Some Thoughts About Molecular-Level Representations in Conceptual Problem Solving

Mary B. Nakhleh
Department of Chemistry
Purdue University

One of the more interesting areas of problem solving attempts to answer the question "What do my students understand about the molecular level of chemistry?" Hopefully, this question is also implicit in the more traditional area of mathematical problem solving, but I have focused on devising ways to help students develop a sound conceptual understanding of chemistry, which includes molecular-level representations (1-4). I have found that having students express their understanding of the molecular level in drawings accompanied by written explanations is a powerful way of helping students shift their focus from the macroscopic (bulk property) level of matter to thinking about the nature of the invisible molecular world. This shift of focus seems to require a difficult transition in students' thinking, and the drawings seem to help students begin to make that transition.

These drawings are also useful tools for the professor or TA to assess their students' understanding of molecular-level concepts. Students truly have nowhere to hide in a drawing. When you draw your understanding of the molecular level, you reveal a great deal about what you know and don't know about the molecular nature of chemistry. Therefore, these drawings can be useful in checking students' developing understanding (formative assessment) and in determining students' level of understanding on an exam (summative assessment).

These molecular-level representations are fairly flexible in the ways that they can be used. Students can create their own drawings or students can analyze drawings made for them. These representations can be used in lecture or recitation to aid exposition and development of a concept or they can be used equally well as an assessment tool. Students can use them to think about open-ended conceptual problems. Molecular-level drawings are not a "magic bullet", but they are a powerful tool in helping students learn conceptual problem solving.

The remainder of this short paper presents some of the ways in which molecular-level representations can be incorporated into a chemistry course. I have incorporated molecular-level representations into my courses using each of the methods discussed in this paper, and I can report that students view them in a variety of ways. Many students find them interesting and challenging. Others are incensed that chemistry does not simply consist of numerical problems. Still others think that a window has been opened to the molecular world for them. All of these students require practice in solving and discussing these types of problems.

My personal bias is that students in chemistry courses must strive for proficiency in many types of problem solving (mathematical, algorithmic, conceptual) and must be able to utilize multiple modes of thinking about and representing problems (5, 6, 8-10). These modes can include text, mathematical equations and graphs, drawings, and symbols. Chemistry uses all these modes of representation and requires students to alternate thinking between the macroscopic level and the molecular level. Small wonder most of our students find chemistry hard going.

The following examples are drawn from various studies by myself and others, and I look forward to receiving the readers' comments.

Interactive problem solving in small groups. Molecular-level representations can provide an appropriate focus for open-ended questions designed to promote group discussions about chemistry concepts (3, 4). Depending on the size of your class, these questions could be the focus of a short discussion in lecture or could be used for a more in-depth discussion in a recitation section. The lecture discussion could be done in small groups of 4-5 or could be done very quickly by asking students to discuss the problem briefly with their neighbors.

The problem I call "What's in the Beaker?" is an example (5, 6) of this approach (see Figure 1, problem 1). In this problem students are told that they have two beakers. One beaker is filled with a dilute solution of a strong acid (HCl). The other beaker is filled with a concentrated solution of a weak acid (CH_3COOH). The task is to draw and explain all the species that are present in each beaker.

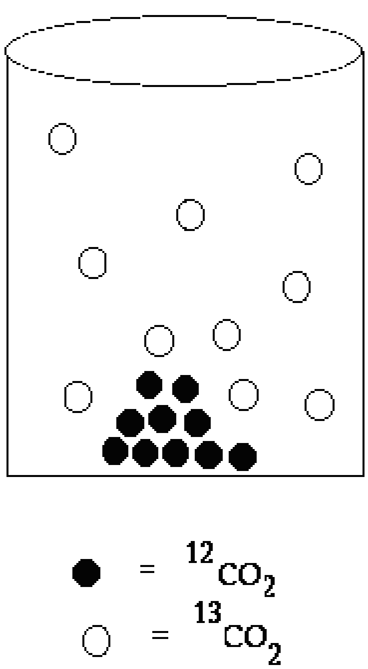
The problem has a variety of solutions, depending on a person's or group's level of expertise with the molecular level and with acid-base chemistry. The main concepts involve knowing the distinctions between strong and weak acids and between concentrated and dilute solutions. The problem appears deceptively simple, but it will elicit a surprising amount of information from students about what they know (and don't know) about acid-base chemistry on the molecular level. Figure 1 displays additional examples of conceptual problems that can be used for interactive groupwork.

