to isolate relevant information from the existing pool of information. Since most people can only store a limited amount of information in their conscious memory at any given time, it makes sense to make use of the type of external memory. Having developed a concise summary of all relevant information (supplied in the problem statement) that are pertinent to the solution of the problem, the problem solvers engage in a thinking process, which leads to the Analysis phase. The Analysis phase provides a framework for the development of solution. The last element of the model, statement, is a declarative statement indicating the answer obtained to the problem at hand. The five elements which constitute the GRASS model are fully discussed as follows:

**Given.** In the Given, the problem solver write down all relevant information of the problem, in symbolic notation if possible, including all units and expanding composite units. At this phase, a problem solver should be able to figure out relevant information from other categories of given: extra information, duplication information, irrelevant information, and hidden but relevant information.

**Required.** This can be simply regarded as the objective of the problem at hand. Here, the problem solver writes down what the problem is demanding, in symbolic notation, with units if appropriate.

**Analysis.** In the Analysis, the problem solver builds a logical solution pathway by stringing together many steps using conceptual knowledge based. Thus, this is a creative process in which intuition has a role to play, but is not absolutely necessary. The student must simply master the concepts sufficiently well to be able to identify the connections, one step at a time. There is no need to solve the whole problem all at once. Once one connection has been made, the student then has a new objective (i.e., Required) to seek; he or she once again attempts to find something that has a logical connection with the new objective. And thus the creative process continues until the new objective has a direct connection with the information in the Given. At this point, all the logical analysis is complete.

**Solution.** Once all the logical connections have been made, only the calculations remain to be done. At this point the problem solver becomes a computer that implements the logical steps of the Analysis. The student may use dimensional analysis (a problem-solving strategy), if the relationships described in the Analysis are either direct or indirect proportionalities.

**Statement.** This is a statement expressing the conclusion derived form the solution segment

**A- Example of a problem solved using the GRASS Model**

**Problem** How many grams of nitrogen must react to form 51-grams of ammonia by the reaction:

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

**Given**

| $N_{2(g)}$ | + | $3H_{2(g)}$ | $\rightarrow$ | $2NH_{3(g)}$ |
|---|---|---|---|---|
| 1 mole | | | | 2 moles |

**Required**

${}^{m}NH_3 = 51g$

${}^{m}N_2 = ?g$

**Analysis**

${}^{m}NH_3 \rightarrow {}^{n}NH_3$ (using molar mass, $NH_3$ = 17g/mol)

${}^{n}NH_3 \rightarrow {}^{n}N_2$ (using mole ratio, 2 mol $NH_3$: 1 mol $N_2$)

${}^{n}N_2 \rightarrow {}^{m}N_2$ (using molar mass, $N_2$ = 28g/mol)

**Solution**

$${}^{n}NH_3 = 51g\ NH_3 \times \frac{1mol\ NH_3}{17g\ NH_3} = 3\ mol\ NH_3$$

$${}^{n}N_2 = 3\ mol\ NH_3 \times \frac{1mol\ N_2}{2mol\ NH_3} = 1.5\ mol\ N_2$$

$${}^{m}N_2 = 1.5\ mol\ N_2 \times \frac{28g\ N_2}{1mol\ N_2} = 42g\ N_2$$

**Statement** A mass of 42g of nitrogen is required

## 2- Conceptual Framework

Modification of the GRASS model through integration of mole-to-mole transformation process (Figure 1) with the Analysis segment is a pedagogical strategy in making the GRASS model teachable during instructional process.

