EFFECTS OF A STUDENT RESPONSE SYSTEM ON
STUDENT LEARNING IN INTRODUCTORY CHEMISTRY

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EFFECTS OF A STUDENT RESPONSE SYSTEM ON STUDENT LEARNING IN INTRODUCTORY CHEMISTRY

ABSTRACT

Courses with large enrollments tend to limit student-instructor interaction. This means that students tend to assume a more passive role and they rarely receive feedback concerning their thinking prior to taking an exam. Active involvement by students and interaction with peers and faculty has been shown to produce positive student learning outcomes. Electronic student response (SR) systems can be used to increase student interaction in both large and small classrooms. This study was designed to examine two aspects of SR systems when used with introductory chemistry classes: 1) the optimum sequence for having students respond to and discuss questions and 2) the affect of SR systems on student performance on delayed assessment measures.

The subjects for this study were 70 students enrolled in three laboratory sections of the second semester course in introductory chemistry. One laboratory section served as the control group while the other two sections utilized a SR system and served as the treatment groups. Data for the study were collected from student responses to lecture questions asked during laboratory sessions, brief quizzes covering lecture material given during the laboratory sessions, and hour-long examinations covering lecture material. These data were analyzed using t-tests and ANCOVA to investigate the research hypotheses.

Results indicate that: 1) the Question-Discussion-Response format optimized student performance on lecture questions asked during laboratory sessions and 2) classes
in which student response systems were used showed improvements on delayed measures of student performance such as quizzes and examinations.
ACKNOWLEDGMENTS

I would like to acknowledge Dr. Charles Ward for accepting me and allowing me to work on this research project. Dr. Ward is the chair on my committee. I would also like to thank Drs. Huber and Reeves for being part of my committee and giving me advice on my thesis. Last I would like to give thanks to my family and my husband for all of their support.
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CHAPTER 1
INTRODUCTION AND REVIEW OF RELATED LITERATURE

College courses with large enrollments are often taught using the lecture format. The lecture format is useful for presenting new concepts. However, this method of teaching does not encourage students to engage in or improve their problem solving skills (1, 9, 10, 11, and 12). The lecture format tends to limit student-instructor interaction and, as a consequence, students rarely receive feedback concerning their thinking prior to taking an exam (1). In addition, the lecture format makes it difficult for the instructor to determine if students fully understand the material presented during the lecture (3).

According to Chickering and Gamson (8), some of the key principles for good practice in undergraduate education are

- student-instructor interaction,
- active learning, and
- prompt feedback.

Active involvement by students and interactions with peers and faculty members has been shown to predict positive student learning outcomes (2). Courses that use techniques to increase interactive engagement with course content show higher levels of concept learning (17,18). Furthermore, numerous studies have shown that student performance in science classes improves with increasing levels of active participation by students in classroom discussions (3, 4, 5, and 6). Finally, it is important for students to have feedback on their understanding of the subject matter, as this helps to develop good critical thinking skills (2,13, 15).
Student response (SR) systems, also known as personal response (PR) systems, audience response (AR) systems, or simply clickers, have been in use for many years. SR systems represent a simple technology that can be used to facilitate open discussion and interaction in the classroom. A basic SR system consists of a student response unit with buttons labeled A through E, a receiver that accepts data from the student response units, and some means to display the collective student responses to the entire class in real time. Early SR systems used wires to connect the student response units to the receiver. Since the mid-1990s, SR systems have used wireless technology to communicate between the student response units and the receiver with computers being used to collect, analyze, and display student response data.

SR systems allow students to answer questions anonymously while providing them with instant feedback. Since students can respond anonymously, they report feeling more comfortable participating in the clicker sessions (1). The anonymity of responding with clickers ensures nearly total student participation (7). Since SR systems allow students to respond anonymously, they are encouraged to take risks with their responses (16, 7). The nature of SR systems introduces a “game atmosphere” into the classroom that may engage students more than traditional approaches (7).

Some of the first studies of SR systems were conducted in the early 1970s. These systems used technologies that were much different than those used by current systems. In 1970, Rubin used footswitches as student response units in an agricultural economics class (15). The footswitches allowed students to respond to questions anonymously. Rubin’s system consisted of wires running from the footswitches to the instructor’s console and a memory unit. Each time a student pressed a footswitch a light bulb on the
The teacher’s console would light up. The results of this study showed that students with footswitches, in classes where the instructor could see the feedback, did no better than students without footswitches. However, students with footswitches, in classes where the instructor could not see the feedback, did better than students without footswitches.

In 2002, Madrill and Mazur designed a study using personal response systems in which mini-lectures were given and then followed by a multiple-choice concept-based question. The mini-lectures comprised a full lecture broken up into four or five segments. Two groups of first-year undergraduate students majoring in Building Surveying/Architecture were the test subjects. Students answered questions from the first test without discussion, then students discussed the questions and answered the questions again. The results indicated that correct responses increased by about 26%.

In 2008, Morling, McAuliffe, Cohen, and DiLorenzo analyzed the efficacy of personal response systems in a large introductory psychology class of 1,790 students. They compared four sections taught by two different instructors. Each instructor taught two sections, one with clickers and one without clickers. They compared the exams of the clicker sections and the non-clicker sections. Using a 2 x 2 x 4 MANOVA analysis they found that there were significant differences between the clicker and non-clicker sections in favor of the clicker sections.

In 1996, Jackson and Trees used seven instructors from a large public university in the Western United States, who were already using clicker technology, to distribute a survey on the effectiveness of SR systems (1). The SR system used in this study was Hyper-Interactive Teaching Technology (1). The survey used in this study was administered during the last week of the semester. Students were made aware that the
survey was specifically related to the SR system and not associated with course evaluation (1). The results of this study showed that: 1) students appreciated the instant feedback the SR system provided, 2) students in their first two years of college seem to experience greater learning gains through the use of clickers, and 3) more research was needed in order to determine if clickers actually produce positive effects on student learning (1).

While the literature is replete with studies reporting on the use of SR systems, the vast majority of these studies, like the work described above by Jackson and Trees, report only anecdotal results. There is a clear need for more quantitative studies of the impact of SR systems on classroom instruction.

**Problem**

The purpose of this study is to examine the use of a Student Response system in introductory chemistry classes to determine if it has a positive impact on student learning. The two main goals of the project are to determine: 1) the optimum sequence for having students respond to and discuss questions and 2) the affect of a SR system on student performance on delayed assessment measures such as quizzes and examinations.

**Hypotheses**

The research hypotheses to be examined in this study are outlined below. The treatment group is the lab section that used a SR system to view, discuss, and respond to questions that covered lecture material while the control group used the traditional paper-and-pencil format for responding to questions covered in lecture. Quizzes and examinations contained questions from the lecture that were related to the questions covered in the review sessions conducted during the laboratory meetings (treatment
questions) as well as questions from the lecture that were not related to questions covered during the review sessions (control questions).

**Hypothesis 1:** When using a SR system, the Question-Discussion-Response sequence for presenting lecture problems in the laboratory will lead to better performance on these problems than the Question-Response-Discussion sequence.

**Hypothesis 2:** The treatment group and the control group will perform the same on control questions contained on quizzes.

**Hypothesis 3:** The treatment group will outperform the control group on treatment questions contained on the quizzes.

**Hypothesis 4:** The treatment group and the control group will perform the same on control questions contained on examinations.

**Hypothesis 5:** The treatment group will perform the same as or slightly outperform the control group on treatment questions contained on the examinations.
Subjects

The subjects for this study were students enrolled in three sections of General Chemistry 102 (CHM-102) at the University of North Carolina Wilmington during the spring semester, 2008. Subjects self-selected into the laboratory sections resulting in the distribution of characteristics, which were relevant to this study, are shown in Table 1. The three laboratory sections are referred to as A, B, and C.

Table 1. Averages of Demographic Variables

<table>
<thead>
<tr>
<th>Section</th>
<th>N</th>
<th>Class</th>
<th>Major</th>
<th>Gender</th>
<th>Exam 1 Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24</td>
<td>2.6</td>
<td>1.7</td>
<td>1.3</td>
<td>46.7</td>
</tr>
<tr>
<td>B</td>
<td>22</td>
<td>1.8</td>
<td>1.8</td>
<td>1.4</td>
<td>49.1</td>
</tr>
<tr>
<td>C</td>
<td>24</td>
<td>2.3</td>
<td>1.7</td>
<td>1.3</td>
<td>48.3</td>
</tr>
</tbody>
</table>

Coding: Class – Freshman=1, Sophomore=2, Junior=3, Senior=4
Major – Non-Science Major=1, Science Major=2
Gender – Female=1, Male=2
Score on Exam 1 (T-Scores) – Individual scores ranged from 18.3 to 68.3

Course / Instructors

CHM-102 is the second semester of a two-semester sequence in general chemistry intended for students majoring in some area of science. Major topics covered in the course include kinetics, equilibrium, acid-base chemistry, and electrochemistry. Students met for lecture three times each week in 50-minute classes that enrolled approximately 120 students. In addition to lecture, students attended one three-hour laboratory session each week. Each laboratory section enrolled a maximum of 24 students. The lecture and one of the laboratory sections were taught by a professor with 31 years of experience.
teaching General Chemistry at the university level. This person is referred to as Instructor 1. Two of the laboratory sections were taught by a Graduate Teaching Assistant with two years of experience teaching General Chemistry labs. This person is referred to as Instructor 2. Table 2 summarizes the sections taught by each instructor.

<table>
<thead>
<tr>
<th>ClassType/Section</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lab</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Grades in CHM-102 were based on students’ performance on examinations, quizzes, and laboratory work. The exams and quizzes were prepared by Instructor 1. The exams were administered during special evening sessions so that all students could take the same exam at the same time (Appendix W). Quizzes were administered during laboratory sessions except for Quiz 3, which was given during lecture. All students took the same quiz (Appendix X).

**Laboratory Sessions**

A typical laboratory session consisted of:

1) a ten minute briefing covering the laboratory experiment,

2) approximately two hours of laboratory work, and

3) a 30-minute review session involving questions from lecture material.

The review questions are referred to as supplemental questions. For lab section C, the supplemental questions (Appendix Y) were in the form of a handout that contained anywhere from three to five questions. Students were allowed to work in groups or individually to answer the questions. The lab instructor was available to provide help if requested.
For lab sections A and B, the supplemental questions were presented by the instructor using PowerPoint (Appendix Z). Each PowerPoint presentation contained between five to seven questions. Students used the iClicker response units to answer these questions. The instructor led a discussion of each question. The discussion sequence was varied, from one lab session to the next, between the following formats: a) Question-Response-Discussion and b) Question-Discussion-Response.

