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# Chemical Kinetics Laboratory Discussion Worksheet

**Dustin Wayne Demoin** and **Silvia S. Jurisson***
Department of Chemistry, University of Missouri, Columbia, Missouri 65211, United States

## Abstract

A laboratory discussion worksheet and its answer key provide instructors and students a discussion model to further the students' understanding of chemical kinetics. This discussion worksheet includes a section for students to augment their previous knowledge about chemical kinetics measurements, an initial check on students' understanding of basic concepts, a group participation model where students work on solving complex-conceptual problems, and a conclusion to help students connect this discussion to their laboratory or lecture class. Additionally, the worksheet has a detailed solution to a more advanced problem to help students understand how the concepts they have put together relate to problems they will encounter during later formal assessments.

### Keywords

First-Year Undergraduate/General; High School/Introductory Chemistry; Inquiry-Based/Discovery Learning; Problem Solving/Decision Making; Kinetics

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With infinite time and resources instructors would have the opportunity to show students representations of chemical concepts in many different forms throughout the learning process and perhaps would be able to work with one individual at a time. The reality is that faculty members (and teaching assistants), especially new faculty members, need ready-made conceptual and mathematically rigorous instructional materials, which students can work together in smaller groups and as a whole class to complete.[1]

The chemical kinetics laboratory discussion worksheet presented here is a one-hour ready-made exercise to further students' understanding of chemical kinetics. This discussion is suitable for a large portion of pre-college and college students to help connect the macroscopic view of chemical kinetics to that of the particle-level, an important step for many students that needs to be incorporated in introductory chemistry courses.[2,3] This discussion-based format can be used to further students' understanding during recitations prior to laboratory classes or during a lecture class period with smaller class sizes (approximately thirty students or less). The discussion worksheet includes three types of learning—individual work, group work, and class discussion—divided among five sections: an introduction, Initial Ideas, Exploring, Comparisons, and Closure. If time permits there is an additional section to help the students apply the knowledge.

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*Corresponding Author: JurissonS@missouri.edu.

**ASSOCIATED CONTENT**

Supporting Information

The discussion worksheet and its answers are included in the supporting information. This material is available via the Internet at http://pubs.acs.org.

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## DESCRIPTION OF THE WORKSHEET COMPONENTS

The discussion worksheet (available in the supporting information) begins with introductory information that can be used to enrich students' current understanding about how scientists collect rapid kinetics data, which is the cornerstone of the traditional kinetics text-based problem. This section is generally read aloud by a student in the class.

Students' initial thoughts on how to approach a kinetics problem are tested in the "Initial Ideas" portion of the discussion. During this portion of the discussion, students are asked to answer the question individually (they are overtly asked not to yell or scream out the answer) and are given a short period of time to answer the question. After all or most of the students are done, the facilitator (i.e., professor, teaching assistant, or teacher) walks students through the derivation of the solution.

Next, students arrange themselves into groups of no more than four (4) or are assigned those groups by the facilitator. If this is an ongoing collaborative group for the semester, then prior grouping by the facilitator might be beneficial, but if this is only periodically done, then grouping students who are physically sitting close to one another is useful. Previous research has shown that ability grouping is not beneficial for lower performing student groups; thus, any facilitator employing prior grouping should use mixed ability grouping (i.e., pairing students with higher grades with students with lower grades to allow peer-tutoring interactions to occur).[4]

As groups of four, students complete the "Exploring" section of the discussion worksheet. First, the groups calculate the concentrations of each of the components in the two-dimensional pictures representing a portion of a flask. To better tie the microscopic view of the pictures to that of the macroscopic observer, the volume of the boxes is included so that students obtain concentrations that one could potentially encounter in the laboratory. As there are four individuals in the group, six flasks, and three components in each flask, there are four people to complete the eighteen calculations. Some students may notice a pattern that a simple relation, eq 1, can be used to determine all of the concentrations,

$$\frac{x \quad \text{molecules}}{3.65 \times 10^{-22} \quad \text{L}} \left| \frac{1 \quad \text{mol}}{6.022 \times 10^{23} \quad \text{molecules}} \right. \qquad (1)$$

where $x$ is the number of a specific type of molecule (A, B, or $AB_2$) and $3.65 \times 10^{-22}$ L is the volume of the containers as given on the worksheet. Some groups will solve each concentration as a new problem and not see the pattern or relationship between each of them. The facilitator should not influence groups' ability to either find this overall equation or not because during the concluding statements (when all of the groups are finished), he or she can point this out to the entire class.

