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Development of curriculum for Next Generation Science Standards in high school chemistry

Abstract

The aim of this project is to develop a unit relevant to students, aligned with three-dimensional performance expectations, and beneficial to teachers in helping students to meet those standards. To effectively meet those goals, an understanding of what curriculum is and how to develop it is needed. Curriculum is “the high-quality delivery system for ensuring that all students achieve the desired end – the attainment of their desired grade- or course-specific standards” (Ainsworth, 2010, p. 4). Without a clear goal for student performance and a detailed plan for how to get them there, lasting, meaningful learning is not likely to happen.

Development of Curriculum for Next Generation Science Standards in

High School Chemistry

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Chapter 1 Introduction and Framework

Teachers in Iowa are currently transitioning to the revised Iowa Core science standards with the recent adoption of Next Generation Science Standards (NGSS) performance expectations by the state of Iowa (IDoE, 2015). Since the NGSS Lead States released the final draft in 2013, several states have chosen to adopt these standards. Standards simply provide goals and expectations for teachers, students, parents, and other shareholders. While these standards provide a strong framework for what should be taught, it is not a curriculum to be used in the classroom since it does not direct how it will be taught (NGSS Lead States, 2013). Teachers still need to develop assessments and quality science and engineering activities that fulfill the desired learning targets. Creating quality curriculum based on the NGSS and best practices for science education is time-consuming work. Many busy teachers lack the time and expertise to put into crafting these units.

NGSS was developed by a large consortium, based on the *Framework for K-12 Science Education* by the National Research Council (NRC), and led by the NRC, National Science Teachers Association, the American Association for the Advancement of Science, and Achieve. These groups worked with multiple experts in science and education through a state-led collaboration (National Science Teachers Association, 2014). The resulting standards outline what content and process skills students should have for a comprehensive K-12 science education in which student understanding deepens over time (NRC, 2011). It provides guidelines for what content, concepts, and practices should be taught in each grade level to become scientifically literate. Scientific literacy is “the knowledge you need to understand public issues” (Hazen & Trefil, 2009,

p. xii)—the general information that allows you to use science news the same way you use other news. Also, according to the introduction to the NGSS, scientific understanding is critical for comprehension of events and decision-making. It goes on to mention how important science is to “this country’s ability to continue to innovate, lead, and create the jobs of the future” (NGSS Lead States, 2013, p. xiii). Scientists and engineers make up only about 4% of the nation’s job force, but they have a disproportionate impact on the other 96% of the workforce (National Science Board, 2010). Innovation that science and engineering provides is what leads to economic growth. This has led to increased focus on Science, Technology, Engineering, and Mathematics (STEM) education in the United States (U.S. Department of Education, 2015).

The previous Iowa Core standards for science also identified expectations of what students should learn at each grade level. The two sets of standards are very similar in terms of content and core ideas. However, there are some key differences between the two which teachers will have to address as they transition. First, NGSS places greater emphasis on science and engineering practices and crosscutting concepts. Each NGSS standard incorporates these practices and concepts with the content, which echoes how scientists work in the real world (NGSS Lead States, 2013). The previous Iowa Core has a separate set of standards for Science as Inquiry and mentions Unifying Concepts and Processes in the introduction (IDoE, 2009). The second significant difference between the old and new standards are explicit connections within the NGSS to mathematics and English language arts (ELA) standards. The Iowa Core contains Math and ELA standards, but does not draw a link between the corresponding standards. The third difference between the old science standards and NGSS is the identification of

performance expectations, which describe what students should be able to do at the end of instruction (Bybee, 2013). They also supply assessment boundaries. The new standards give much more specific guidance to teachers about what is appropriate at each grade level according to cognitive science and research. The previous Iowa Core (IDoE, 2009) also showed increasing complexity with progression based on the National Science Education Standards, developed by the National Research Council (1996). However, in this case, standards were grouped into larger grade bands and do not mention the boundaries to what is appropriate to assess as the level of student thinking becomes more sophisticated. Through these differences, the revised Iowa Core standards emphasize the skills needed for college and careers rather than presenting science as a multitude of facts for students to learn. This allows for deeper understanding and application of learning.