The only variance in this schedule was when students took quizzes. Quizzes were given at the beginning of the lab and lasted 20 minutes. Quizzes were given approximately every three weeks.

iClicker Student Response System

The SR system used in this study was iClicker, distributed by Macmillan Publishing. The iClicker system uses radio frequency signals to communicate between the students' units and the base unit (Figure 1).

Figure 1. iClicker Student Remote and Base Unit

Once the student chooses an answer (A, B, C, D, or E), the signal is sent to the base unit. The iClicker software stores the individual answers for each question (Figure 2).
The program also has an option to display a bar graph to show the number of students who chose each answer option (Figure 3).

**Figure 2. iClicker Tabular Display of Student Response Data**

<table>
<thead>
<tr>
<th>Average</th>
<th>Question 1</th>
<th>Question 2</th>
<th>Question 3</th>
<th>Question 4</th>
<th>Question 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>01B</td>
<td>100 %</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Total:</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02B</td>
<td>82 %</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Total:</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04B</td>
<td>100 %</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Total:</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05B</td>
<td>100 %</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Total:</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3. iClicker Graphical Display of Student Response Data**
Experimental Design

The experimental design used to investigate Hypothesis 1 is shown in Table 3. This part of the study looked at the effect of varying when the discussion of a question took place on the students’ performance on the question.

**Table 3. Experimental Design for Testing Hypothesis 1**

<table>
<thead>
<tr>
<th>Section A</th>
<th>N</th>
<th>D</th>
<th>O₁</th>
<th>ND</th>
<th>O₂</th>
<th>D</th>
<th>O₃</th>
<th>ND</th>
<th>O₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section B</td>
<td>N</td>
<td>D</td>
<td>O₁</td>
<td>ND</td>
<td>O₂</td>
<td>ND</td>
<td>O₃</td>
<td>D</td>
<td>O₄</td>
</tr>
</tbody>
</table>

D = discussion occurred before student answered question
ND = discussion occurred after student answered question
N = nonequivalent groups, since students were not randomly assigned to a section
O = observations of the clicker sessions

Hypothesis 1: \( \overline{O}_{A_0} > \overline{O}_{B_{SD}} \)

The statistical analysis for this design was conducted using t-tests of the mean scores on the supplemental questions in lab sections A and B. The \( \alpha \) level for all t-tests was 0.05.

The t-tests were performed using Prostat (19).

The experimental design used to investigate Hypotheses 2, 3, 4, and 5 is shown in Table 4. This part of the study examined the effect that the SR system had on student learning by looking at the scores students earned on quizzes and exams.

**Table 4. Experimental Design for Testing Hypotheses 2, 3, 4 and 5**

<table>
<thead>
<tr>
<th>Section A</th>
<th>N</th>
<th>O₁</th>
<th>X</th>
<th>O₂;O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section C</td>
<td>N</td>
<td>O₁</td>
<td>O₂;O₃</td>
<td></td>
</tr>
</tbody>
</table>
\( X = \) Treatment (use of clickers)
\( O_1 = \) Covariate (scores on Exam 1)
\( O_2 = \) Questions not related to treatment (control questions), \( O_3 = \) Questions related to treatment (treatment questions)
\( N = \) Nonequivalent groups, since students were not randomly assigned to a section

For Quizzes:
- Hypothesis 2: \( O_{2r} = O_{2c} \)
- Hypothesis 3: \( O_{2r} > O_{2c} \)

For Exams:
- Hypothesis 4: \( O_{3r} = O_{3c} \)
- Hypothesis 5: \( O_{3r} \geq O_{3c} \)

The statistical analysis for this design used a two-way factorial analysis of covariance (ANCOVA) to analyze student scores on quizzes and exams. ANCOVA was used because students were not randomly assigned to the treatment and control groups. The covariate used for the ANCOVA was student performance on Exam 1. Post hoc analysis of adjusted means was conducted using the Tukey procedure. The \( \alpha \) level for all statistical tests was 0.05. The ANCOVA was performed using VassarStats (20). The Tukey post hoc tests were performed using WebStat (21).

The classification of questions from quizzes and exams as treatment questions (\( QT \)) and control questions (\( QC \)) was performed independently by an undergraduate chemistry major and Instructor 2. Disagreements with question classifications were resolved by Instructor 1. Table 5 summarizes the classifications of quiz and exam questions used in this study.
Table 5. Summary of Quiz and Exam Question Classifications

<table>
<thead>
<tr>
<th>Quiz</th>
<th>Quiz Question</th>
<th>Q&lt;sub&gt;T&lt;/sub&gt;/Q&lt;sub&gt;C&lt;/sub&gt;</th>
<th>Mean Score Section A</th>
<th>Mean Score Section B</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.73</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.60</td>
<td>0.40</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Q&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.47</td>
<td>0.82</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Q&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.67</td>
<td>0.82</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Q&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.75</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.79</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.70</td>
<td>0.59</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.78</td>
<td>0.35</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Q&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.41</td>
<td>0.76</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>Q&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.47</td>
<td>0.62</td>
</tr>
</tbody>
</table>
This study was designed to investigate the use of a student response system in introductory chemistry. More specifically, it examined: a) the effects of altering the order in which the discussion of questions occurred and b) the effects of a SR system on student performance on quizzes and exams. In this chapter, data collected and analyzed as part of the study are presented according to the hypotheses they were designed to test.

**Hypothesis 1**

This hypothesis states that when using a SR system, the Question-Discussion-Response (D) sequence for presenting lecture problems in the laboratory will lead to better performance on these problems than the Question-Response-Discussion (ND) sequence. The null hypothesis being tested states that student performance on lecture problems presented in the laboratory will be the same regardless of the order of the discussion.

To test this hypothesis, t tests were performed on the means of student scores for lecture problems over a nine week period. The order in which the discussion of the problems occurred was rotated between lab sections A and B. Table 6 summarizes these comparison data. In every case where one group discussed the question prior to answering it (labeled as D) and the other group discussed the question after answering it (labeled as ND), the D group outperformed the ND group (weeks 2, 3, 4, 5, 6, and 9).
Table 6. Comparison of Discussion Order with the Means of Sections A and B

<table>
<thead>
<tr>
<th>Week</th>
<th>Discussion Order</th>
<th>Mean Scores</th>
<th>Maximum Possible</th>
<th>t test</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sec A</td>
<td>Sec B</td>
<td>Sec A</td>
<td>Sec B</td>
<td>(A - B)</td>
</tr>
<tr>
<td>1</td>
<td>ND</td>
<td>ND</td>
<td>10.7</td>
<td>7.7</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>ND</td>
<td>9.6</td>
<td>7.4</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>ND</td>
<td>4.8</td>
<td>3.8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>ND</td>
<td>D</td>
<td>9.5</td>
<td>11.8</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>ND</td>
<td>5.8</td>
<td>3.1</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>ND</td>
<td>D</td>
<td>7.8</td>
<td>8.2</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>ND</td>
<td>ND</td>
<td>8.3</td>
<td>7.4</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>ND</td>
<td>ND</td>
<td>8.1</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>ND</td>
<td>10.4</td>
<td>4.0</td>
<td>10</td>
</tr>
</tbody>
</table>

*Statistically significant difference at 0.05 level or less

Figure 4 is a graphical representation of these data and clearly shows that the D group always outperformed the ND group. In five of these six comparisons (weeks 2, 3, 4, 5, and 9), the differences in favor of the D group were statistically significant. Therefore, the null hypothesis is rejected. The order in which the discussion of a question takes place during a SR session does matter, and it favors having the discussion take place before the question is answered by the students.

Figure 4. Analysis of Discussion Sequencing

The remainder of this chapter will focus on the testing of hypotheses related to the effects of a SR system on student performance on quizzes and exams.
Hypothesis 2

This hypothesis states that the treatment group (Trt) and the control group (Ctrl) will perform the same on control questions ($Q_c$) contained on quizzes. The quizzes contained five questions each and were given close to the time (within two weeks) that the material was covered in the SR sessions in lab. Since students were not randomly assigned to the treatment and control groups, there is the possibility that performance differences unrelated to the treatment exist between the two groups. To help control for these possible differences, the analysis of Hypothesis 2 was performed using a 2 x 2 ANCOVA with student scores on the first exam in the course used as the covariate. It was found that students in the control group performed slightly better than students in the treatment group on the first exam (Table 1). Table 7 shows the ANCOVA adjusted means for the combined quiz scores.

Table 7. Adjusted Means for Combined Quiz Scores

<table>
<thead>
<tr>
<th></th>
<th>Trt Group</th>
<th>Ctrl Group</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_c$</td>
<td>1.78</td>
<td>2.33</td>
<td>2.06</td>
</tr>
<tr>
<td>$Q_T$</td>
<td>2.61</td>
<td>2.12</td>
<td>2.36</td>
</tr>
<tr>
<td>Totals</td>
<td>2.20</td>
<td>2.23</td>
<td>2.21</td>
</tr>
</tbody>
</table>

A plot of the adjusted means for the combined quiz scores shows that students in the control group had higher scores on control questions than did students in the treatment group, but students in the treatment group had higher scores on treatment questions (Figure 5).
The ANCOVA summary for the quiz scores is presented in Table 8. An analysis of the main effects (Group and Question Type) shows no statistically significant differences for either the groups or the question types. This means that Hypothesis 2 cannot be rejected, indicating that there was no difference in quiz scores between students in the treatment and control groups on control questions.

### Table 8. ANCOVA Summary for Quiz Scores

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Question Type</td>
<td>2.09</td>
<td>1</td>
<td>2.09</td>
<td>1.34</td>
<td>0.250</td>
</tr>
<tr>
<td>Adjusted Group</td>
<td>0.02</td>
<td>1</td>
<td>0.02</td>
<td>0.01</td>
<td>0.921</td>
</tr>
<tr>
<td>Adjusted Questions Type x Group</td>
<td>6.28</td>
<td>1</td>
<td>6.28</td>
<td>4.03</td>
<td>0.048</td>
</tr>
<tr>
<td>Adjusted Error</td>
<td>138.63</td>
<td>89</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since the main effects were not statistically significant, no post hoc analysis of the means was performed.
Hypothesis 3

This hypothesis states that the treatment group will outperform the control group on treatment questions contained on the quizzes. The null hypothesis to be tested states that there will be no difference in the mean scores for students in either group on the treatment questions. For the same reasons stated under Hypothesis 2, the analysis of Hypothesis 3 was performed using a 2 x 2 ANCOVA with student scores on the first exam in the course used as the covariate. While the data in Figure 5 show that students in the treatment group did better on treatment questions than did students in the control group, the lack of statistical significance for the main effects in the ANCOVA analysis (Table 8) means that the null hypothesis cannot be rejected. Therefore, the conclusion is that students in the treatment group performed no better than students in the control group on treatment questions found on the quizzes.