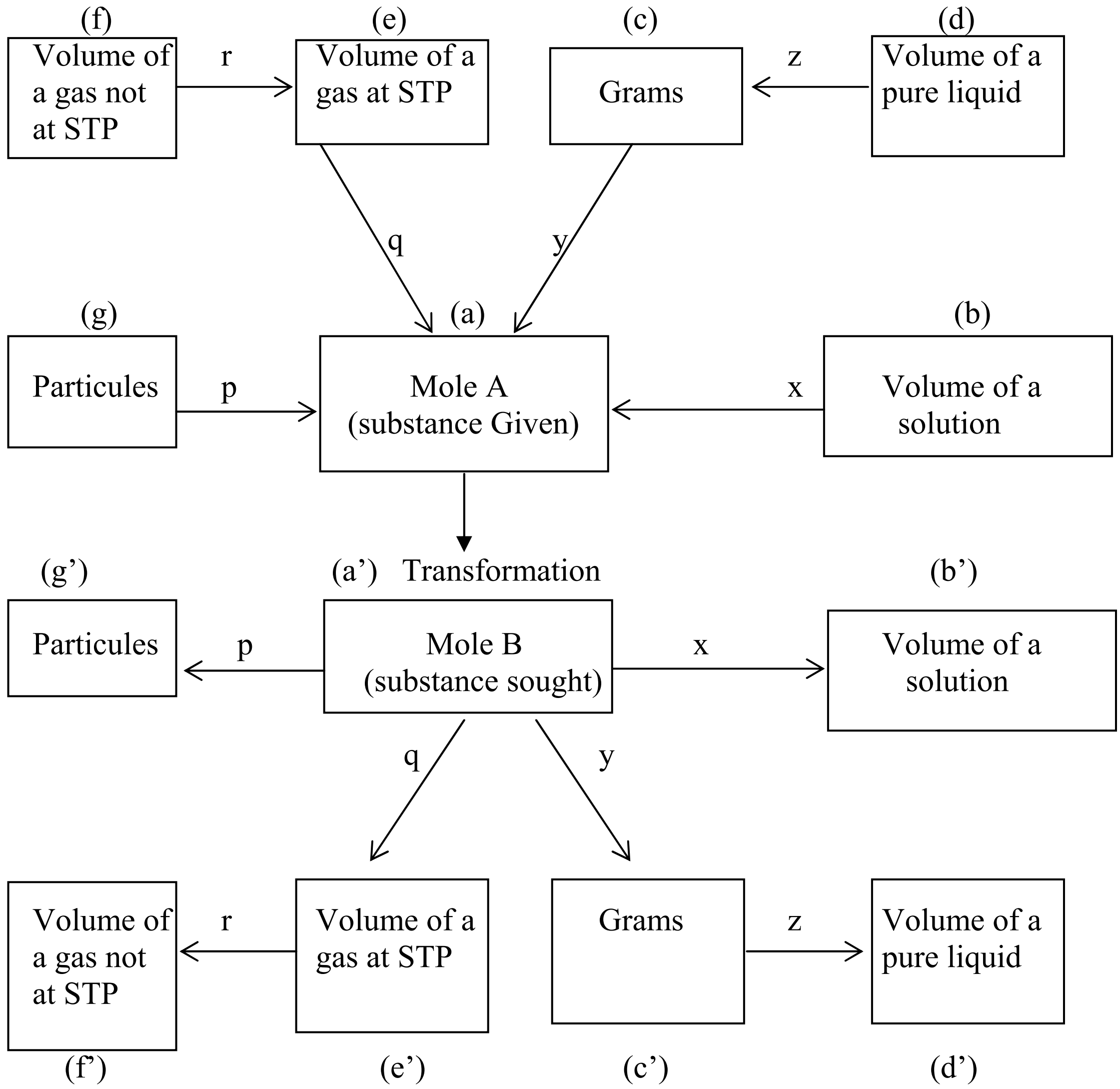


**Figure 1:** Mole-to-mole Transformation Process

**Key:**

r = P, T adjustment (i.e. $(^{P}/_{Pstp})$ $(^{Tstp}/_{T})$ adjustment)
q = molar volume ($V_m$)
p = Avogadro's constant
x = molar concentration (C)
y = molar mass
z = Density

The mole-to-mole transformation process enables a problem solver to develop solution pathway on which the analysis segment of the GRASS model is based upon. Students can make use of the mole-to-mole transformation process as a guide in mapping out the steps that must be followed when solving any given stoichiometric problem. For instance, using the mole – to – mole transformation process, the solution pathways to the different categories of stoichiometric problems are present in Table 1.