The previous Iowa Core (IDoE, 2009) stated that inquiry is important, and science needed to be taught in engaging and relevant ways. It even gave some suggestions of lessons on the rigor and relevance quadrants but was not as specific about what students should be able to do with what they have learned. NGSS is intended to be assessed in real-world contexts rather than multiple-choice questions that put an emphasis on definitions (NGSS Lead States, 2013). That is not to say vocabulary is unimportant, but science is the study of phenomenon, and uses words to communicate the process and results of that study (Konicek-Moran & Keeley, 2015). The result is an increased focus on making the information relevant to students and building an interest in science and engineering. This will hopefully lead to more students entering STEM fields and prepared for college and careers (National Science Teachers Association, 2014).

This type of reform has been attempted in the past, with varying levels of success. In the “golden age of science education” of the 1960s, there were many new curricula developed to address the desire for the United States to be the leader in space exploration and technology. Most of these programs are no longer used, partially because they lacked sufficient the professional development and the practices and content were seen as separate entities (Konicek-Moran & Keeley, 2015). Project 2061 followed in 1985 with the Atlas of Science Literacy, Benchmarks for Science Literacy, and Science for All Americans.

In order to successfully implement NGSS, teachers, including myself, need to develop good curriculum that utilizes best practices. This curriculum needs to incorporate the many aspects of NGSS including science and engineering practices, crosscutting concepts, and disciplinary core ideas, together referred to as three-dimensional learning, and be assessed in a real-world context which are some significant changes from the previous Iowa Core. The purpose of this project will be to design three-dimensional high school chemistry instructional activities and assessments based on two performance expectations of the NGSS (NGSS Lead States, 2013, p.251):

- HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Reaction rate and equilibrium performance expectations were the topics chosen because the ability to make predictions about how changes will affect the rate of a reaction is necessary to make decisions about which will be advantageous changes to a system at equilibrium. These performance expectations bundle well with one another for assessment purposes, providing greater context and demonstrating connection between the practices (NGSS Lead States, 2013). They are a favorite topic for me personally because of student responses to clock reactions and color changes due to shifts in an equilibrium reaction. They immediately want to know what is going on and how I made that happen. Although the students are really engaged, I do not always feel like they develop a deep understanding of the underlying principles and relevance, so I wanted to revamp how I teach the topics.

Chapter 2 Literature Review

The aim of this project is to develop a unit relevant to students, aligned with three-dimensional performance expectations, and beneficial to teachers in helping students to meet those standards. To effectively meet those goals, an understanding of what curriculum is and how to develop it is needed. Curriculum is “the high-quality delivery system for ensuring that all students achieve the desired end – the attainment of their desired grade- or course-specific standards” (Ainsworth, 2010, p. 4). Without a clear goal for student performance and a detailed plan for how to get them there, lasting, meaningful learning is not likely to happen.

There are many aspects to consider when creating a curricular unit (e.g. assessment pieces, teaching methods, student engagement, level of rigor, etc.). Wiggins & McTighe (2011) describe a process for curriculum development called backward design. This method is a rational way of thinking about curriculum design with the destination in mind, utilizing research about learning and cognition to plan student learning experiences.

Backwards Design for Curriculum

Ainsworth (2010) and Wiggins & McTighe (2011) advocate for a backward design approach to give direction and focus to planning. The backwards design process starts with in depth study of the performance expectations to be taught, which leads to identification of long-term desired results. Next, assessments, both summative and formative, should be carefully planned to measure student learning of those essential skills and ideas; then instruction and learning activities should be designed to scaffold student skills to successful completion of the assessment using the best practices

according to research about how students learn (Ainsworth, 2010; Wiggins & McTighe, 2011). Starting with a clear goal for student learning gives the advantage of working toward that goal through instruction. Instead of starting with content to be taught, planning starts with what students should be able to do with the content. This process provides clear priorities and purposes for learning rather than simply covering what is in the textbook or doing a bunch of favorite activities without a plan for how they will accomplish the intended purposes (Wiggins & McTighe, 2011).