Hypothesis 4

This hypothesis states that the treatment group and the control group will perform the same on control questions contained on exams. The exams contained 21 questions each and were given from one to four weeks after the material was covered in the SR sessions in lab. For reasons similar to those stated under Hypothesis 2, the analysis of Hypothesis 4 was performed using a 2 x 2 ANCOVA with student scores on the first exam in the course used as the covariate. Table 9 shows the ANCOVA adjusted means for the combined exam scores.
Table 9. Adjusted Means for Combined Exam Scores

<table>
<thead>
<tr>
<th></th>
<th>Trt Group</th>
<th>Ctrl Group</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_c$</td>
<td>3.84</td>
<td>5.20</td>
<td>4.53</td>
</tr>
<tr>
<td>$Q_T$</td>
<td>3.19</td>
<td>3.28</td>
<td>3.23</td>
</tr>
<tr>
<td>Totals</td>
<td>3.51</td>
<td>4.24</td>
<td>3.88</td>
</tr>
</tbody>
</table>

A plot of the adjusted means for the combined exam scores shows that students in the control group had higher scores on control questions than did students in the treatment group, but students in both groups had essentially the same scores on treatment questions (Figure 6).

Figure 6. Profile of Exam Scores by Group and Question Type

The ANCOVA summary for the exam scores is presented in Table 10. An analysis of the main effects shows statistically significant differences between the groups (Trt and Ctrl) and question types ($Q_c$ and $Q_T$).
Since the main effects showed statistically significant differences, a Tukey post hoc analysis of the adjusted means was performed. The formula for computing the Tukey Honestly Significant Difference (HSD) for comparing the adjusted means is shown in Figure 7 (21).

**Figure 7. Tukey’s Honestly Significant Difference**

$$HSD = q_{.05} \sqrt{\frac{MS_{error}}{n}}$$

The critical value of q at the 0.05 level with 89 degrees of freedom is 2.81. The value of n, which is the number of observations in each cell of the 2 x 2 adjusted means matrix (Table 9), is 24. This leads to a Tukey HSD of 0.68, which means that any difference between adjusted means equal to or greater than 0.68 is statistically significant at the 0.05 level or less.

Applying the Tukey HSD to the adjusted means shown in Table 9 indicates that Hypothesis 4 is rejected (5.20 – 3.84 > 0.68). The control group significantly outperformed the treatment group on control questions on the exams.

**Hypothesis 5**

This hypothesis states that the treatment group will perform the same as or slightly outperform the control group on treatment questions contained on the
examinations. For reasons similar to those stated under Hypothesis 2, the analysis of Hypothesis 5 was performed using a 2 x 2 ANCOVA with student scores on the first exam in the course used as the covariate. Table 9 shows the ANCOVA adjusted means for the combined exam scores and Table 10 shows the ANCOVA summary for the exam scores.

The main effects in Table 10 show statistically significant differences between the groups (Trt and Ctrl) and question types (QC and QT). Therefore, a Tukey post hoc analysis of the adjusted means was performed. The procedure for computing the Tukey HSD was discussed under Hypothesis 4.

Comparing the adjusted means for the treatment and control groups on treatment questions showed that the two groups performed essentially the same. The difference between the means did not exceed the Tukey HSD value of 0.68 (3.28 – 3.19 < 0.68). Therefore, Hypothesis 5 is not rejected indicating that the treatment and controls groups performed the same on treatment questions on the exams.

Summary of Results

Hypothesis 1 is supported. The Question-Discussion-Response sequence for presenting lecture problems in the laboratory using a SR system does lead to better performance on these problems than the Question-Response-Discussion sequence.

Hypothesis 2 is supported. The treatment group and the control group were found to perform the same on control questions presented on quizzes.

Hypothesis 3 is not supported. While the mean for the treatment group was higher than the mean for the control group on treatment questions presented on the quizzes, the difference was not found to be statistically significant.
Hypothesis 4 is not supported. The control group significantly outperformed the treatment group on control questions presented on the exams.

Hypothesis 5 is supported. The treatment group and the control group performed the same on treatment questions presented on the exams.
Discussion

Student response systems have the ability to increase the level of student engagement in classroom discussions by providing a convenient, rapid, and anonymous way for students to submit individual answers to a question posed to the entire class by the instructor and for the instructor to provide three important types of feedback to the students: 1) immediate feedback regarding the correctness of each student’s answer, 2) a profile of the entire class’s performance on the question, and 3) feedback to each student regarding his or her rank in the class on the question being discussed. There is no other classroom teaching method or technology capable of providing such powerful feedback to students in such a short period of time.

Since SR systems increase student engagement and provide students with prompt feedback, it is reasonable to assume that students who use SR systems in their classes should outperform students who do not when assessed with standard classroom quizzes and exams. Furthermore, it is reasonable to assume that students who have learned a concept through the give-and-take processes associated with SR systems should retain their understanding of these concepts over a longer period of time. These points formed the basis of this study and were the direct focus of hypotheses 2, 3, 4, and 5.

Hypothesis 1 focused on the question of discussion sequencing. While using an SR system in classroom discussion, when is the best time to discuss the question being presented, before students submit their answers or after? The results show that
more students answer the question correctly when they discuss the question before submitting their answers. In five out of six instances, there was a statistically significant difference in favor of the “discussion before submitting answers” format. In the one instance that did not reach statistical significance, the means of the two groups were very close to the maximum possible score, which prevented detecting any differences that might have existed between the two groups.

While the “discussion before submitting answers” format produces higher scores, it does lead to some ambiguity about whose answers are being submitted. During the discussion of an item, it is possible that lower performing students might succumb to the temptation to simply go with the answer being proposed by the higher performing students in the class. If this was happening on a regular basis, it could affect the quiz and exam performance of lower performing students since they were not being pushed to think more deeply about a question for themselves prior to submitting their answers. Unfortunately, the design of this study did not permit a closer examination of this issue.

Hypotheses 2 and 3 examined the quiz performance of students who did and did not use the SR system as part of the classroom discussion of topics (Trt and Ctrl groups respectively). The quizzes were given within two weeks of the time the quiz topics were discussed in class and were therefore considered measures of short-term retention of concepts, facts, and skills. Furthermore, the questions on the quizzes were classified as treatment questions ($Q_T$) if they were related to topics discussed in lab by the Trt and Ctrl groups, or control questions ($Q_C$) if they covered topics that were only discussed in lecture. The analyses of these two hypotheses were complicated by the fact that the Ctrl group contained a higher percentage of high performing students than did the
Trt group. In an attempt to compensate for these group differences, ANCOVA was used to make group comparisons. The covariate for the ANCOVA was student performance on the first hour-long examination in the course, which occurred prior to the implementation of the SR system.

Hypothesis 2 specifically looked at the performance of students in the Trt and Ctrl groups on QC questions on the quizzes. Since the QC quiz items covered topics that were only discussed in lecture, the two groups should perform at roughly the same level. The results show that the Ctrl group did slightly better than the Trt group on the QC quiz questions (the differences were not statistically significant), which is not too surprising given that the Ctrl group was a higher performing group in the first place.

Hypothesis 3 examined the performance differences between students in the Trt and Ctrl groups on QT questions on the quizzes. QT quiz items covered topics that were discussed in both lecture and lab. In lab, the Ctrl group discussed these questions as part of a written assignment while the Trt group discussed them using the SR system. The results show that the Trt group did better on the QT quiz items than did the Ctrl group, although the differences were not statistically significant. Given that the Ctrl group was comprised of higher performing students, the fact that the Trt group posted a higher mean score on the QT quiz items supports the use of SR systems for enhancing short-term retention of concepts, facts, and skills.

Hypotheses 4 and 5 focused on exam performance of students in the Trt and Ctrl groups. The exams were given three to four weeks after the time the exam topics were discussed in class. Also, the exams covered many more topics than did the quizzes and were therefore considered measures of long-term retention of concepts, facts, and
skills. In a similar fashion to what was done with the quizzes, the questions on the exams were classified as treatment questions (QT) if they were related to topics discussed in lab by the Trt and Ctrl groups, or control questions (QC) if they covered topics that were only discussed in lecture. Due to the inherent performance differences among students in the Trt and Ctrl groups, ANCOVA was again used to make group comparisons with the covariate being student performance on the first hour-long examination.

Hypothesis 4 examined the performance of students in the Trt and Ctrl groups on QC questions on the exams. Since the QC exam items covered topics that were only discussed in lecture, the two groups should be expected to have similar means. The results show that the Ctrl group did significantly better than the Trt group on the QC exam items. This result is not unexpected given the initial differences noted for the Trt and Ctrl groups.

Hypothesis 5 explored the performance differences between students in the Trt and Ctrl groups on QT questions on the exams. Since the QT exam items covered topics that were discussed in both lecture and lab, and the Trt group discussed these topics using the SR system, the Trt group should be expected to do as well as or better than the Ctrl group on these exam questions. The results show that the Trt group did just as well as the Ctrl group on the QT exam items. Comparing the QC and QT exam results for the Trt and Ctrl groups shows that the Trt group made significant gains over the Ctrl group on questions that were discussed in lab using the SR system. This indicates that the SR system produced measureable gains in the long-term retention of concepts, facts, and skills for students involved in this study.
Conclusion

In determining the optimum sequencing for having students respond to and discuss questions in SR mediated classes, it was found that having students discuss questions before they answered them resulted in significantly greater performance on the questions.

The results of the study of the effect of SR systems on student performance on delayed assessment measures such as quizzes and exams supports the use of SR systems in the classroom. In every comparison, initial performance differences between the Trt and Ctrl groups on QC questions were erased when the groups were tested with QT questions. Therefore, it is reasonable to state that the performance of students on both short-term and long-term assessment measures was enhanced through the use of an SR system.

Educational Implications

SR systems show considerable potential in general chemistry courses for helping students retain an understanding of the concepts they learned. Students seem to retain more information over a longer period of time from the active engagement that the SR system provides. The low cost and ease of use of SR systems make them a useful instructional tool.

Limitations of Study

Like all studies done in authentic educational settings, this study has limitations that narrow the scope of conclusions drawn from it. The study groups were not randomly assigned and the Ctrl group was found to contain a greater number of high performing
students. The study group sizes were not as large as one would like. The assessment measures (quizzes and exams) had to be written to satisfy the needs of chemistry sections beyond those studied here. This limited the number of $Q_C$ and $Q_T$ questions available for analysis.
LIST OF REFERENCES


16. [http://www.be.coventry.ac.uk/BPBNetwork/casestudy/uce_tla3i.htm](http://www.be.coventry.ac.uk/BPBNetwork/casestudy/uce_tla3i.htm)

19. Prostat (statistical software package) – used for descriptive statistics and t tests
20. VassarStats (online statistics resource) – used for ANCOVA analysis
   https://faculty.vassar.edu/lowry/VassarStats.html
21. Webstat (online statistics resource) – used for Tukey post hoc tests
Question 1:
The energy required to expand the area covered by a liquid is known as the liquid’s _____.