**Table 1. Different categories of stoichimetric problems and their solution pathways**

| S/N | Problem Category | Example | Solution pathway |
|---|---|---|---|
| 1. | Mole-to-mole problems | Ammonia ($NH_3$) can be made from nitrogen gas and hydrogen gas. The balanced equation for the chemical reaction is $N_2 + 3H_2 \longrightarrow 2NH_3$ How many moles of $NH_3$ can be made by the complete reaction of 3.5molse of hydrogen gas? | (a) → (a') |
| 2. | Gram- to - gram problems | Sodium chloride reacts with 10.0g of silver trioxonitrte(v) solution. How many grams of $AgN0_3(aq)$ react? | (c)→ (a)→ (a') → (c') |
| 3. | Gas volume-to – gas volume problems | What volume of oxygen at stp is required to oxidize 20.0L of carbon (ii) oxide at stp to carbon (iv) oxide? | (e) → (a) → (a') → (e') |
| 4. | Problems extended to amount of gas expressed by volume not at stp | In a common laboratory experiment, $KCl0_3$ is decomposed by heating to give KCl and $0_2$. What mass of $KCl0_3$ must be decompose to give 238mL of $0_2$ at a temperature of $28^0C$ and a pressure of 752 torr? | (f) →(e)→ (a)→ (a')→ (c') |
| 5. | Limiting reagent | How many grams of KCl can be made from 0.549g of potassium metal mixed with 0.669g of $Cl_2$? | Limiting Reagent Determination → (c) → (a) → (a')→ (c') |
| 6. | Percentage yield problems | What is the percentage yield of zinc chloride formed when 0.2583g of Zn0 reacts with excess HCl producing 0.2999g of $ZnCl_2$? | (c) → (a) → (a') → (c')→ Calculating % yield |
| 7. | Combination of Limiting reagent /Percentage yield problems | The reaction of 0.213g $Mn(N0_3)_2$ and 0.407g $K_2C0_3$ produces $MnC0_3$ with a percentage yield of 95.6% How many grams of Manganese(ii) trioxocarbonate(iv) will be made? | Limiting Reagent Determination → (c) → (a)→ (a') → (c')→ calculating actual yield |
| 8. | Extension to problems that involve volume and density of a solid | How many grams of copper can you make from 0.094mL of Zinc (density = 7.13g/mL) and 7.74 x $10^{22}$ molecules of copper(ii) tetraoxosulphate(vi) | (d) → (c) → (a) → (a')→ (c')→ [ Zinc = Limiting Reagent] |
| 9. | Extension to problems that involved a solution | What mass of calcium trioxocarbon(iv) is required to react with tetraoxosuplphate(vi) acid in 137.8mL of 0.6943mol/L solution? | (b) → (a) → (a') → (c') |
| 10. | Extension to a typical titration problems | Given that $15.00cm^3$ of $H_2S0_4$ was required to completely neutralize 25.00cm3 of 0.125mol. $dm^{-3}$ NaOH, Calculate molar concentration of the acid. | (b) → (a) → (a') → Calculating molar concentration |

Mole-to-mole transformation process is based on the interconnectivity among prior knowledge required in solving stoichiometric problems. When meaningful learning of prerequisite knowledge skills takes place, that implies that information has been well-represented and well-connected. The strength of those connections is determined by experience and learning (Solso, 1994). The greater the interconnectivity and the number of connections, the greater the understanding (White, 1988). When information is regrouped into well-integrated categories, it is stored and retrieved more efficiently than when it exists as isolated facts and strings. The case is true with stoichiometry where previously learnt materials are integrated together in solving stoichiometric problems. The mole-to-mole transformation process allows a problem solver to see the interconnectivities that exist among the prerequisite knowledge skills and how they can be applied in solving stoichiometric problems.

The importance of cognitive connections in learning has been invoked across a wide range of discipline, from art (Koroscik, 1996) to physics (Robertson, 1990). Major and Palmer (2001) argued that cognitive connections play an important role in problem-based learning, and Mastropieri and Scruggs (1996) also insisted that the failure to make cognitive connections between already known and to-be-learned information was a primary characteristic of students that lacked conceptual understanding.