Assessments

Assessments are an important part of curriculum design and should be woven seamlessly with instruction. Without assessments, there is no way to know what students learned or if instruction needs to be altered to address holes in student understanding. In 1967, Michael Scriven identified formative evaluation as a means to constantly improve curriculum (Wiliam, 2011). Students and teachers use formative assessments during instruction to guide instructional decision-making. Summative evaluation measures and documents student achievement at the end of instruction; diagnostic assessments can be used to identify preconceptions (Keeley, 2008). By using this range of assessments, all stakeholders can make informed decisions about instruction. As a teacher, I use the information to evaluate the effectiveness of a strategy, adjust instruction, and identify students who need additional assistance.

Students, as stakeholders in their education, should also understand and participate in their own assessment. Chappuis (2005) describes steps that can be taken to help students understand assessment, including providing learning targets, showing examples of strong and weak work, offering descriptive feedback, teaching students to

self-assess and set goals, designing lessons to focus on one aspect of quality at a time, teaching students focused revision, and engaging students in self-reflection. These strategies help all students focus on improvement, no matter their current level of understanding.

Formative assessments. Stiggins (2005) cites the expectation that all students meet standards as reason to change practices in teaching. Grades are no longer meant to simply sort students, but to prepare all students to meet certain minimum levels of achievement (Stiggins, 2005). The focus of assessments then becomes giving all students the opportunity to succeed at some level so they are encouraged to continue to learn and improve. Allowing some students to give up must be replaced with promoting continued improvement and motivating all learners (Stiggins, 2005). Formative assessment gives students the opportunity to demonstrate what they know and identify areas for improvement.

Formative assessments are an integral part of curriculum because they not only improve student performance, they have the potential to raise the achievement of students who show the lowest performance the most (Black & Wiliam, 1998). This means that the spread in student performance is decreased while the overall level of learning is increased. For this to be effective, the assessment results have to be used to adjust teaching and learning. Black & Wiliam (1998) describe the importance for students to be able to identify the purpose of the learning and self-assess what they need to do to reach the intended learning target. They warn that teachers need to believe these changes are valuable in order to invest the time to teach students to assess their learning and that this time investment will pay off in the future as all students achieve high levels of learning.

In order to create lifelong learners, my students need to be given chances to reflect on their own understanding and seek out additional learning opportunities as needed.

Just giving students formative assessments is not enough. How those assessments are utilized is even more important. Stiggins & Chappuis (2006) contend that simply identifying students who need help earlier does not necessarily help them achieve at higher levels. Instead, there needs to be assessment *for* learning. If everyone is aware of what it means to be successful from the start and students monitor their growth towards those success criteria, they are more involved in the process as instructional decision makers. Assessment for learning helps students avoid the thinking that they are either winners or losers (Stiggins, 2007). First, it sets students up for success by providing criteria for success and by scaffolding learning toward that goal. Second, if students are not successful, they are provided help to identify gaps in their abilities and correct those gaps in order to be successful. Since our new objective is to help all students reach a minimum proficiency, this practice is necessary to help students to reach that level or progress past it.

Authentic assessments. At the end of instruction, students should be able to demonstrate that they met the performance expectations set in the NGSS. There is no prescribed assessment tool or method, so multiple ways of assessing these expectations are possible. Assessment can be a written product, a presentation, or a final project or task. No matter what form the assessment takes, students demonstrate they have met the expectation through authentic assessment because it “requires students to use their prior knowledge, recent learning, and relevant skills to complete complex, real-world projects” (Myers, 2015, “Purpose,” para. 1). An emphasis on real-life applications assesses

transfer of learning to new situations and provides relevance for the learning (Bransford, Brown, & Cocking, 1999). Because students are asked to apply what they learned, this helps answer the question of why the learning is important. These assessments gauge higher order thinking skills and allow students multiple opportunities to reflect on their own learning (Myers, 2015). With all of these advantages, we can easily see that this kind of assessment is a better option than one where recall and memorization are favored.

Theories of Learning

Constructivism is a prevailing learning theory in science education. Piaget theorized that knowledge is actively constructed by processing and understanding experiences, referred to as cognitive constructivism (Proulx, 2006). A teacher's role is to facilitate that process through appropriate instruction and activities and utilize formative assessments to help monitor progress and provide feedback to students. John Dewey felt that learning was an active process, and students should be given relevant problems to solve that activated a personal interest (Llewellyn, 2013). Dewey warned against teaching science as a body of knowledge or collection of facts (Konicek-Moran & Keeley, 2015).