A) viscosity  
B) surface tension  
C) volatility  
D) meniscus

Question 2:
The resistance of a liquid to flow is known as the liquid’s _____.

A) viscosity  
B) surface tension  
C) vapor pressure  
D) meniscus
Question 3:
Which one of the following compounds has the highest surface tension?
A) H₂O
B) CH₃CH₂-O-CH₂CH₃
C) H₂C=O
D) CH₃CH₂CH₂CH₃

Question 4:
Which one of the following compounds has the highest vapor pressure?
A) H₂O
B) CH₃CH₂-O-CH₂CH₃
C) H₂C=O
D) CH₃CH₂CH₂CH₃
**Question 5:**

The following heating curve is for heating 50 g of water. Which portion of this heating curve requires the greatest amount of energy?

![Heating Curve Image]

**Question 6:**

What is the phase change occurring when the substance illustrated in the diagram below, originally at 5.0 atm pressure, is cooled from 50 ºC to 20 ºC at constant pressure?

A) sublimation  
B) deposition  
C) fusion  
D) condensation  

![Phase Change Diagram Image]
**Question 1:**

Which part of the phase diagram shown below corresponds to this nanoscale view of matter?

![Phase Diagram](image1)

**Question 2:**

Which part of the phase diagram shown below corresponds to this nanoscale view of matter?

![Phase Diagram](image2)
Question 3:
Aluminum metal crystallizes with a face-centered cubic unit cell structure. How many Al atoms are there in a unit cell of the crystal?
A) 1  
B) 2  
C) 4  
D) 14

Question 4:
Iron metal crystallizes with a body-centered cubic unit cell structure. How many Fe atoms are there in a unit cell of the crystal?
A) 1  
B) 2  
C) 4  
D) 9
Question 5:

Aluminum metal crystallizes with a face-centered cubic unit cell structure. Assume that the aluminum atoms can be represented as spheres as shown below. If each Al atom has a radius of 143 pm, what is the length of a side of the unit cell?

A) 286 pm
B) 330 pm
C) 404 pm
D) 809 pm
Question 1:
Which one of the following substances would be the most soluble in water?

A) CH₃CH₂CH₂CH₂Cl
B) CH₃CH₂CH₂CH₂OH
C) C₆H₆

Question 2:
Which one of the following substances would be the most soluble in water?

A) CBr₄
B) C₆H₅OH
C) CaBr₂
Question 3:

Which one of the following substances would be the most soluble in CCl₄?

A) CBr₄  
B) CH₃CH₂CH₂CH₂Cl  
C) CaCl₂  
D) CH₃CH₂CH₂CH₂OH

Question 4:

The diagram below shows a unit cell for the ionic crystal structure known as rutile. The green balls represent cations and the red balls represent anions. What is the general formula for ionic compounds that crystallize with the rutile structure?

A) XY  
B) X₂Y  
C) XY₂  
D) X₂Y₃
Question 1:
Which of the following are colligative properties of a solution?

A) mass
B) vapor pressure
C) viscosity
D) b and c
E) all of the above

Question 2:
As the concentration of a solute in a solution increases, the boiling point goes _____ and the freezing point goes _____?

A) up, up
B) down, down
C) up, down
D) down, up
**Question 3:**

What is the van’t Hoff factor (i) for Na₂SO₄ when it dissolves in water?

A) 1  
B) 2  
C) 3  
D) 4  
E) 7

**Question 4:**

Determine the boiling point of an aqueous solution prepared by dissolving 35.0 g of Ca(NO₃)₂ (FW = 164) in 250 g of water? The value of Kₙ for water is 0.512.

A) 1.31 °C  
B) 0.44 °C  
C) 100.44 °C  
D) 101.31 °C
**Question 5:**

Consider the following chemical reaction.

\[ A + 2B \rightarrow 2C + D \]

Which line corresponds to change in concentration of C with time?

A) I  
B) II  
C) III  
D) IV

---

**Question 6:**

Consider the following kinetic data for the first-order reaction:

\[ A \rightarrow B \]

What is the average rate of formation of product B between 0 and 9 seconds?

A) 0.088 Ms\(^{-1}\)  
B) 0.18 Ms\(^{-1}\)  
C) 0.048 Ms\(^{-1}\)  
D) 0.14 Ms\(^{-1}\)
Question 7:

Consider the following kinetic data for the first-order reaction:

\[ \text{A} \rightarrow \text{B} \]

What is the half-life for this reaction?

A) 3 s  
B) 6 s  
C) 9 s  
D) 12 s

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>[A] (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.22</td>
</tr>
<tr>
<td>3</td>
<td>0.86</td>
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<td>9</td>
<td>0.43</td>
</tr>
<tr>
<td>12</td>
<td>0.31</td>
</tr>
<tr>
<td>15</td>
<td>0.22</td>
</tr>
<tr>
<td>18</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Question 1:

Using the reaction mechanism shown below, predict the rate law for this reaction?

\[ 2 \text{A} \rightarrow \text{B} + \text{C} \text{ (fast)} \]
\[ 2 \text{D} + \text{A} \rightarrow \text{E} + \text{F} \text{ (slow)} \]
\[ \text{B} + \text{F} \rightarrow \text{H} \text{ (fast)} \]

A) \( \text{Rate} = k[\text{A}]^2 \)
B) \( \text{Rate} = k[\text{B}][\text{C}] \)
C) \( \text{Rate} = k[\text{A}][\text{D}]^2 \)
D) \( \text{Rate} = [\text{B}][\text{F}] \)

Question 2:

Which one of the following statements about a chemical reaction at equilibrium is true?

A) The concentration of reactants and products are equal.
B) The rates of the forward and reverse reactions are equal.
C) No more reactants are converted to products.
D) The concentrations of reactants and products change with time.
Question 3:
Use the following diagram to indicate when the following reaction is at equilibrium.

A) i  
B) ii  
C) iii  
D) iv

Question 4:
What is the value of the equilibrium constant for this reaction?

A) 0.50  
B) 0.90  
C) 1.0  
D) 9.0
**Question 1:**

Consider the following reaction at equilibrium. Is this a homogeneous or heterogeneous equilibrium?

\[
N_2(g) + O_2(g) \rightleftharpoons 2 \text{NO}(g)
\]

A) Homogeneous  
B) Heterogeneous

---

**Question 2:**

What is the equilibrium expression for this reaction?

\[
N_2(g) + O_2(g) \rightleftharpoons 2 \text{NO}(g)
\]

A) \[
\frac{[\text{NO}]}{[N_2][O_2]} \]

B) \[
\frac{[\text{NO}]^2}{[N_2][O_2]} \]

C) \[
\frac{[N_2][O_2]}{[\text{NO}]} \]

D) \[
\frac{[N_2][O_2]}{[\text{NO}]^2} \]
**Question 3:**

Consider the following reaction at equilibrium. Is this a homogeneous or heterogeneous equilibrium?

\[ 4 \text{HCl}(g) + \text{O}_2(g) \rightleftharpoons 2 \text{H}_2\text{O}(l) + 2 \text{Cl}_2(g) \]

A) Homogeneous  
B) Heterogeneous

**Question 4:**

What is the equilibrium expression for this reaction?

\[ 4 \text{HCl}(g) + \text{O}_2(g) \rightleftharpoons 2 \text{H}_2\text{O}(l) + 2 \text{Cl}_2(g) \]

A) \( \frac{[\text{HCl}]^4[\text{O}_2]}{[\text{H}_2\text{O}]^2[\text{Cl}_2]^2} \)  
B) \( \frac{[\text{H}_2\text{O}]^2[\text{Cl}_2]^2}{[\text{HCl}]^4[\text{O}_2]} \)

C) \( \frac{[\text{Cl}_2]^2}{[\text{HCl}]^4[\text{O}_2]} \)  
D) \( \frac{[\text{HCl}]^4[\text{O}_2]}{[\text{Cl}_2]^2} \)
Question 5:

Consider the following reaction at equilibrium. If 0.150 mol each of N₂ and O₂ are placed in a 1.00 liter flask, what is the concentration of N₂ at equilibrium?

\[ \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{NO}(g) \quad K = 2.30 \times 10^3 \]

A) 0.000 M
B) 0.006 M
C) 0.144 M
D) 0.288 M
**Question 1:**

A mixture of 0.6816 mol of $\text{H}_2$, 0.4400 mol of $\text{Br}_2$, and 2.268 mol of $\text{HBr}$ is in a 2.00 L flask at 700 K. They react according to the following equation

$$\text{H}_2(g) + \text{Br}_2(g) \rightleftharpoons 2 \text{HBr}(g)$$

The equilibrium constant for this reaction is 58.4 at 700 K. Is the reaction at equilibrium? If it is not at equilibrium, which way will it shift to attain equilibrium?

A) The reaction is at equilibrium

B) The reaction is not at equilibrium and it will shift left to attain equilibrium.

C) The reaction is not at equilibrium and it will shift right to attain equilibrium.

---

**Question 2:**

Consider the following reaction at equilibrium.

$$\text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \quad \Delta H = 176 \text{ kJ} \quad K = 1.1 \times 10^{-4}$$

Adding $\text{NH}_3(g)$ to the reaction will

A) produce no change in the reaction.

B) cause the equilibrium to shift left.

C) cause the equilibrium to shift right.

D) decrease the value of $K$. 
Question 3:
Consider the following reaction at equilibrium.

\[ \text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \quad \Delta H = 176 \text{ kJ} \]

\[ K = 1.1 \times 10^{-4} \]

Removing HCl\(_{(g)}\) from the reaction will

A) produce no change in the reaction.
B) cause the equilibrium to shift left.
C) increase the concentration of \(\text{NH}_3(g)\).
D) decrease the value of \(K\).

Question 4:
Consider the following reaction at equilibrium.

\[ \text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \quad \Delta H = 176 \text{ kJ} \]

\[ K = 1.1 \times 10^{-4} \]

Adding NH\(_4\)Cl\(_{(s)}\) to the reaction will

A) produce no change in the reaction.
B) cause the equilibrium to shift right.
C) increase the concentration of \(\text{NH}_3(g)\).
D) decrease the value of \(K\).
**Question 5:**
Consider the following reaction at equilibrium.

\[
\text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \quad \Delta H = 176 \text{ kJ} \\
K = 1.1 \times 10^{-4}
\]

Decreasing the temperature of the reaction will

A) use up some of the \(\text{NH}_4\text{Cl}(s)\).
B) cause the equilibrium to shift right.
C) increase the concentration of \(\text{NH}_3(g)\).
D) decrease the value of \(K\).