Cross (1999) have gone so far as to assert that "learning is about making connections." If the problem solvers are unable to make the relevant connections they may have difficulty in solving problems, even though they may have the required prior knowledge and are able to translate adequately the problem statements. Chemistry educators (Gabel & Bunce, 1994; Niaz, 1995; Heyworth, 1999) have stressed earlier that an effective problem solving requires the following problem-solving ability and skills;

(a) a good understanding of and meaningfully learnt knowledge
(b) appropriate problem-solving procedures, which include the re-description of the original problem in a way facilitating the subsequent search for its solution;
(c) relevant linkages of information between the information of problem statements and the existing cognitive structure

### 3- Using the Modified GRASS Model during Problem-solving Instruction

The links between problem-solving models and learning to solve problems are indisputable. Teachers use problem solving models as aids to help students develop their problem-solving skills (analysis, planning, execution and checking). Problem-solving models have long been used and appreciated as useful tools that provide general strategy that may be applied to many (but not all) problems; surprisingly, most secondary school chemistry teachers are ignorant of the newly developed problem solving problem-solving models (Tsaparlis and Angelopsulos, 2000); and also do not aware of the specific steps that must be serially followed in developing problem solving skills (Okanlawon, 2005). Due to those deficiencies, the following guidelines are suggested for effective classroom instruction when dealing with stoichiometric problems using the modified GRASS model.

1. Present the stoichiometric problem to be solved by projecting it on the screen (or writing it on the chalkboard) for students to see clearly.
2. Allow one student to read the problem statement loudly.
3. Encourage a student to reread the problem statement again.
4. Ask questions to ensure that the learners understand the problem statement, the vocabulary and the type of stoichiometric problem involved.

5. Ask many questions that are helpful in planning a solution strategy. Questions such as these can be asked during the problem-solving process using the modified GRASS model.
   (a) What facts or information are given in the problem statement? This question is requesting students to state the Given.
   (b) What are you trying to find out? This question leads the students to the second segment of the GRASS model (i.e, Require)
   (c) What ideas have you studied that are useful in solving the problem at hand? This question engages students in cognitive activities which involve retrieval of relevant information from long-term memory. This cognitive activity is necessary at the Analysis stage.
   (d) Is there any connection between the data given and ideas previously studied? Or how can you connect facts given in the problem statement with ideas previously studied together in formulating a reasonable solution pathway? To answer these questions, the use of mole-to-mole transformation process is necessary. Attempt to answer the preceding question engages the students in the Analysis and Solution segments of the GRASS model
   (e) Does the answer obtained make sense – reasonable magnitude?
   The above questions assist the teacher in directing students in following the GRASS model – a five-stage problem-solving model.
6. Solve the stoichiometric problem which has been previously presented to the students.
7. After solving the problem, outline the step-by-step procedure or format taken in bridging the gap between the problem and the solution.
8. Where applicable, ask the student to suggest other methods of solution to the problem
9. Provide students with tasks (problems) which are neither too difficult and therefore beyond their knowledge and skills, nor too simple, and therefore cheap, but problems which are real problems because the solution will not be immediately obvious, and yet the knowledge and reasoning demands are likely to be within their cognitive structures.

Having suggested the preceding guidelines for using the modified GRASS model in stiochiometry lesson, it becomes necessary to apply it to solve complex stiochiometrics problems so as to illustrate its application during prolem-solving process. The worked out examples based on the modified GRASS model are presented in Appendix 1.

Apart form the teacher's effort in developing problem solving skills in their students, efforts could be made by the students to practice problem-solving at school and at home. For this purpose, Goldwhite and Spielman (1984) suggested certain techniques that have been proven helpful in building the base for acquiring problem-solving skills in chemistry. These are;

1. **Understanding**: Read over the problem carefully and be sure you understand every part of it. If you have difficulty with any of the terms or ideas in the problems reread the text material on which the problem is based. Make certain that you understand what kind of answer will be required. If the problem is quantitative, make an estimate of the magnitude of the answer.
2. **Analyzing:** Break the problem down into its components. Ask yourself
   (a) What are the data?
   (b) What is (are) the unknown(s)?