Because students construct their knowledge, we cannot discount prior knowledge. Students "do not simply accept and retain explanations presented by authority figures" (National Science Teachers Association, 2003, p. 3), they need to grapple with the information and reach a point where they find their previous understanding to be lacking. It has also been shown by Bransford, Brown, & Cocking (1999) that learning requires the ability to transfer information to new situations and to solve various problems. Rote memory is less effective than understanding general principles and abstract representations can help promote this transfer (Bransford, Brown, & Cocking, 1999).

Teaching to Support Learning

The process of guided inquiry following a learning cycle in science classes results in higher student achievement and engagement than a traditional direct instruction class (Farrell, Moog, & Spencer, 1999; Vlassi & Karaliota, 2013). Bybee (2013) recommends using the BSCS 5E Instructional Model, where activities are structured so that students *engage* by activating prior knowledge and focus students on the upcoming lesson, *explore* to give students a common experience to begin to develop ideas, *explain* the concepts, *elaborate* to extend to new experiences that allow them to apply the learning, and *evaluate* based on the performance expectations.

Even the best planning and teaching will not be effective without student motivation, which can affect the amount of time and effort a student will dedicate to learning. Challenges, at the proper level of difficulty, can be motivating, and learners are more motivated when they see the application of what they are learning (Bransford, Brown, & Cocking, 1999). Ideas are best introduced when students see a need or reason for their use. (Bransford, Brown, & Cocking, 1999).

Page Keeley recently spoke to the joint conference for Iowa Council of Math Teachers and Iowa Science Teachers Section about her experiences that led her to focus on formative assessments and, specifically, on eliciting misconceptions and prior knowledge from her students. Without this type of diagnostic assessment, she found that students were coming to her with misconceptions that she had not anticipated (Keeley, September 2015). Building on existing knowledge is often helpful to facilitate new learning, but it can be incorrect and impede learning. Preconceptions arise from attempts to make reasonable sense of everyday experiences, and if faulty preconceptions are not

addressed, students will likely not refine or replace them with more accurate scientific explanations (NRC, 2005). If not addressed, students may retain information presented by the teacher for the purpose of a test and then revert to misconceptions (National Science Teachers Association, 2003). No matter how incorrect a misconception may be, it provides the basis for new conceptual understanding and gives teachers information needed to plan the next steps if they take the time to listen to students (Konicek-Moran & Keeley, 2015).

Teaching Reaction Kinetics and Equilibrium

Students have trouble describing what is actually happening in a chemical change (Hacker, 2015). The use of language like “dissolving” or “disappearing” for reactants in a chemical change can lead to students’ misunderstandings about particle collisions and chemical change. Care must be taken to provide opportunities for students to make connections between chemical changes in macroscopic, sub-microscopic, and symbolic representations. Students occasionally see demonstrations and use a chemical equation to describe the change but may not make the connection that particles are exchanged during collisions (Hacker, 2015). This understanding is necessary before students can understand the factors that affect the rates of a reaction.

Studies show a tendency for students to confuse thermodynamics and kinetics – rates changing when temperature is changed dependent on whether a reaction is endothermic or exothermic and that there is a direct relationship between equilibrium constant and reaction rate (Sözbilir, Pınarbaşı, & Canpolat, 2010). Students must understand that sufficient energy needs to be available to meet or exceed the activation energy in order for a reaction to take place (Hacker, 2015). One misconception that

students may hold is that as activation energy decreases, reaction rate decreases or that increasing the temperature will increase the activation energy, so that the rate of reaction decreases (Kaya & Geban, 2012). Maxwell-Boltzmann distributions can be used to introduce the idea that increasing the temperature increases the proportion of particles with enough energy to react successfully, but the graph is easily confused with an energy diagram for the reaction due to the similarities in shape (Hacker, 2015).

Students typically struggle with describing the connection between particle size and surface area. In order to aid students understanding of this relationship, we can take a piece of modeling clay and cut it into smaller pieces, measuring surface area as the pieces get smaller. Once they see that smaller pieces lead to an increase in surface area available for reaction collisions, they can extend this to the smallest pieces possible in liquid, gas or aqueous forms (Hacker, 2015).