**Question 6:**
Which acid is the strongest?

<table>
<thead>
<tr>
<th>Acid</th>
<th>(K_a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{CH}_3\text{CO}_2\text{H})</td>
<td>(1.8 \times 10^{-5})</td>
</tr>
<tr>
<td>HF</td>
<td>(7.2 \times 10^{-4})</td>
</tr>
<tr>
<td>HCN</td>
<td>(4.0 \times 10^{-10})</td>
</tr>
<tr>
<td>(\text{H}_2\text{CO}_3)</td>
<td>(4.2 \times 10^{-7})</td>
</tr>
<tr>
<td>HNO(_2)</td>
<td>(4.5 \times 10^{-4})</td>
</tr>
</tbody>
</table>

A) nitrous acid
B) hydrocyanic acid
C) acetic acid
D) carbonic acid
Question 7:

Determine the pH of a 0.18 M solution of HCN.

<table>
<thead>
<tr>
<th>Acid</th>
<th>$K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$CO$_2$H</td>
<td>$1.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>HF</td>
<td>$7.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>HCN</td>
<td>$4.0 \times 10^{-10}$</td>
</tr>
<tr>
<td>H$_2$CO$_3$</td>
<td>$4.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>HNO$_2$</td>
<td>$4.5 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

A) 4.70  
B) 5.07  
C) 8.93  
D) 10.14
**Question 1:**
Which is the stronger acid?

A) HNO₃  
B) HNO₂

---

**Question 2:**
Which is the stronger acid?

A) H₂S  
B) HCl
Question 3:
Which is the stronger acid?

A) CCl₃COOH
B) CH₃COOH

Question 4:
What is the pH of a 0.10 M solution of sodium acetate (NaCH₃COO)? The $K_a$ of acetic acid is $1.8 \times 10^{-5}$.

A) 5.13
B) 6.17
C) 8.87
D) 12.25
Question 5:

Predict the acid-base properties of aqueous solutions of the following

\[ \text{NH}_4\text{Br} \quad \text{Na}_2\text{CO}_3 \quad \text{KClO}_4 \quad \text{CuCl}_2 \]

A) acidic, basic, acidic, basic
B) basic, basic, acidic, acidic
C) acidic, basic, neutral, acidic
D) neutral, basic, neutral, acidic
Question 1:
Which one of the following 0.10 M aqueous solutions would be the most acidic?

A) NaNO₃
B) Cu(NO₃)₂
C) CaF₂
D) Mg(OH)₂

Question 2:
Which one of the following 0.10 M aqueous solutions would be the most basic?

A) KNO₂
B) NH₄Cl
C) HNO₃
D) BaBr₂
**Question 3:**

Which one of the following pairs of substances could be used to make a buffer solution?

A) HCl, KCl  
B) HNO₂, NaNO₂  
C) HNO₃, KNO₃  
D) H₂SO₃, H₂SO₄

**Question 4:**

What is the pH of 1.0 L of solution that is 0.10 M acetic acid (HOAc) and 0.13 M sodium acetate (NaCH₃COO)? The $K_a$ of acetic acid is $1.8 \times 10^{-5}$.

A) 2.87  
B) 9.14  
C) 4.85  
D) 4.63
Question 5:
Adding a small amount of a strong acid to a buffer solution made from hydrofluoric acid (HF) and sodium fluoride (NaF) will _____ the pH slightly by reacting with _____ in the solution.

A) lower, F-
B) lower, HF
C) raise, Na+
D) raise, HF
1. The energy required to expand the surface area of a liquid by a unit amount of area is known as the liquid’s
   a. viscosity          b. surface tension          c. volatility
   d. meniscus

2. Which of the following liquids has the highest surface tension?
   a. H₂O                 b. CH₃CH₂-O-CH₂CH₃       c. H₂C=O
   Why?

3. The heat of fusion of water is 6.01 kJ/mol. The heat capacity of liquid water is 75.2 J/mol·K. How much heat is required to convert 50.0 g of ice at 0 °C to liquid water at 22 °C.
4. Use the phase diagram shown below to describe all of the phase changes that would occur in each of the following cases for this substance. (a) The substance, originally at 0.1 atm and –10 °C, is slowly compressed at constant temperature until the final pressure is 5 atm. (b) The substance, originally at 50 °C and 5 atm, is cooled at constant pressure until the temperature is –10 °C.
1) Aluminum metal crystallizes with a face-centered cubic unit cell. (a) How many Al atoms are there in a unit cell of the crystal? (b) Assume that the aluminum atoms can be represented as spheres as shown below. If each Al atom has a radius of 143 pm, what is the length of a side of the unit cell?

![Face-centered cubic unit cell diagram]

2. For each of the following pairs of substances predict which would have the higher melting point and why

Ar, Xe support ________________
SiO₂, CO₂ support ________________
KBr, Br₂ support ________________
CCl₄, C₆H₆ support ________________  
CHM-102 Lab Questions  (From Chapter 13 and 14 of the Textbook)

Name _________________________________________________   Section _____________

1) Calculate the freezing point of a solution prepared by dissolving 15g Na₃PO₄ in 135 ml of water. Kf −1.86 °C·kg/mol; density of water =1g/ml.

Consider the following kinetic data for a first order reaction, A → B:

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>[A] (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.22</td>
</tr>
<tr>
<td>3</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>0.61</td>
</tr>
<tr>
<td>9</td>
<td>0.43</td>
</tr>
<tr>
<td>12</td>
<td>0.31</td>
</tr>
<tr>
<td>15</td>
<td>0.22</td>
</tr>
<tr>
<td>18</td>
<td>0.15</td>
</tr>
</tbody>
</table>

2. What is the half-life (in seconds) for the reaction?
3. What is the average rate of formation of product B between 0 and 9 seconds

4. A first order reaction has a rate constant of 0.075 s\(^{-1}\). What is the concentration of the reactant after 15 seconds if the initial concentration is 0.056 M?
1. A catalyst changes

i) the forward activation energy $E_a(f)$.  

ii) the reverse activation energy $E_a(r)$.  

iii) the enthalpy change $\Delta H$.  

iv) the free energy change $\Delta G$.  

a. i & ii  

b. iii & iv  

c. i & iv  

d. ii & iii  

2. Given the energy diagram pictured below what is the activation energy in the forward direction of the reaction $A + B \rightarrow C + D$
3. What is the overall energy change of the reaction in the forward direction for the energy diagram pictured above?

CHM-102 Lab Questions (From Chapter 15 of the Textbook)

Name ______________________________________________ Section ______

1. Which one of the following statements about a chemical reaction at equilibrium is correct?
   a) The concentrations of reactants and products are equal.
   b) The rates of the forward and reverse reactions are equal.
   c) No more reactants are converted to products.
   d) The concentrations of reactants and products change with time.

Use the following graph of the first-order reaction of A reacting to produce B to answer question 2 and 3.

2. Circle the portion of the graph that represents the reaction at equilibrium.

3. What is the value of the equilibrium constant (K) for this reaction?
4. Write the equilibrium expressions for the following reactions. In each case indicate whether the reaction is homogeneous or heterogeneous.

a) \( \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{NO}(\text{g}) \)    homogeneous or heterogeneous (Circle answer)

b) \( \text{Ti}(\text{s}) + 2 \text{Cl}_2(\text{g}) \rightleftharpoons \text{TiCl}_4(\text{l}) \)    homogeneous or heterogeneous (Circle answer)

c) \( 4 \text{HCl}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{H}_2\text{O}(\text{l}) + 2 \text{Cl}_2(\text{g}) \)    homogeneous or heterogeneous (Circle answer)
1. A mixture of 0.6816 mol of H₂, 0.4400 mol of Br₂, and 2.268 mol of HBr is in a 2.00 L flask at 700 K. They react according to the following equation:

\[ \text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2 \text{HBr}(\text{g}) \]

The equilibrium constant for this reaction is 58.4 at 700 K. Is the reaction at equilibrium? If it is not at equilibrium, which way will it shift to attain equilibrium?

2. Consider the following reaction

\[ \text{NH}_4\text{Cl(s)} \rightleftharpoons \text{NH}_3(\text{g}) + \text{HCl(g)} \quad \Delta H = 176 \text{ kJ}. \quad K = 1.1 \times 10^{-4} \text{ at } 1200 \text{ K}. \]

If the above system is at equilibrium, adding some NH₃(g) will:

a) shift the reaction to right  
b) shift the reaction to the left  
c) decrease the equilibrium constant  
d) increase the equilibrium constant  
e) decrease the amount of HCl  
f) increase the amount of NH₄Cl  
g) have no effect
3. The $K_a$ for hypochlorous acid ($\text{HClO}$) is $3.0 \times 10^{-8}$ and the $K_a$ for chlorous acid ($\text{HClO}_2$) is $1.1 \times 10^{-2}$.

   a) Which is the stronger acid, $\text{HClO}$ or $\text{HClO}_2$?

   b) Which is the stronger base, $\text{ClO}^-$ or $\text{ClO}_2^-$?

4. Calculate the pH of a 0.125 M hypochlorous acid solution.
1. Circle the member of each pair which is the stronger acid. Explain your answers based on the structure of the acid.

   a. HNO₃ or HNO₂
   b. HCl or H₂S
   c. CCl₃COOH or CH₃COOH

2. What is the pH of a 0.10 M aqueous solution of sodium acetate (NaC₂H₃O₂) if Kₐ=1.8 x 10⁻⁵ for acetic acid?
3. Predict whether aqueous solutions of the following salts will be acidic, basic, or neutral. If the solution would be acidic or basic, circle the ion that causes the pH to change.

   (a) NH₄Br  
(c) KClO₄
(b) Na₂CO₃

CHM-102 Supplemental Questions (From Chapters 16 and 17 of the Textbook)

Name ___________________________________________   Section ___________

1. Circle the member of each pair which produces the more acidic aqueous solution. Explain your answers.

   (a) K⁺ or Cu²⁺  
(c) Al³⁺ or Ga³⁺  
(b) Fe²⁺ or Fe³⁺

2. Which of the following pairs could be used to make a buffer solution? Explain.

(a) HCl, KCl  
(d) NH₃, NH₄Cl
(b) HNO₂, NaNO₂  
e) HF, NaOH
(c) HNO₃, KNO₃

3. Consider 1.0 L of a buffer solution that is 0.10 M acetic acid (HOAc) and 0.13 M sodium acetate (NaOAc). $K_a = 1.8 \times 10^{-5}$ for acetic acid.

(a) What is the pH of this buffer?
(b) What is the pH of the buffer after the addition of 0.010 mol of HCl?