(c) What equation, law, or definition connects the data to the unknowns?

3. **Planning:** Trace a connection between the data and the unknown as a series of discrete operations (steps). This often involves manipulating one or more mathematical or chemical expressions to isolate unknown quantities once you have a clear, stepwise path between data and solution, take note of any steps that require ancillary operations, such as balancing equations or converting units.
4. **Execution:** Follow your plan and execute any mathematical operations. It helps to work with symbols whenever possible: Substituting data for variables should be the last thing you do. Make sure you have used the correct signs, exponents, and units.
5. **Checking:** Never consider a problem solved until you have checked your work. Does your answer
   (a) Make sense?
   (b) Have the right units?
   (c) Answer the question
6. **Reporting:** Make sure you have shown your reasoning and method clearly, and that your answer is readable.

By practicing the use of the preceding technique, mastery of science problem-solving strategy such as analyzing, planning and doing calculations would be improved. More importantly, constant use of this problem-solving technique is expected to transform the beginners in problem solving (i.e., those who tend to be slow and hesitating and make errors and mistakes) into experts (i.e., skilled performers of problem solving).

## IMPLICATIONS

Bodner (2007) contends that one of the causes of students' lack of understanding of chemistry is the failure to integrate knowledge. One reason for this could be that lessons were frequently seen by students as isolated events with no connections to previous lessons or topics (Duit and Treagust, 1995), so that students lacked appropriate framework that could guide their thinking at the Analysis and solution segments of the problem solving process. One way to help students develop correct solution pathway to a given complex stoichiometric problem is through the use of mole-to-mole transformation process (proposed by the author). This paper suggests that integration of the mole-to-mole transformation process into the GRASS model at the analysis segment would improve the pedagogical value of the model. Since students encountered difficulties in relating concepts they had studied previously to the problem at hand while planning solution strategies, then the use of mole-to-mole transformation process becomes useful. At this point, it would be interesting to know if the proposed modification of the GRASS model would actually improve its efficiency. Therefore, more research is needed in this direction.