Mathematical models are another hurdle for student thinking. Sometimes, students write and solve an equation by using procedural knowledge, but do not understand the reasoning behind the equation. Scott (2017) showed that students have a limited understanding about the nature and purpose of models in science and lack awareness that mathematical models are evaluated based on how well they fit empirical data. As a result, constructing and evaluating models and interpreting data must be more explicit during initial kinetics instruction (Scott, 2017).

Some potential road blocks in learning about equilibrium are a lack of understanding of the nature of reversible reactions and the opposing ideas of chemical change and stability (Hacker, 2014). Students might believe the reaction stops once equilibrium is reached or that equilibrium means there must be an equal concentration of

reactants and products (Cloonan, Nichol, & Hutchinson, 2011). Introducing the idea that reactions are reversible using examples like the water cycle and indicator color change can be helpful (Hacker, 2014). Particle modeling activities are necessary to help students understand the dynamic nature of equilibrium. By observing manipulatives that represent reacting particles coming together and being taken apart simultaneously, and through guided discussions, students begin to understand how equilibrium is dynamic at the particle level while it appears to be static macroscopically (Cloonan, Nichol, & Hutchinson, 2011). An analogy like walking up a down escalator may provide students a visual of opposing actions (Hacker, 2014). All these misconceptions must be drawn out and confronted in order to be replaced by the correct concepts.

According to Posner, Strike, Hewson, and Gertzog (1982) there are four conditions to conceptual change: dissatisfaction, intelligibility, plausibility, and fruitfulness. Kaya and Geban (2012) found that students who were taught using pedagogies that support this conceptual change model of learning had higher levels of understanding than those who did not. First, students were asked questions about the concept and discovered their explanations were not sufficient (dissatisfaction). Students were then shown demonstrations with explanations from the teacher (intelligibility), then encouraged to use the new concept to solve new problems (plausibility). Their homework helped students explain unfamiliar phenomena using the new concepts (fruitfulness). Showing students demonstrations and how current theory explains their observations is important to their ability to adopt the new concept over their previous ideas.

Studies have shown misconceptions even among chemistry teachers involving what the rate of a reaction is, how it changes during a reaction, and explaining

relationships between enthalpy, activation energy and reaction rates (Kolomuç & Tekin, 2011). This would suggest that we need to continue to provide learning experiences that help teachers through conceptual change as well, so that they do not pass their alternative ideas on to their students.

I am doing this project to help my students gain a deeper understanding of reaction rates and equilibrium. It is necessary to consider and address possible misconceptions carefully and build connections between the topic and its various applications throughout the unit.

Chapter 3 Project

In 2014, the Cedar Rapids Community School District began to discuss the changes needed to meet NGSS adoption. Even though it was not yet legislated by the state of Iowa, district leaders felt NGSS was aligned with the Core standards at the time and helped provide additional guidance to teachers. A group of science teachers from across the district recommended steps including changing graduation course requirements and assigning performance expectations to courses that would meet those requirements. Teachers in the district also started to identify essential questions and scaffold skills students would need. The progress has seemed slow at times, and my experiences during summers since then has lead me to believe the NGSS should be implemented as soon as possible. This sense of urgency has led me to develop this unit, “Reaction Rates and Chemical Equilibrium” to use for my high school chemistry classes.

Curriculum Topic Study

In order to effectively decide desired results, it is necessary to get an in-depth understanding of the learning outcomes that are expected, sometimes referred to as “unwrapping” a standard. A curriculum topic study (CTS) accomplishes this in a number of ways (Keeley, 2005). CTS includes analyzing the standard in multiple facets, identifying the big ideas, key skills, and essential questions relevant to adult scientific literacy. Often, connections across disciplines, which can be highlighted during instruction, are discovered. Additionally, it is helpful to recognize the learning progression for a child’s development K-12. Knowing the learning progressions allows one to identify the background knowledge needed for student understanding as well as provide a context for why students need to learn the content and how they might use it in

the future (Keeley, 2005). Identifying preconceptions - a student's initial understanding that has been acquired informally (NRC, 2005) - that are common among students can help with designing assessments and learning activities so those preconceptions are brought forth and addressed. If preconceptions are not addressed, students often memorize content for a test and then revert to prior understanding outside of class (NRC, 2005). This strategy of eliciting prior knowledge is effective in eliminating alternative conceptions (Atasoy, Akkus, & Kadayifci, 2009). My goal is for students to leave my class with lasting knowledge they can use in the future, so this is critical.