1. The diagram below shows one face of a simple cubic unit cell. If the length of the edge of the unit cell is 175 pm, what is the diameter of the hole that exists in the middle of the face of the unit cell?

   a. 36.2 pm   b. 72.5 pm   c. 87.5 pm   d. 128 pm

2. Zincblende is the name given to the crystal structure that consists of a face-centered-cubic array of anions with four cations occupying tetrahedral holes inside each unit cell. What is the ratio of anions to cations in zincblende?

   a. 14:4   b. 7:2   c. 2:1   d. 1:1

3. Nitrogen gas has a solubility of 0.0014 mol/L in water at 25 ºC and 2.0 atm pressure. What is the Henry’s Law constant for nitrogen gas dissolved in water?
4. A solid substance is found to be very hard, have a high melting point, and does not conduct electricity as either a solid or liquid. This substance is most likely a _____ solid.

a. ionic  
b. metallic  
c. molecular  
d. network
5. The following phase diagram is for water. Draw a “dot” on the phase diagram that corresponds to water freezing at 0.50 atm.

![Phase Diagram](image)

**Equations and Constants:**

For sc: $2r = a$  
For fcc: $4r = a\sqrt{2}$  
For bcc: $4r = a\sqrt{3}$

$C_g = kP_g$
1. What is the value of $\Delta H$ for the uncatalyzed reaction in the diagram shown above?
   a) 100 kJ   b) 175 kJ   c) -50 kJ   d) 50 kJ

2. A certain chemical reaction is known to have a reaction mechanism that consists of a single elementary step. The rate law for this reaction is $R = k[A][B]^2$. Which of the following mechanisms fits this rate law?
   a) $2A + B \rightarrow A_2B$
   b) $A_2 + B_2 \rightarrow 2AB$
   c) $A + B_2 \rightarrow AB_2$
   d) $A + 2B \rightarrow AB_2$

The following information is used to answer questions 3 and 4.

$$\text{CH}_3\text{COCl}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CH}_3\text{CO}_2\text{H}(aq) + \text{HCl}(aq) \quad K = 6.2 \times 10^{10}$$

$\Delta H = -127 \text{ kJ}$

3. The equilibrium expression for this reaction is
   a) $\frac{[\text{CH}_3\text{COCl}]}{[\text{CH}_3\text{CO}_2\text{H}][\text{HCl}]}$   b) $\frac{[\text{CH}_3\text{CO}_2\text{H}][\text{HCl}]}{[\text{CH}_3\text{COCl}]}$
4. When this reaction is at equilibrium,

a) the rate of the forward reaction is much higher than the rate of the reverse reaction due to the large value of the equilibrium constant.

b) there is a much higher concentration of reactants than products.

c) Raising the temperature will shift the equilibrium to the right.

d) none of these choices is correct.

5. The reaction of $H_2(g)$ and $I_2(g)$ to produce $HI(g)$ has an equilibrium constant of 54 at room temperature. What is the equilibrium concentration of $HI$ for this reaction if you started with 0.045 moles of both $H_2(g)$ and $I_2(g)$ in a 1.00 L flask? (Assume no $HI(g)$ is present at the start of the reaction.)

a) 0.043  
   b) 0.071  
   c) 0.035  
   d) 0.086
The titration curve shown below was obtained by titrating 30.00 mL of an unknown substance with 0.155 M NaOH. Use the information provided below to answer questions 1 – 3.

1. The unknown substance being titrated is a
   (a) strong base  (b) strong acid  (c) weak base  (d) weak acid

2. Determine the molarity of the unknown substance.
   (a) 0.103 M  (b) 0.129 M  (c) 0.186 M  (d) 0.207 M

3. Determine the approximate equilibrium constant (K_a) for the unknown acid and use this to determine the identity of the unknown acid from the table above.

   Write the formula for your answer here: __________________
4. What is the oxidation number of S in Na$_2$S$_2$O$_3$ (sodium thiosulfate)?
   (a) 2  (b) 3  (c) 6  (d) 7

5. Fe$^{2+}$ reacts with ClO$_2$ in acidic solution to produce Fe$^{3+}$, Cl$^-$, and H$_2$O. What is the
   coefficient on H$^+$ when the equation for this reaction is correctly balanced?
   (a) 2  (b) 3  (c) 4  (d) 5
CHM-102

Exam I

Spring 2008

Form A

NAME __________________________

Raw Score _____

T-Score

- You will have 70 minutes to complete the exam.
- There is one best answer to each question and all questions are worth the same number of points.
- Sign your name on the answer sheet above the General Purpose logo on the front.
- Write the form of the test you are taking next to your name.
- Print and fill in your name (last name-space-first name) on the back of your answer sheet.
- Be sure to mark the correct answers on your exam booklet so you can compare your answers to the answer key.
- An answer key will be posted immediately following the test at the course website as well as outside DO-236.

Use the following structural formulas to answer questions 1 and 2.

1. Which of the above molecules are polar?
a. i and iii only  

b. ii and iv only  
c. ii and iii only  
d. i, ii, and iii

2. Which of the above molecules are nonpolar, but contains polar bonds?

   a. ii and iv only  
   b. ii only  
   c. i only  
   d. i and iii only

3. What is the hybridization of the carbon atom in the molecule shown below?

   a. sp³d  
   b. sp³  
   c. sp²  
   d. sp

4. What two types of orbitals are overlapping to form the C-C bond denoted by the arrow?

   a. sp, sp²  
   b. s, p  
   c. sp³, sp²  
   d. s, sp³

5. How many sigma and pi bonds are there in the molecule shown below?

   a. 5 σ, 5π  
   b. 7 σ, 3π  
   c. 10 σ, 3π  
   d. 7 σ, 2π

6. Which of the following statements describes the properties of a gas?
a. Gases are highly compressible.
b. There are relatively large distances between gas molecules.
c. Gases form homogenous mixtures.
d. All of these statements are true.

7. How many moles of gas are contained in a 325 mL vessel at 0.914 atm and 19 °C?
   a. 1.24 × 10⁻² mol  
   b. 0.190 mol  
   c. 5.26 mol  
   d. 80.6 mol

8. If a gas occupies 56.2 L at 44 °C and 3.21 atm, what volume does the same amount of gas occupy at 5.29 atm of pressure at the same temperature?
   a. 0.011 L  
   b. 92.6 L  
   c. 0.029 L  
   d. 34.1 L

9. What is the identity of a gas with a density of 0.900 g/L at STP?
   a. CH₄  
   b. Ne  
   c. CO  
   d. NO

10. The thermal decomposition of potassium chlorate can be used to produce oxygen in the laboratory.
    \[ 2 \text{KClO}_3(s) \rightarrow 2 \text{KCl}(s) + 3 \text{O}_2(g) \]
    What volume of oxygen gas at 25 °C and 1.00 atm pressure is produced by the decomposition of 7.5 g of KClO₃ (FW = 122.55 g/mol)?
    a. 4.5 L  
    b. 7.5 L  
    c. 2.2 L  
    d. 3.7 L

11. What is the total pressure (in mmHg) in a 12.2 L vessel that contains 2.34 g of carbon dioxide, 1.73 g of sulfur dioxide and 3.33 g of argon all at 42 °C?
    a. 263 mmHg  
    b. 0.346 mmHg  
    c. 395 mmHg  
    d. 116 mmHg
12. A gas is considered ideal when
   a. it is not compressible.
   b. it has zero volume at 0 °C.
   c. one mole in a 1 L container has a pressure of 1 atm at STP.
   d. its behavior is described exactly by PV = nRT.

13. A flask containing an equimolar mixture of three odorous substances, in gaseous form, is placed several feet away from a person who is able to smell all three gases with equal sensitivity. The gases are chlorine (Cl₂), butyric acid (C₄H₈O₂), and hydrogen sulfide (H₂S). When the flask is opened, what is the order in which this person is most likely to detect the three substances (arranged first to last)?
   a. Cl₂, H₂S, C₄H₈O₂
   b. Cl₂, C₄H₈O₂, H₂S
   c. H₂S, Cl₂, C₄H₈O₂
   d. H₂S, C₄H₈O₂, Cl₂

14. The Van der Waals equation is similar to the Ideal Gas equation but it contains a correction to the pressure term and well as the volume term in order to compensate for the differences between real and ideal gases.

\[(P + x)(V - y) = nRT\]

The pressure correction (x), is the result of the fact that the atoms or molecules of real gases
   a. take up some of the space in the container.
   b. move more rapidly than those of ideal gases.
   c. have a higher average kinetic energy than those of ideal gases.
   d. have intermolecular attractive forces.

15. Shown below is the heating curve for a substance. What is the physical state of this substance at room temperature?
There is insufficient information to answer this question.

a. solid  b. liquid  c. gas

Use the following structural formulas to answer questions 16 and 17.

16. Which of these substances has London dispersion forces and hydrogen bonds as intermolecular attractive forces?
   a. i, ii, iii, iv  b. iii and iv only  c. iii only  d. iv only

17. Three of these substances are gases at room temperature and the fourth is a liquid. Which one is the liquid?
   a. i  b. ii  c. iii  d. iv

18. Motor oil is composed primarily of hydrocarbons, which are compounds that contain only carbon and hydrogen. In cold climates, some car manufacturers recommend the
(i) Longer chains get more entangled
(ii) London dispersion forces are stronger between the longer chains
(iii) The longer chains can interact via hydrogen bonds

a. i and ii  b. i and iii  
c. ii and iii  d. all are correct

19. What amount of heat is given off when 10 g of water, initially at 10 °C, are converted to ice at 0 °C? [The specific heat of water is 4.18 J/g·K and ΔH_{fus} = 6.01 kJ/mol]

a. 421 J  b. 1.2 x 10^3 J  c. 6.3 x 10^2 J  d. 3.8 x 10^3 J

20. Which one of the following liquid substances has the highest vapor pressure at room temperature?

a. H_2O  b. CHCl_3  c. CH_2Cl_2  d. CH_3OH

The phase diagram shown below is used to answer questions 21 and 22.