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## APPENDIX 1

### Examples of complex stoichiometric problems solved using the modified GRASS Model

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|---|---|
| **Problem 1** | The concentration of an unknown solution of $KMnO_4$ can be determined by mixing an unknown solution with $H_2O_2$ and measuring the oxygen evolved. If 30.0mL of x mol. $L^{-1}KMnO_4$ solution liberates 0.150L of $0_2$ at $25^oC$ and 750mmHg, what is the molar concentration of $KMnO_4$ solution? (The oxygen was collected over water)<br>The equation for the reaction in acid medium is<br>$2MnO_4^- + 5H_2O_2 + 6H^+ \rightarrow 2Mn^{2+} + 5O_2 + 8H_2O$<br>[Standard temperature = 273K; standard pressure = 760mmHg: The vapour pressure of water at $25^oC$ = 23.8mmHg; 1 mole of gas occupies 22.4L at stp] |
| **Given** | $\underline{2MnO_4^-} + 5H_2O_2 + 6H^+ \rightarrow 2Mn^{2+} + \underline{5O_2} + 8H_2O$<br>2 mol 5mol<br><br>${}^{V}MnO_4^-$ = 30.0mL = 3.0 x $10^{-2}$ $P_V$ = 23.8mmHg<br>${}^{V}O_2$ = 0.150L ${}^{To}O_2$ = 273K<br>${}^{T}O_2$ = $25^oC$ = 298K ${}^{Po}O_2$ = 760mmHg<br>$P_T$ = 750mmHg $V_m$ = 22.4L |
| **Required** | Molar concentration of $KMnO_4$ solution = xmol. $L^{-1}$ |
| **Solution Pathway** *(based on mole-to-mole transformation process)* | Using figure 1, we have<br>(f) → (e) → (a) → (a') → (x). That is vol $O_2$ (not at stp) → Vol $O_2$ (at stp) → mol $O_2$ → mol $MnO_4^-$ → ${}^{C}MnO_4^-$ |
| **Analysis** | ${}^{V}O_2$ (T = 298K; P = 726.2mmHg) → ${}^{V}O_2$ (stp) (using ${}^{P}O_2 = P_T - P_V$; ${}^{V}O_2$ (stp) = (${}^{P}O_2\ {}^{V}O_2\ {}^{To}O_2/{}^{T}O_2\ {}^{Po}O_2$)<br>${}^{V}O_2$ (stp) → ${}^{n}O_2$ (using n = V(stp)/Vm)<br>${}^{n}O_2$ → ${}^{n}MnO_4^-$ (using mole ratio; 2mol $MnO_4^-$ = 5mol $O_2$)<br>${}^{n}MnO_4^-$ → ${}^{C}MnO_4^-$ (using C = n/v) |
| **Solution** | ${}^{V}O_2(stp) = \frac{726.2mmHg \times 0.15L \times 273K}{298K \times 760mmHg} = 0.1313L$<br><br>${}^{n}O_2 = 1mol\ O_2 \times \frac{0.1313LO_2}{22.4L\ O_2} = 5.86 \times 10^{-3}mol$<br><br>${}^{n}MnO_4^- = 5.86 \times 10^{-3}mol \times \frac{2mol\ MnO_4^-}{5mol\ O_2} = 2.344 \times 10^{-3}mol$<br><br>${}^{C}MnO_4^- = \frac{2.344 \times 10^{-3}mol\ MnO_4^-}{3.0 \times 10^{-2}LMnO_4^-} = 0.0781mol.L^{-1}$ |
| **Statement** | The molar concentration of $KMnO_4^-$ solution is 0.0781mol. $L^{-1}$ |

**Problem 2**

40.0mL of 0.270mol. $L^{-1}$ $Ba(OH)_2$ are added to 25.0mL of 0.330mol. $L^{-1}Al_2(SO_4)_3$. What total mass of precipitate is formed?

The equation for the reaction is;

$3Ba(OH)_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + 2Al(OH)_3$

[H = 1, O = 16, Al = 27, S = 32, Ba = 137)

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**Given**

| $3Ba(OH)_2$ | + | $Al_2(SO_4)_3$ | $\rightarrow$ | $3BaSO_4$ | + | $2Al(OH)_3$ |
|---|---|---|---|---|---|---|
| 3mol | | 1mol | | 3mol | | 2mol |

${}^{C}Ba(OH)_2$ = 0.270mol $L^{-1}$ ${}^{C}Al_2(SO_4)_3$ = 0.330mol. $L^{-1}$

${}^{V}Ba(OH)_2$ = 40.0mL ${}^{V}Al_2(SO_4)_3$ = 25.0mL

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**Required**

$M_{Total\ ppt}$ = ?g

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**Analysis (1st part)**

${}^{V}Ba(OH)_2$, ${}^{C}Ba(OH)_2$ $\rightarrow$ ${}^{n}Ba(OH)_2$ calculated (using n = cv)

${}^{V}Al_2(SO_4)_3$, ${}^{C}Al_2(SO_4)_3$ $\rightarrow$ ${}^{n}Al_2(SO_4)_3$ calculated (using n = cv)

${}^{n}Ba(OH)_2$ calculated $\rightarrow$ ${}^{n}Ba(OH)_2$ calculated/$nBa(OH)_2$ derived from the equation (using stoichiometric co-efficient of $Ba(OH)_2$)

${}^{n}Al_2(SO_4)_3$ calculated $\rightarrow$ ${}^{n}Al_2(SO_4)_3$ calculated/$nAl_2(SO_4)_3$ derived from the equation (using stoichiometric co-efficient of $Al_2(SO_4)_3$)