Page Keeley (2005) compiled resources that can be used to study the content that will be taught, coherency of topic development and vertical articulation, and potential difficulties that may arise in teaching that topic beyond what is explicitly included in NGSS. Unfortunately, there is no guide specifically for reaction rates and chemical equilibrium. Therefore, the suggested reading for "Chemical Properties and Change" and "Constancy, Equilibrium, and Change" was examined and some additional research was completed before beginning planning. This additional research about learning in kinetics and equilibrium uncovered specific misconceptions and difficulties students may have with these topics. It made me realize that part of the reason students have had so much trouble with particle size and reaction rates is that they do not understand how smaller particles create more surface area. It would be worth the time to have them explore that relationship in class. I also read an analogy of a person walking up a down escalator to provide students with another analogy for equilibrium. Although to someone watching from the outside, it may appear that the person is still, there is movement in both

directions. There are five sections to a curriculum topic study (CTS), which is briefly described below.

Section	Contents
I	Adult content knowledge that is important for a scientifically literate adult life and participation in public issues
II	Instructional implications, including development through grade levels and suggestions for effective instruction, keeping possible misconceptions in mind
III	Concepts and specific ideas included in the goal statements – what is most important and what can have less emphasis
IV	Current research on students learning and possible misconceptions, as well as information that needs to be understood for students to successfully meet the expectations
V	Coherency and articulation within the K-12 educational experience – clarify limits of content at a particular level and prerequisite ideas

The full CTS for this unit can be found in Appendix A.

Unit Plans

I have chosen to use Understanding by Design, which approaches curriculum design in a way that lends itself to NGSS. I start by defining the desired results and essential questions. Then I develop an assessment to measure whether students have achieved the desired results, and finally, plan for daily activities to help students reach proficiency or mastery on the assessment.

Stage 1: Desired Results. To develop deep conceptual understanding, knowledge is organized around core concepts (NRC, 2005). The performance expectation was unwrapped and organized into the template found in Appendix B. The essential questions in this unit are:

- How can we improve our quality of life by optimizing chemical reactions to fit our needs?
- How can we solve real-world problems by optimizing chemical reactions?
- How does our body use enzymes and equilibrium to keep us healthy?

Learning Targets were developed around these questions, and I created a handout to help students track their own progress toward those learning targets (Appendix C).

Stage 2: Evidence. In order to know my students have met the desired learning targets, various assessments are needed throughout the learning process and after the learning cycle is complete. The summative assessment I used is found in Appendix D. So I would have comparison data, I gave this assessment at the beginning of the unit as well. Formative assessments were mostly informal in format and included things such as assignment responses and listening to student conversations. When class assignments were collected, I concentrated on the questions with asterisks on the handouts to quickly tell if students learned what was expected for the day. This also allowed me to give them some written feedback or probing questions about their responses.

Stage 3: Learning plan. When planning for the unit, I expected my students would have some prior knowledge from previous units. This included the following:

- A solution is a mixture of two or more substances, a solute and a solvent.
- An aqueous solution is one in which the solvent is water.

- A solution can be described in terms of concentration, which is the amount of solute per a unit of volume. It can be expressed in many different ways.
- Molarity is the number of moles of solute per liter of solution.
- Temperature is proportional to the average kinetic energy of particles.
- A reaction is the rearrangement of atoms into new molecules.

This unit requires two 5E learning cycles. The first addresses factors that affect the rate of a chemical reaction and collision theory as a way to explain those factors. The second learning progression revolves around the application of Le Châtelier's principle to predict changes to a system at equilibrium. The learning cycles are briefly described in Appendix E and more detailed daily teacher notes are included in Appendix F. Finally, students handouts and answer keys are located in Appendix G and H respectively. Throughout both learning cycles, there is very little math. The reasoning, application, and analysis of the data was far more important than equations, which I thought could confuse some students unnecessarily while allowing other students to hide a surface level understanding behind math skills. Therefore, no rate expressions or equilibrium constants are used in this course, which is a shift from past years.