![Phase Diagram](image)

21. The point marked “x” in the phase diagram is the
22. Describe the phase change that would occur if the pressure on the substance is increased from 1 to 3 atm at room temperature?

a. deposition  
b. condensation  
c. sublimation  
d. evaporation

Important Formulas and Constants

\[ PV = nRT \]
\[ \frac{PV_1}{n_1T_1} = \frac{PV_2}{n_2T_2} \]
\[ PV = \frac{mRT}{M} \]
\[ P_T = P_1 + P_2 + P_3 + \ldots \]

\[ X_a = \frac{n_a}{n_T} \]
\[ P_a = X_aP_T \]
\[ \frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \]

\[ q = m \cdot c \cdot \Delta t \]
\[ q = n \cdot \Delta H \]

\[ R = 0.0821 \text{ L} \cdot \text{atm} \cdot \text{K}^{-1} \cdot \text{mol}^{-1} \]
\[ N_A = 6.02 \times 10^{23} \]

\[ K = ^\circ C + 273 \]

1 atm = 760 mmHg = 760 torr = 101.3 kPa
1. Which one of the following solid substances is most likely to form a crystal lattice with body-centered-cubic unit cells?
   a. rubber       b. wood       c. glass       d. Fe

2. Some ionic compounds crystallize in what is called the fluorite structure. In this structure, the cations (X) form a face-centered-cubic (fcc) array and the anions (Y) occupy the eight tetrahedral holes inside the fcc array. What is the general formula for an ionic compound that crystallizes using the fluorite structure?
   a. XY       b. X₂Y       c. XY₂       d. X₇Y₄

3. Which cation from the table will fit in the holes along the edges of a face-centered-cubic array of bromide ions? The radius of a bromide ion is 195 pm.
   a. Zn²⁺ only   b. Ti²⁺ and Zn²⁺
   c. Ti²⁺ and Ag⁺   d. K⁺ only

4. In 1783, the Elhuyar brothers isolated a new substance from a Portuguese ore that they called wolfram. Wolfram was found to be hard, high melting, and conducted electricity as a solid. The forces holding wolfram together are most likely to be
   a. ionic bonds   b. London forces
   c. metallic bonds   d. covalent bonds

- You will have 70 minutes to complete the exam.
- There is one best answer to each question and all questions have the same weight.
- Sign your name on the answer sheet above the General Purpose logo on the front.
- Print and fill in your name (last-space-first) on the back of your answer sheet.
- Be sure to mark the correct answers on your exam booklet so you can compare your answers to the answer key.
5. The dissolution of gases in water is almost always exothermic because ________
   a. the endothermic step of separating solute particles is unnecessary.
   b. the partial pressure of a gas above a liquid decreases as the gas dissolves.
   c. the entropy change is zero for this process.
   d. the solvation of gas molecules is an endothermic process.

6. Which of the following will have hydrogen bonding as one of its solute-solvent interactions when mixed with HF?

   ![Chemical structures]

   i. ii. iii.

   a. ii and iii   b. ii  
   c. i and iii   d. i, ii, iii

7. The solubility of oxygen gas in water at 25 ºC is 1.2 x 10^{-3} mol/L. This value will increase if
   a. the temperature is raised  b. the volume of solution is increased
   c. the partial pressure of O₂ is increased  d. all of the above

8. Which compound would be the most soluble in C₈H₁₈?
   a. CCl₄  b. CH₃OH  c. KCl  d. MgSO₄

9. A solution is prepared by dissolving 15.0 g of NH₃ in 250 g of water. What is the molarity of the NH₃ assuming the density of the resulting solution is 0.974 g/mL.
   a. 0.00324  b. 0.882  c. 3.53  d. 3.24
10. Calculate the molality of a solution prepared by dissolving 16 g of urea (MW = 60.0 g/mol) in 39 g of water. Assume the density of the resulting solution is 1.2 g/mL.

   a. 96  
   b. 6.8  
   c. 5.8  
   d. 0.41

11. A solution contains 1.0 mL of HCl and 1.0 L of water. How does this solution compare to pure water?

   i. The freezing point of the solution is greater than that of pure water
   ii. The boiling point of the solution is greater than that of pure water
   iii. The vapor pressure of the solution is less than that of pure water
   iv. The osmotic pressure of the solution is the same as that of pure water

   a. i  
   b. i and ii  
   c. ii and iii  
   d. iv

12. Which solution has the lowest freezing point?

   a. 0.8 m glucose (C₆H₁₂O₆)  
   b. 0.4 m KCl  
   c. 0.3 m FeCl₃  
   d. 0.4 m NaHCO₃

13. What is the freezing point of a solution containing 100 g of methanol (CH₃OH) dissolved in 1.00 L of ethanol? The density of ethanol is 0.78 g/mL, the freezing point of pure ethanol is -114.6 ºC, and the value of K_f for ethanol is 1.99 ºC/m.

   a. -122.6 ºC  
   b. -106.6 ºC  
   c. -115.4 ºC  
   d. -113.8 ºC

14. A solution at 20 ºC contains 250 g of ammonium nitrate in 1.0 L of water. The solubility of ammonium nitrate is 190 g in 100 mL of water at 20 ºC. This solution is

   a. saturated  
   b. unsaturated  
   c. supersaturated  
   d. There is not enough information to answer the question

15. The reaction shown below has the rate equation Rate = k [A]¹. Which of the following will increase the rate of the reaction?
A + B → C

a. increasing the concentration of B
b. reducing the concentration of C
c. increasing the concentration of B and decreasing the concentration of C
d. none of these will affect the rate of the reaction

16. The following data were collected for the decomposition of hydrogen iodide, HI.
What is the average rate of the reaction between 0 and 100 seconds?

- Time (s): 0, 100, 200, 300, 400, 500
- [HI] (M): 0.6, 0.5, 0.4, 0.3, 0.2, 0.1

a. 2 x 10⁻³ M/s  b. 0.4 M/s  c. 50 M/s  d. 0.01 M/s

17. The iodate anion (IO₃⁻) reacts with sulfite anions (SO₃⁻) to form iodide (I⁻) and an unknown compound X according to the reaction equation below. The IO₃⁻ ions disappear at a rate of 8.0 x 10⁻⁵ Ms⁻¹. The unknown compound X appears at a rate of 2.4 x 10⁻⁴ Ms⁻¹. What is the coefficient of X in the balanced reaction equation below?

\[ \text{IO}_3^- (aq) + 3 \text{SO}_3^- (aq) \rightarrow \Gamma^- (aq) + ? \text{X} (aq) \]

a. 1  b. 2  c. 3  d. 4

18. A reaction rate that does not change by changing the concentration of a reactant is

a. impossible  b. of 0th order with respect to that reactant  c. of 1st order with respect to that reactant  d. of 2nd order with respect to that reactant

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19. The following concentrations were measured for the reaction of nitric oxide with molecular hydrogen:

\[ \text{NO}(g) + \text{H}_2(g) \rightarrow \frac{1}{2} \text{N}_2(g) + \text{H}_2\text{O}(g) \]

<table>
<thead>
<tr>
<th>Initial concentration of NO (M)</th>
<th>Initial concentration of H₂ (M)</th>
<th>Rate of formation of N₂ (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.10</td>
<td>6.2 x 10⁻⁴</td>
</tr>
<tr>
<td>0.45</td>
<td>0.10</td>
<td>5.6 x 10⁻³</td>
</tr>
<tr>
<td>0.15</td>
<td>0.20</td>
<td>1.2 x 10⁻³</td>
</tr>
</tbody>
</table>

What is the reaction order with respect to NO and the overall reaction order?

a. 2 and 2  
b. 1 and 1  
c. 2 and 1  
d. 2 and 3

20. Use the chart below to determine the half-time \((t_{1/2})\) of the disappearance of reactant A?

![Graph showing the decay of reactant A over time](chart.png)

a. 2.5 s  
b. 25 s  
c. 5 s  
d. 10 s

21. The first-order rate constant for the decomposition of N₂O₅ is 6.2 x 10⁻⁴ s⁻¹. If you start out with 2.3 moles of N₂O₅, how much N₂O₅ will you have left after 30 minutes?

a. 0.75 moles  
b. 2.5 moles  
c. 0.28 moles  
d. 0.019 moles
22. Under acidic conditions sucrose is hydrolyzed according to the reaction equation below. The first-order rate constant for this reaction is $6.2 \times 10^{-5}$ s$^{-1}$. Your advisor asked you to conduct the reaction using a 0.35 M solution of sucrose and to stop the reaction when the sucrose concentration is exactly 0.10 M. How much time do you have to wait?

\[ C_{12}H_{22}O_{11}(aq) + H_2O(l) \rightarrow C_6H_{12}O_6(aq) + C_6H_{12}O_6(aq) \]

\begin{align*}
&\text{sucrose} & & \text{glucose} & & \text{fructose} \\
& C_{12}H_{22}O_{11} & & H_2O & & C_6H_{12}O_6 + C_6H_{12}O_6 \\
\end{align*}

a. 16.4 hr  
b. 5.6 hr  
c. 14 min  
d. 43 min
Important Formulas and Constants

\[ PV = nRT \quad \frac{PV_1}{n_1T_1} = \frac{PV_2}{n_2T_2} \quad PV = \frac{mRT}{M} \quad P_T = P_1 + P_2 + P_3 + \ldots \]

\[ X_a = \frac{n_a}{n_T} \quad P_a = X_a P_T \quad \frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \quad q = \Delta H_{vap} m \quad q = cm \Delta t \]

\[ R = 0.0821 \text{ L·atm·K}^{-1}·\text{mol}^{-1} \]
\[ K = ^\circ \text{C} + 273 \]
\[ 1 \text{ atm} = 760 \text{ mmHg} = 760 \text{ torr} = 101.3 \text{ kPa} \]

For sc: \( 2r = a \) \quad For fcc: \( 4r = a\sqrt{2} \) \quad For bcc: \( 4r = a\sqrt{3} \)

\[ M = \frac{\text{moles}_{\text{solute}}}{L_{\text{solution}}} \quad m = \frac{\text{moles}_{\text{solute}}}{\text{kg}_{\text{solvent}}} \quad \text{ppm} = \frac{\text{mg}_{\text{solute}}}{\text{kg}_{\text{solution}}} \]

\[ \text{ppb} = \frac{\mu g_{\text{solute}}}{\text{kg}_{\text{solution}}} \]

\[ C_g = kP_g \quad P_A = \chi_A P_A^0 \quad \Delta T_b = i K_b m \quad \Delta T_f = -i K_f m \]

\[ \text{Rate} = \frac{-\Delta[A]}{\Delta t} \quad \text{Rate} = k[A]^m[B]^n \quad \text{ln}[A] = -kt + \text{ln}[A]_0 \]

\[ t_{1/2} = \frac{0.693}{k} \]
You will have 70 minutes to complete the exam.

There is one best answer to each question and all questions have the same weight.

Sign your name on the answer sheet above the General Purpose logo on the front.

Print and fill in your name (last-space-first) on the back of your answer sheet.

Be sure to mark the correct answers on your exam booklet so you can compare your answers to the answer key.