In the next section of the discussion, students plot the concentrations of the three components for each time point (included below the pictures next to the flask number). Graphing the data should help visual and kinesthetic learners connect what is done in calculation-based kinetics problems with actual laboratory data. In order to tie the discussion to desired goals of the traditional general chemistry laboratory, a discussion of this section at the end of the discussion period should include proper graphing techniques (i.e., adding a title to the graph, labeling the axes, including appropriate units, and adding an appropriate legend).

At this point, the group of four splits itself into sets of two to carry out the next calculations. One set of two will calculate the average rate of the reaction with respect to each component. The other set will calculate the reaction rate from flask I to flask II with respect

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to each component. The reaction rate from flask I to flask II could be compared in this discussion to the initial rate, although this is not quite true, as this represents a 30 second time lapse. For more advanced classes, this discussion could be adapted to utilize graphing programs so that the derivative near the beginning of the curve could be calculated to determine the true initial rate.

Next, the group of four reconvenes to answer the “Comparisons” section to solidify their understanding. Making connections between the reaction rates of each of the components and their relative stoichiometry are sometimes difficult for students and this exercise helps to demonstrate those relationships. These comparisons, questions, and prompts are designed to help students, with the help of their group, to make their own connections from the activities they have just completed. There may be disputes between groups about the appropriate answer to each of these comparisons, but the facilitator should not interject to settle disputes. The facilitator could point out to group members that they may want to listen to a certain group member who is on the right track.

Finally, students work independently to complete the “Closure” section about their learning. These closing statements provide another level of reflection for the students to make the connections between what is being taught in the lecture class with that of this discussion.

The bulk of the hour discussion should take place during the Exploring, Comparisons, and Closure sections of the discussion, where the facilitator is not impeding the group of four, the set of two, or the individual’s ability to learn from other peers and make connections.

## HAZARDS

There are no chemical hazards associated with this activity.

## ROLE OF THE FACILITATOR

While students are working in groups, it is important that the facilitator is available to answer student questions, but the facilitator should only guide students to make their own connections and students should be allowed to come up with alternate pathways to solve the problems. Also, students should work these questions out in their groups; thus, the facilitator may let a group know that an answer or calculation is incorrect, but should not tell them why. The groups should be allowed to struggle to fix the mistakes themselves without the facilitator interfering.

After all of the students are finished with the Exploring, Comparisons, and Closure sections or when there are about 10–15 minutes remaining of the hour, the facilitator brings the class back together for closing statements. Here is where a discussion of the proper graphing techniques and the answers will be provided to the students so that they can, with the facilitator’s help, correct any errors previously made. During this time, the facilitator should let students answer or give ideas on how to solve the problems. A good facilitator should take the information provided by the students and reshape their answers or encourage the students to rethink their thought process to arrive at the correct answers.

The facilitator needs to be able to complete all of the material to the end of the Closure section before the end of the class period. If there is time remaining, then the “Applying the Ideas” section should be discussed. The problem from the Applying the Ideas” section is a modified version of a lengthy problem from the Zumdahl and Zumdahl textbook, but the solution is our own.[5]

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## DISCUSSION

Using this discussion worksheet with the interactive graphing technique to help students tie the microscopic view of chemical kinetics provides a kinesthetic, cooperative-learning, and discussion-based approach for students to improve their knowledge of kinetics. The importance of this discussion worksheet is to help students make connections between what is taught in the lecture period and problems found in most introductory general chemistry texts. The discussion was seamlessly included into our course with no adjustment to the current curriculum, which is useful to professors and instructors who are looking for another way to discuss chemical kinetics outside of a traditional lecture, without radically changing their current syllabus or teaching style. Additional content was added through the introduction of the discussion worksheet to enrich students' understanding of how experiments would give initial rates. Because no content was removed from the current chemistry curriculum, the additional discussion was used to help those students who either had not made these connections to the molecular level or were still having difficulties with their calculations for these kinetics-based problems. No formal assessment of students' perceptions of the activity or student gains was performed. The teaching assistants who implemented the discussion reported student interest during the discussion and ease of implementation in the discussion period. Additional assessments need to be done to determine the extent to which the students' understanding is improved with the use of this discussion, rather than our traditionally used problem-solving session.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgments

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