Chapter 4 Reflection

Students were very engaged from the beginning with the reaction rate engineering task but needed some additional support to find success. Some students thought the ratio of A:B would affect the rate and were encouraged to test that hypothesis. Some students also struggled with the concept of concentration and simply reduced the amount of one reactant rather than diluting it with water. It was necessary to reinforce the idea that without adding water, the concentration was not going to change. Some students measured the temperature of the ice bath or hot water bath, then mixed the solutions in test tubes in the bath but did not allow them to adjust separately to the temperature first. Conversations during the lab about best practices for measuring the temperature of solutions were needed. The general lack of laboratory skills highlights the importance of giving students more opportunities to design and conduct experiments.

We found from one day to the next, the reaction times changed slightly for the same concentration at the same temperature. When I was trying to find the source of the error, I knew that solution B needed to be made fresh each year but did not know how quickly it would degrade. I suspected solution B needed to be made fresh as close to the lab time as possible. The time was still slightly different from day to day, but it was more consistent when it was as fresh as possible. The acid acts as a catalyst for the reaction, so that may be another factor affecting the times. I've considered leaving the acid out of solution B and allowing students to add small amounts, making that another variable they can test. I would be interested to see their lab results in the absence of acid, and how much the time increases with additional amounts. It will add another set of data for students to collect, so more time may need to be devoted to the lab.

I was able to question students to assess their learning when they presented their reaction to song, and all were able to tell me the relationships between temperature, concentration, and the time it took for the color change to occur. It worked out well that we did the PhET simulation before they presented, so I could also assess their ability to articulate the effects in terms of collision theory as they presented. Because these presentations became very repetitive, I plan to have each group prepare a graphic or drawing to explain their results and share as a class. This will allow for student creativity and different visual representations from each group. As groups present, we can analyze the strengths and weaknesses of each model. I also want to specifically address the performance expectation in the rubric by adding a requirement that students utilize collision theory in their explanation.

As the class took notes, students were able to recall two factors that affect the rate from the engineering task. The other two were introduced by demonstration, and students were able to recognize the relationship and come up with some preliminary ideas for how collision theory explained the relationships. Since I have accidentally set off our extremely sensitive fire alarms with other labs in the past, I was concerned that the powdered milk burning would lead to another round of scolding from the fire department first responders. Consequently, I was probably more conservative with this demonstration than I would have otherwise been. If it was warmer, it would be nice to do outside on a larger scale for a more exciting experience.

I struggled a bit with helping students understand rate dependence without going so far as to write the equation. It is simple when the reaction is first order with respect to a reactant since students can just say the rate changes by the same factor as the

concentration. It is more difficult when there is an exponential relationship. Students range in their understanding of mathematical concepts of proportions and exponents, such that they have trouble accurately stating the relationship in words. I was trying to avoid rate constants, but it may be easier for students to learn through an equation. We can still avoid calculating the value of the constant.

When reading the responses from students concerning the article about how catalytic converters work, I noticed many students were unable to connect the idea that if the converter is closer to the engine, it would reduce emissions. The article mentions that it performs better when hotter, but students needed to put that together with the idea that the engine is the first place to heat up. Additionally, some students thought the honeycomb pattern would act like a filter, rather than just providing additional surface area for the reaction to take place. It was discouraging, considering we learned about gases early in the year. They must not be conceptualizing the scale of individual molecules present in gas form compared to solid particles that might be large enough to be caught in a filter. It may be they have a stubborn misconception that the pollutants are “big” particles that can get stuck, while letting the less harmful air particles through. I will use this to modify my instruction about the nature of gases in coming years, identifying and confronting those misconceptions so students can better recognize the error in their thinking.