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**Solution (1st Part)**

${}^{n}Ba(OH)_2$ = 0.270mol. $L^{-1}$ x 0.04L = 1.08 x $10^{-2}$ mol Ba $(OH)_2$

${}^{n}Al_2(SO_4)_3$ = 0.330mol. $L^{-1}$ x 0.025L = 8.25 x $10^{-3}$mol $Al_2(SO_4)_3$

${}^{n}Ba(OH)_2$ cal/${}^{n}Ba(OH)_2$ derived = 1.08 x $10^{-2}$mol/3 = 3.6 x $10^{-3}$

${}^{n}Al_2(SO_4)_3$ cal/${}^{n}Al_2(SO_4)_3$ derived = 8.25 x $10^{-3}$mol/1mol = 8.25 x $10^{-3}$

$Ba(OH)_2$ is the limiting reactant because 3.6 x $10^{-3}$ is less than 8.25 x $10^{-3}$. Then ${}^{n}Ba(OH)_2$ is to be used in planning the solution strategy.

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**Solution Pathway**

Correct determination of limiting reagent leads to the following solution pathway

(a) $\rightarrow$ (a') $\rightarrow$ (c'); That is

mol$Ba(OH)_2$ $\rightarrow$ mol$BaSO_4$ $\rightarrow$ mass $BaSO_4$ (sub-solution pathway 1)

mol $Ba(OH)_2$ $\rightarrow$ mol $Al(OH)_3$ $\rightarrow$mass $Al(OH)_3$(sub-solution pathway 2)

mass $BaSO_4$ + mass $Al(OH)_3$ = Solution

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**Analysis (2nd Part)**

${}^{n}Ba(OH)_2$ $\rightarrow$ ${}^{n}Ba(SO_4)$ (using mole ratio, 1mol $Ba(OH)_2$: 1mol $BaSO_4$)

${}^{n}BaSO_4$ $\rightarrow$ ${}^{m}BaSO_4$ (suing molar mass, $BaSO_4$ = 233g.$mol^{-1}$

${}^{n}Ba(OH)_2$ $\rightarrow$ ${}^{n}Al(OH)_3$ (using mole ratio, 3 mol $B(OH)_2$ : 2mol $Al(OH)_3$)

${}^{n}Al(OH)_3$ $\rightarrow$ ${}^{m}Al(OH)_3$ (suing molar mass, $Al(OH)_3$ = 78g.mol-1)

${}^{m}BaSO_4$, ${}^{m}Al(OH)_3$ $\rightarrow$ $m_{Total\ ppt}$ (using $m_{Total\ ppt}$ = ${}^{m}BaSO_4$ + ${}^{m}Al(OH)_3$)

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**Solution (2nd part)**

$${}^{n}BaSO_4 = 1.08 \times 10^{-2}\text{mol } Ba(OH)_2 \times \frac{1\text{mol.}BaSO_4}{1\text{ mol. }Ba(OH)_2} = 1.08 \times 10^{-2}\text{mol}BaSO_4$$

$${}^{m}BaSO_4 = 1.08 \times 10^{-2}\text{mol}BaSO_4 \times \frac{233\text{g } BaSO_4}{1\text{ mol. }BaSO_4} = 2.52\text{g } BaSO_4$$

$${}^{n}Al(OH)_3 = 1.08 \times 10^{-2}\text{mol } Ba(OH)_2 \times \frac{2\text{mol.}Al(OH)_3}{3\text{ mol. Ba }(OH)_2} = 7.2 \times 10^{-3}\text{mol } Al(OH)_3$$

$${}^{m}Al(OH)_3 = 7.2 \times 10^{-3}\text{ mol } Al(OH)_3 \times \frac{78\text{g } Al(OH)_3}{1\text{mol } Al(OH)_3} = 0.56\text{g}Al(OH)_3$$

$m_{Total\ ppt.}$ = 2.52g$BaSO_4$ + 0.56g $Al(OH)_3$ = 3.08g precipitate

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**Statement**

The total mass of precipitate formed is 3.08g

**Problem 3**

A mixture of aluminium and zinc weighing 1.67g was completely dissolved in acid and evolved 1.69L of hydrogen, measured at 273k and 1 atm pressure. What was the weight of aluminium in the original mixture?

