UNTANGLING CHEMICAL KINETICS THROUGH TANGIBLE AND VISUAL REPRESENTATION OF MATTER

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ABSTRACT

Second semester General Chemistry students are introduced to Chemical Kinetics as part of their curriculum. Often, instructors require that students plot Concentration vs. Time graphs for elementary chemical reactions as part of the learning process. Despite employing graphical tools, students often find it difficult to conceptualize conservation of mass (matter) under constant volume conditions and thus, are unable to accurately depict concentration changes that occur during chemical reactions. We propose that the use of elementary shapes (e.g. triangles, circles, squares) to represent different atoms in molecules facilitates the comprehension of chemical kinetics. Specifically, generation of "Concentration vs. Time" graphs rendered with the aid of tangible and/or pictorial representations of atoms using fixed numbers of distinct and representative shapes helps students visualize and track the conversion of reactant "R" into product "P" as a function of time. Importantly, it also helps understand that reaction processes "start" and "end" with the same number of atoms as the reaction progresses from reactants to products. Through such a proposed visual and/or tangible tool, students can visualize which compound is the limiting reagent; how much of the other reactant is "left over"; and how much product can be made. *[African Journal of Chemical Education—AJCE 7(1), January 2017]*

INTRODUCTION

Chemical kinetics is the study of the rates of chemical processes [1-3]. The reaction rate is the defined as the change in the concentrations of a reactant or a product as a function of time (M/s) [4]. A second and noteworthy aspect of chemical kinetics as taught in General Chemistry 2 is that the reaction proceeds to completion. The reaction stops when one or more reactants are completely consumed. If one reactant is consumed before the consumption of other participating reactants, that reactant is called the "limiting reagent". The limiting reagent determines the quantity of product that can be made [4].

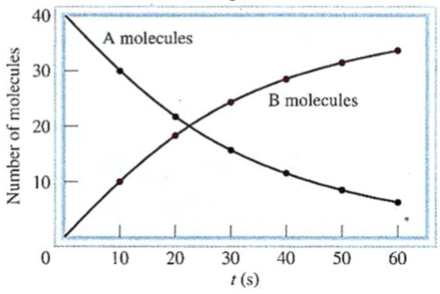
In the simplest case in which a single reactant (R) converts to a unique product (P), the reaction is often represented as "R → P" [4]. Here, R automatically qualifies as the limiting reagent to form P. While it is not possible to determine the rate of this reaction without more details, we can state how the rates of R and P relate to each other. Rate is equal to the change in concentration over time or Rate = Δ M/t. In this case, for every one molar reactant lost there is a gain of one molar concentration of product. This can be shown as Rate = $-\Delta [R]/t = \Delta [P]/t$ for this reaction [4].

For the reaction R → 2P, for every one molar (1M) concentration of R lost, there is a gain of two molar P. This implies that the rate of consumption of the reactants is only half as rapid, relative to the rate of appearance of the products. The overall reaction rate is represented as rate= $-\Delta [R]/t = \frac{1}{2} (\Delta [P]/t)$. For the reaction type, 2R → P, the equality would be the reverse of the aforementioned scenario. This is because two molar reactants are being consumed for every one molar product produced. Therefore, the rates would relate as $-\frac{1}{2} \Delta [R]/t = \Delta [P]/t$.

Concentration vs. Time

A typical pictorial representation of the relation between reaction rates of reactants and their products involves the use of a concentration vs. time graph. For example, General Chemistry textbooks provide a graphical representation of reaction progress as shown in Figure 1. The molecules versus time graph is representative of reaction progress in the reaction type A → B. Since the reaction stoichiometry is 1:1, the rates of reactant consumption and product production are equal. Inspection of the curve reveals that as the reaction proceeds to completion, the rate of the reaction decreases. While the precise rate of the reaction may not be easily inferred from the graph, it can be determined that the rate of reactant consumption equals the rate of which products are formed (both rates represented in "molecules" per second). While this graph depicts reaction progress as a function of "molecules" consumed and produced, the data can be suitably transformed to obtain a concentration versus time graph.