Problems requiring molecular-level drawings and explanations are usually revealing. Often these drawings indicate a weak (or nonexistent) understanding of ions, atoms, and molecules, but incomplete or incorrect drawings are also a very powerful "teaching moment." The professor can really see what further explanations are needed, and the students are really willing to listen to this explanation.

Figure 1. Examples of Molecular-Level Groupwork Questions

1. You have two beakers in front of you that contain clear, colorless liquids. One beaker contains a concentrated solution of a weak acid, CH_3COOH (acetic acid). The other beaker contains a dilute solution of a strong acid, HCl (hydrochloric acid). Draw the ions and molecules that you would find in each beaker. Don't forget to think about the role of water in these systems!

2. Consider a closed system which is maintained at equilibrium and which contains 10 molecules of solid $^{12}CO_2$ and 10 molecules of gaseous $^{13}CO_2$. The diagram below shows how the system would look on the molecular level at time = initial. Complete two more diagrams which show the contents of the container at time = one hour later, and time = 1 day later.



3. Use drawings and text to explain the molecular-level processes that occur at the surface of a zinc anode immersed in zinc sulfate solution as oxidation takes place.

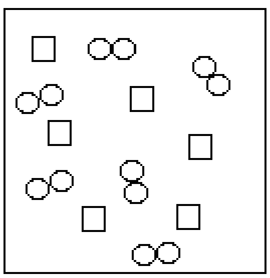
4. Draw what a saturated solution of AgBr would look like on a molecular level. The K_{sp} of AgBr = 5.0×10^{-13}.

5. Explain on a molecular level why the common ion effect decreases the solubility of a salt.

Using molecular-level representations on exams. Many of the problems from groupwork activities can be used for the conceptual questions or can be modified to be suitable. Useful insights into students' understanding can also be obtained by comparing performance on a conceptual question with a more traditional mathematical question on that same topic (7, 8, 9). Studies have shown that students usually do pretty well on solving traditional questions, but often have difficulty with conceptual problems, unless they have been explicitly taught how to approach conceptual problems (6, 8, 9). Figure 2 displays examples of conceptual molecular-level exam questions.

Figure 2. Examples of Molecular-Level Exam Questions

1. The equation for a reaction is 2 S + 3 O_2 ------> 2 SO_3. Consider the mixture of S (□) and O_2 (○○) in a closed container as illustrated below:



Draw what is in the container after the reaction has stopped.

2. Consider the reaction $Pb(NO_3)_2$ *(aq)* + 2 KI *(aq)* ---> 2 KNO_3 *(aq)* + PbI_2 *(s)*
Draw and explain what this equation means on a molecular level.

3. Explain using words and/or drawings what chemical species are predicted to be present when 2 moles of $Pb(NO_3)_2$ finish reacting with 1 mole of KI.

Caveats. To be most effective, these molecular-level conceptual problems require some careful thinking about implementation. First, students need to become familiar with these problems; they may not have been required to think on the molecular level before. Therefore, they will find these problems unfamiliar and challenging. Second, you have to show the students that you value this approach, and you usually must overtly and clearly spell out why you value the approach. Otherwise, students view them as just pretty pictures to be memorized and then "brain dumped." Third, it is important to discuss the students' efforts at solving these problems in a positive manner; building on what is appropriate in their solution and not being sarcastic about what was wrong. In fact, the molecular-level problems done in my lectures or recitations are not graded. We simply discuss the merits of the presented solution and make whatever revisions are necessary. However, I do emphasize to the students that similar problems will be on the exams and quizzes in the course. Therefore, students perceive that they can practice the problems (and their thinking) before it really counts. Finally, having done all of the preceding, you must insure that the conceptual problems do indeed appear on the exams and quizzes and that they appear in sufficient quantity to make it worthwhile for students to learn to reason through them. For example, on my exams, typically 40% of the questions deal with concepts (many of which can be represented on the molecular level). The other questions are the more traditional calculation questions.

Why use molecular-level conceptual questions? A common pattern exists in all of the studies discussed in this paper: students have trouble reasoning through conceptual questions. Further, students have difficulty thinking about and representing the molecular level in these conceptual questions. Therefore, if we want our students to think in macroscopic and molecular terms and to employ mathematical and conceptual reasoning, then we must incorporate conceptual, molecular-level problems in our courses to help students learn this way of understanding chemistry.

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