1. Dinitrogen pentoxide decomposes according to the reaction equation below. The rate law for the reaction is \( \text{Rate} = k [\text{N}_2\text{O}_5] \). What happens as the temperature of the reaction is lowered?

\[
\text{N}_2\text{O}_5(g) \quad \text{N}_2\text{O}_4(g) + \frac{1}{2} \text{O}_2(g) \quad \rightarrow
\]

A. Nothing, because monomolecular reactions are independent of temperature.
B. The activation energy for the reaction will increase.
C. The rate constant for the reaction will decrease.

a. A only b. B only c. C only d. B and C

2. Consider the following elementary reactions.
The rate law for the overall reaction is \( \text{Rate} = k \ [AB] \). Which of the following must be the reactant(s) in the slow step?

a. AB 

b. A + B 

c. 2 B 

d. A

3. What are the intermediates in the reaction that occurs in the following elementary steps?

\[
\begin{align*}
2\text{NO}(g) & \rightarrow \text{N}_2\text{O}_2(g) \\
\text{N}_2\text{O}_2(g) + \text{H}_2(g) & \rightarrow \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g) \\
\text{N}_2\text{O}(g) + \text{H}_2(g) & \rightarrow \text{N}_2(g) + \text{H}_2\text{O}(g)
\end{align*}
\]

a. \( \text{N}_2\text{O}_2(g), \text{H}_2(g) \) 

b. \( \text{N}_2\text{O}_2(g), \text{N}_2\text{O}(g), \text{H}_2(g) \)

c. \( \text{N}_2\text{O}_2(g), \text{H}_2\text{O}(g) \) 

d. \( \text{N}_2\text{O}_2(g), \text{N}_2\text{O}(g) \)

4. The solid lines in the diagrams below depict the energy profile of an uncatalyzed reaction. Which of the dotted lines correctly indicates the change in the reaction profile in the presence of a catalyst?
5. The equilibrium constant, $K$, for the reaction below is 5.7 at 1500 °C. The reaction mixture is tested and found to contain 0.2 M CO, 0.6 M H$_2$, 0.7 M CH$_4$, and 0.1 M H$_2$O. Will the reaction continue to form product?

$$\text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + 3 \text{H}_2(g)$$

a. Yes, because $Q < K$  
b. Yes, because $Q > K$

c. No, because $Q < K$  
d. No, because $Q > K$

6. The equilibrium constant, $K$, for the reaction below is 13.3 at 753 K.

$$4 \text{HCl}(g) + \text{O}_2(g) \rightleftharpoons 2 \text{Cl}_2(g) + 2 \text{H}_2\text{O}(g)$$

What is the equilibrium constant for the following reaction?

$$\text{Cl}_2(g) + \text{H}_2\text{O}(g) \rightleftharpoons 2 \text{HCl}(g) + \frac{1}{2} \text{O}_2(g)$$

a. 3.65  
b. 0.0752  
c. 0.274  
d. 177

7. At 100 °C, the equilibrium constant for the following reaction is $K = 4.56 \times 10^9$.

$$\text{CO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{COCl}_2(g)$$

If an equal molar mixture of CO and Cl$_2$ are introduced into a reaction vessel, what is the predominant species at equilibrium?
8. The equilibrium constant, $K$, for the reaction below is 0.0080. At equilibrium, the concentration of NOCl($g$) is 0.25 M and the concentration of NO($g$) is 0.10 M. What is the equilibrium concentration of Cl$_2$(g)?

$$2 \text{NOCl}(g) \rightleftharpoons 2 \text{NO}(g) + \text{Cl}_2(g)$$

a. 0.20 M  

b. 0.050 M  

c. 2.0 M  

d. 0.50 M

9. The following reaction was carried out at 25 °C with the initial concentration of NO$_2$ being 0.70 M. Assume that no NO and O$_2$ are initially present. At equilibrium, the NO$_2$ concentration was found to be 0.28 M. What is the equilibrium constant for this reaction?

$$2 \text{NO}_2(g) \rightleftharpoons \text{NO}(g) + \text{O}_2(g)$$

a. 3.8  

b. 1.9  

c. 0.14  

d. 0.47

10. Which equilibrium expression applies to the reaction below?

$$2 \text{CaCO}_3(s) + 2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{CaSO}_4(s) + 2 \text{CO}_2(g)$$

a. $K = \frac{[\text{CaCO}_3]^2[\text{SO}_2]^2[\text{O}_2]}{[\text{CaSO}_4]^2[\text{CO}_2]^2}$  

b. $K = \frac{[\text{CO}_2]^2}{[\text{SO}_2]^2[\text{O}_2]}$  

c. $K = \frac{[\text{CO}_2]^2}{[\text{O}_2]}$  

d. $K = \frac{[\text{CaSO}_4]^2[\text{CO}_2]^2}{[\text{CaCO}_3]^2[\text{SO}_2]^2[\text{O}_2]}$

11. In the diagrams below, open circles (o) represent atoms of element A and closed circles (●) represent atoms of element B. The diagram on the left shows the starting conditions for the reaction of A$_2$ with B$_2$. The diagram on the right shows the reaction at equilibrium. What is the equilibrium expression for this reaction?
12. Consider the following reaction at equilibrium. Which substance, when added to the reaction at equilibrium, will cause the equilibrium to shift to the left?

\[ 2 \text{NO}(g) + 2 \text{H}_2(g) \rightleftharpoons \text{N}_2(g) + 2 \text{H}_2\text{O}(g) \]

a. He(g)           b. H_2O(g)           c. NO(g)           d. H_2(g)

13. Consider the following reaction at equilibrium. Lowering the temperature of this reaction will

\[ \text{C}(s) + \text{CO}_2(g) \rightleftharpoons 2 \text{CO}(g) \quad K = 14 \]
\[ \Delta H = 172 \text{ kJ/mol} \]

a. cause the equilibrium to shift to the right.
b. increase the value of K.
c. increase the amount of CO_2(g) present.
d. decrease the amount of C(s) present.

14. Which one of the following substances would have a K_a value closest to 1 x 10^{-5}?

a. HF           b. HNO_3           c. HBr           d. KOH

15. Which one of the following is the conjugate acid of NH_3?
a. NH₄⁺  

16. Which one of the following is the conjugate base of PO₄³⁻?

a. PO₃³⁻  

b. HPO₄²⁻  

c. OH⁻  

d. none of these

17. Calculate the pH of a 0.089 M solution of HNO₃.

a. 0.051  

b. 0.12  

c. 1.051  

d. 2.42

18. Calculate the pH of a 3.5 x 10⁻² M solution of Sr(OH)₂.

a. 12.85  

b. 12.54  

c. 1.46  

d. 1.15

Use the following table of $K_a$ and $K_b$ values to answer questions 19 – 21.

<table>
<thead>
<tr>
<th>Acid Dissociation Constants</th>
<th>$K_a$</th>
<th>Base Dissociation Constants</th>
<th>$K_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid (HC₂H₃O₂)</td>
<td>1.8 x 10⁻⁵</td>
<td>Ammonia (NH₃)</td>
<td>1.8 x 10⁻³</td>
</tr>
<tr>
<td>Chlorous (HClO₂)</td>
<td>1.1 x 10⁻²</td>
<td>Carbonate (CO₃²⁻)</td>
<td>1.8 x 10⁻⁴</td>
</tr>
<tr>
<td>Citric (H₂C₆H₅O₇)</td>
<td>7.4 x 10⁻⁴</td>
<td>Hydroxylamine (HONH₂)</td>
<td>1.1 x 10⁻⁸</td>
</tr>
<tr>
<td>Hydrofluoric (HF)</td>
<td>6.8 x 10⁻¹</td>
<td>Hypochlorite (ClO⁻)</td>
<td>3.3 x 10⁻⁷</td>
</tr>
<tr>
<td>Hydrocyanic (HCN)</td>
<td>4.9 x 10⁻¹⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrous (HNO₂)</td>
<td>4.5 x 10⁻⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrosulfuric (H₂S)</td>
<td>9.5 x 10⁻⁸</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. Place the following in order of weakest to strongest acid?

HCN    H₂S    HClO₄    HClO₂

a. HClO₂ < HCN < H₂S < HClO₄  

b. HCN < H₂S < HClO₂ < HClO₄  

c. HClO₄ < HCN < H₂S < HClO₂  

d. HClO₄ < HClO₂ < H₂S < HCN

20. Calculate the hydroxide concentration in a 0.10 M solution of hydroxylamine.

a. 3.0 x 10⁻¹⁰ M  

b. 0.10 M  

c. 1.1 x 10⁻⁹ M  

d. 3.3 x 10⁻⁵ M
21. Calculate the number of moles of acetic acid that must be added to 1.0 L of solution in order to prepare a solution with a pH of 3.10.

a. $7.9 \times 10^{-4}$  

b. $3.5 \times 10^{-2}$  

c. $1.2 \times 10^{-5}$  

d. $1.8 \times 10^{-5}$

---

**Important Formulas and Constants**

\[
PV = nRT \\
\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2} \\
\frac{PV}{M} = \frac{mRT}{M} \\
PV = \frac{mRT}{M} \\
P_T = P_1 + P_2 + P_3 + ... \\
X_a = \frac{n_a}{n_T} \\
P_a = X_a P_T \\
\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \\
q = \Delta H_{\text{vap}} m \\
q = cm \Delta t
\]

\[R = 0.0821 \text{ L} \cdot \text{atm} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}\]

\[K = ^\circ \text{C} + 273\]

\[1 \text{ atm} = 760 \text{ mmHg} = 760 \text{ torr} = 101.3 \text{ kPa}\]

For sc: $2r = a$  

For fcc: $4r = a \sqrt{2}$  

For bcc: $4r = a \sqrt{3}$

\[
M = \frac{\text{moles}_{\text{solute}}}{L_{\text{solution}}} \\
m = \frac{\text{moles}_{\text{solute}}}{\text{kg}_{\text{solvent}}} \\
ppm = \frac{\text{mg}_{\text{solute}}}{\text{kg}_{\text{solution}}} \\
ppb = \frac{\mu g_{\text{solute}}}{\text{kg}_{\text{solution}}}
\]
\[ C_g = kP_g \]
\[ P_A = \chi_A P_A^0 \]
\[ \Delta T_h = iK_b m \]
\[ \Delta T_f = -iK_f m \]

\[ \text{Rate} = \frac{-\Delta[A]}{\Delta t} \quad \text{Rate} = k[A]^n[B]^m \quad \ln[A] = -kt + \ln[A]_0 \]
\[ t_{1/2} = \frac{0.693}{k} \]
\[ k = A e^{-\frac{E_a}{RT}} \]

For the reaction: \( aA + bB \rightleftharpoons cC + dD \)
\[ K = \frac{[C]^c[D]^d}{[A]^a[B]^b} \]

For the reaction: \( \text{HA}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{A}^-(aq) \)
\[ K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} \]

For the reaction: \( \text{B}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{BH}^+(aq) + \text{OH}^-(aq) \)
\[ K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]} \]

\[ \text{pH} = -\log[H_3O^+] \]
\[ K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14} \]
\[ \text{pH} + \text{pOH} = 14 \]
\[ K_a K_b = K_w \]