Figure



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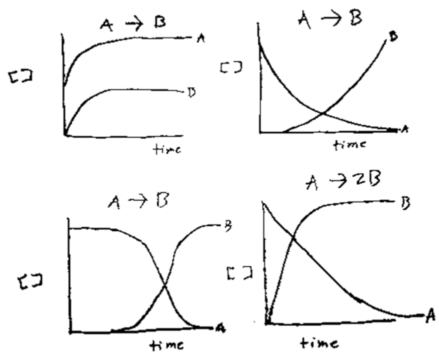
METHODOLOGY/EXPERIMENTATION

The Tangible and Visual Model (Instillation in a "Peer-Lead Workshop")

Even though the (above) material is well articulated in the textbook and in the classroom, students are often unable to construct concentration versus time graphs correctly [5]. One contributing factor could be the students' difficulty in conceptualizing conservation of mass under constant volume. In Peer-Lead Team-Learning Workshops, students would generate curves that would create end results with surplus or deficit concentrations of reactants and/or products [6, 7]. This is particularly true with respect to non 1:1 stoichiometric reactions. Typical student generated curves are shown in Figure 2. Frequently, the rendered plots have amounts of concentration spontaneously and incorrectly appear or disappear (Top and bottom left).

Figure 2: Typical generated concentration vs. time curve

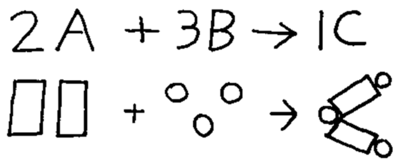


If students are unable to create the graphs correctly or comprehend the reaction quantitatively, then they are unable to answer related questions regarding the limiting reagent, leftover reagent(s), or the amounts of product(s) produced.

It is therefore essential for students to understand what a reaction equation is stating. A number of techniques involving the use of objects and blocks to understand chemical kinetics, equilibrium, and stoichiometry have been previously described in an effort to help General Chemistry students assimilate material related to kinetics and equilibrium [8-20]. Yet, a gap exits in the application of tools that relate stoichiometry, the consumption of reactant, generation of product, and their representation using graphs, to aid in the comprehension of chemical kinetics.

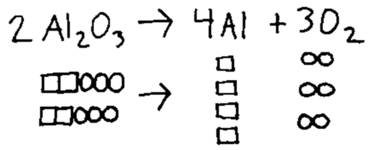
We propose that the application of an integrative tool involving visual and tactile responses to translate reaction progress to a graph significantly facilitates comprehension of chemical kinetics. We also suggest that such a tool is even more effective when implemented in peer-led team learning workshops. Note that in the workshop model, students practice and apply what they have learned in lectures with facilitation from a peer leader.

Figure 3: representation of a reaction using different shapes as the reactants



Consider the reaction represented in Figure 3. The reaction is of the type 2A + 3B → 1C. While it should be evident that it takes two moles of A and three moles of B to make one mole of C, the use of rectangles and circles to represent the reactants promotes comprehension of the stoichiometry. During the course of the reaction, the geometric shapes help make evident that no matter has been destroyed; rather, it has chemically reacted ("rearranged" or transformed) to form a new compound (utilizing all available circles and rectangles as dictated by the stoichiometry).

Figure 4: aluminum trioxide decomposes to form aluminum and oxygen

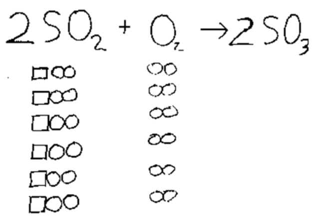


For reactions with more complicated compounds, we may need to visualize every element involved. For example, when aluminum trioxide decomposes to form aluminum and oxygen, represented by squares and circles, respectively (Figure 4), if we look at both sides of the reaction (reactants and products) we can infer that there exist equal amounts (concentrations) of oxygen and aluminum. This reinforces the fact that there is no new creation or elimination of matter, but just a rearrangement into products.

Application

Sample problem: 6 M of sulfur dioxide and 6 M of oxygen react to form sulfur trioxide. State how much product can be made, identify the limiting reagent, and how much of the other reagent is left over. Also draw a concentration versus time graph.