The equation for the reactions are:

$2Al_{(s)} + 6H^+_{(aq)} \rightarrow 2Al^{3+}_{(aq)} + 3H_{2(g)}$

$Zn_{(s)} + 2H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$

[Al = 27; Zn=65.4; 1mole of gas occupies 22.4L at stp]

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**Given**

$2Al_{(s)} + 6H^+_{(aq)} \rightarrow 2Al^{3+}_{(aq)} + 3H_{2(g)}$
2mol 3mol

$Zn_{(s)} + 2H^+ \rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$
1mol 1mol

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|---|---|---|---|
| ${}^{V}H_2(stp)$ | = | 1.69L | P = 1atm |
| $m_T$ | = | 1.67g | Al = 27 |
| $V_m$ | = | 22.4L | Zn = 65.4 |
| T | = | 273K | |

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**Required**

${}^{m}Al$ = ?g

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**Solution pathway** (Based on mole-to-mole transformation process)

(c) → (a) → (a')

$m_{Al}$ → mol Al → mol$^1$ $H_2$ (sub solution pathway 1)

$m_{Zn}$ → mol Zn → mol $^2H_2$ (sub solution pathway 2)

mol $^1H_2$ + mol $^2H_2$ = mol $^tH_2$ (sub solution)

(e') → (a'): That is

$Vol_{stp}$ $H_2$ → $n^oH_2$ (sub solution pathway 3)

$Mol^tH_2$ = $n^oH_2$ (solution)

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**Analysis**

$m_{Al}$ → w (using mAl = w)

$m_T$ → $m_{Zn}$ (using $m_{Zn} = m_T - w$)

$m_{Al}$ → $n_{Al}$ (using relative atomic mass; Al = 27)

$n_{Al}$ → $n^1H_2$ (using mole ratio, 2 mol Al : 3 mol $H_2$)

$m_{Zn}$ → $n_{zn}$ (using relative atomic mass; Zn = 65.4)

$n_{Zn}$ → $n^2H_2$ (using mole ratio; 1 mole Zn: 1mol $H_2$)

$n^1H_2$, $n^2H_2$ → $n^tH_2$ (using $n^tH_2 = n^1H_2 + n^2H_2$)

${}^{V}H_2$ (stp) → $n^oH_2$ (using molar volume, $V_m$ = 22.4L)

$n^tH_2$, $n^oH_2$ → $m_{Al}$ (using $n^tH_2 = n^oH_2$)

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**Solution**

$m_{Al}$ = wg

$m_{Al}$ = (1.67 – w)g

$$n_{Al} = wg \times \frac{1mol\ Al}{27g\ Al} = \frac{w\ mol\ Al}{27}$$

$$n^1H_2 = \frac{w}{27}\ mol\ Al \times \frac{3mol\ H_2}{2mol\ Al} = \frac{3w}{27 \times 2}\ mol\ H_2$$

$$n_{zn} = (1.67 - w)g \times \frac{1mol\ Zn}{65.4g\ Zn} = \frac{(1.67 - w)}{65.4}\ mol\ Zn$$

$$n^2H_2 = \frac{(1.67 - w)}{65.4}\ mol\ Zn \times \frac{1\ mol\ H_2}{1\ mol\ Zn} = 1.67 - \frac{w\ \ mol\ H_2}{65.4}$$

$$n^tH_2 = \frac{3w}{54} + \frac{1.67 - w}{65.4} = 90.2 \times \frac{142.2w}{3531.6}$$

$$n^oH_2 = 1.69LH_2 \times \frac{1\ mol\ H_2}{22.4L\ H_2} = \frac{1.69\ \ mol\ H_2}{22.4}$$

$n^tH_2$ = $n^0H_2$

$$90.2 \times \frac{142.2w}{3531.6} = \frac{1.69}{22.4}$$

$m_{Al}$ = w = **1.24g**

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**Statement**

The weight of aluminum in the original mixture is 1.24g.