Figure 5



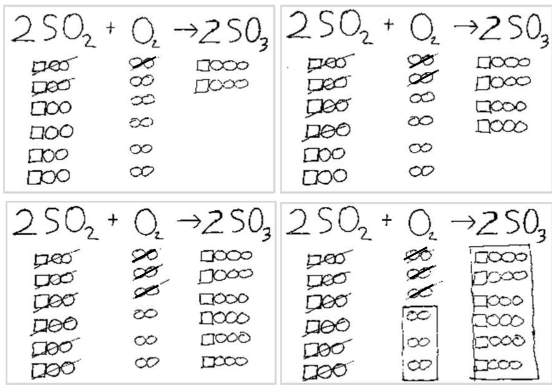
Step 1. Write down the balanced reaction (Figure 5).

Step 2. Choose the shapes of your elements. In this case, we depict squares for sulfur atoms and circles for oxygen atoms.

Step 3. "Draw the amount of molarity" you have where each compound you draw represents one molar concentration.

Step 4. Complete the reaction one time, and show the used reactants and how much product is produced. Figure 6.

Figure 6

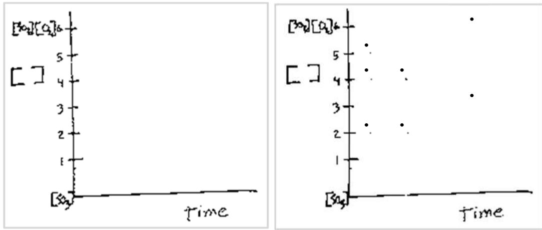


Step 5. Repeat step 4 until you run out of a reactant. Be aware that the reactant which runs out first is the limiting reagent.

Step 6. Enclose in a box any reactant leftover and the entire product created at the end of the reaction.

Step 7. Begin to draw the graph by labeling the axis as shown in Figure 7.

Figure 7

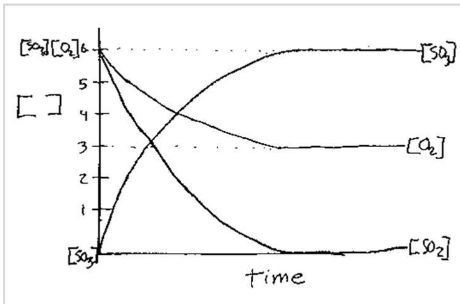


Step 8. Label the y-axis where your reactants and product begin (Note: We had no product in the beginning).

Step 9. Show the changes in concentration of each compound from the first time you completed step 4 by placing dots on the graph at a time.

Step 10. Repeat for each time you completed step 4. Keep in mind to increase the gap between the times it took to reach those concentrations, because as stated before, the rate of reaction continues to slow down as the reaction moves towards completion.

Figure 8



Step 11. Connect the dots to form a curved line for each different compound.

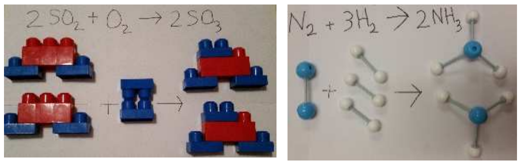
Step 12. Label the final concentration of each compound as shown in Figure 8.

CONCLUSIONS

By plotting accurate graphical representations of reaction progress, the students can visualize how the rates of appearance and disappearance of each compound relate to each other at any given point along the reaction. They can also become cognizant of the fact that matter is conserved throughout the course of the reaction.

In the Workshop, Peer Leaders can provide students with more practice problems to help reinforce the understanding of chemical kinetics and the relationship between rates by: a) changing concentrations, b) adding product at the beginning of the reaction, c) asking students to change the concentration so that no reactant is present at the end of a multi-reactant reaction, and d) querying what is present at the half-time of the reaction [20].

Figure 9: Students can visualize reaction rates with building blocks or molecular kits



An enhancement that can be made to the activity is to use building blocks or molecular kits to represent the compounds. By doing this, the students are able to physically "disassemble the reactants" and create products (Figure 9).

Review of previous material and preparation of future material

By completing the above activity students are able to review material previously learned in general Chemistry 1, which includes balancing equations, stoichiometry, and concentration. They are also able to review molecular geometry and hybridization material if molecular kits or Lewis structures are included. By helping them understand the conservation of mass and reaction rates, students are better prepared for future material in equilibrium and Organic Chemistry.

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