As we began working in the topic of equilibrium, most students predicted that adding a clear liquid to a colored solution in the demonstration would make the color fade. This makes sense based on previous experiences, like adding water to a colored drink. Student predictions were all over the place regarding what happens with changes in

temperature. The unexpected results of the changes in the demonstrations of equilibrium were good for getting students interested and eliciting questions. Next time I teach this unit, I would like to experiment with the use of a driving question board to organize our collective thoughts and track our learning on this topic.

During the M&M equilibrium activity, students all started to remark around the fourth round in that the number of M&M's would stay the same. I asked them why they think it will stay the same, which drives the point home that while the M&M's are still being exchanged, they will switch the same number of M&M's every round. However, I wish the model was a little better in showing how the particles are changing during the reaction, but it is effective in teaching the concept of equilibrium. I may need another visualization where they can see molecules coming together and breaking apart.

After the demonstrations and virtual lab, I felt I may be introducing the misconception that equilibrium reactions involve a color change. I wanted to address that idea, so we talked about examples that do not change color and why our demonstrations and the virtual lab all had color changes. I hope they were able to see it was simply a low-tech way to gauge the changes, but I see the need to develop a formative assessment tool to check for understanding.

The bailing water demonstration was a fun way to review what causes equilibrium in an ongoing reaction and what factors might affect equilibrium. I decided to add a little food coloring to the water to make it easier for students to see. I will bring a tarp and extra towels next time, since it was rather messy.

I had the idea to have students use white boards and change the sizes of the arrows indicating forward or reverse reactions according to our learning about factors that

affect rate. For instance, they would make the forward arrow larger if the concentration of a reactant was increased. If a gaseous product was removed, their reverse arrow would decrease. We could then compare the arrows to predict the change in equilibrium. This was really helpful, because I was able to see which groups were in need of extra help, and it gave students a visual way to model the changes in rates that shifts the equilibrium.

Assessment Results

The results of pre-assessment and post-assessment on both topics (Appendix D) are listed below, along with averages for the class. Scores were given based on the scale in Appendix C. The classes consisted of 39 students, who were given the same assessment before instruction began and after instruction was complete. Student names are removed from the data, replaced by numbers in no particular order.

Table 1
Summative Assessment Data

Student Number	Pre-Test Scores		Post-Test Scores		Change in Score	
	Kinetics	Equilibrium	Kinetics	Equilibrium	Kinetics	Equilibrium
1	1	1	3	3	2	2
2	1	0	2	2	1	2
3	1	0	3	1	2	1
4	1	1	2	2	1	1
5	1	1	3	4	2	3
6	1	1	1	1	0	0
7	2	1	3	3	1	2
8	3	2	3	4	0	2
9	1	1	2	4	1	3
10	1	1	3	2	2	1
11	1	1	1	3	0	2
12	1	1	2	2	1	1
13	1	1	1	1	0	0
14	1	1	2	2	1	1

15	1	1	3	2	2	1
16	2	1	2	1	0	0
17	1	0	1	1	0	1
18	1	1	3	3	2	2
19	2	1	2	2	0	1
20	1	0	2	2	1	2
21	1	1	3	4	2	3
22	1	1	2	2	1	1
23	1	1	2	3	1	2
24	1	1	2	2	1	1
25	1	0	3	4	2	4
26	1	1	2	2	1	1
27	1	1	3	3	2	2
28	1	1	4	4	3	3
29	1	1	2	4	1	3
30	1	0	3	2	2	2
31	1	1	3	2	2	1
32	1	1	3	3	2	2
33	1	0	2	1	1	1
34	1	0	3	2	2	2
35	1	1	2	3	1	2
36	1	1	1	2	0	1
37	1	1	2	2	1	1
38	1	1	2	2	1	1
39	1	0	3	3	2	3
Average	1.13	0.79	2.33	2.44	1.21	1.64

Note. Colors are used to highlight students' summative understanding. Green indicates proficient or better, yellow indicates a developing understanding, and red indicates insufficient learning.

Analyzing the data collectively was encouraging, but looking at individual results, there is cause for some concern. The average scores increased by 1.20 for kinetics and 1.65 for equilibrium. I am troubled that some students did not show any growth during

the unit, and there were a number that did not reach a developing level of understanding by the end of the unit. The data would indicate some students learned nothing during this unit based on this assessment data. While I do not typically collect pre-assessment data, I would suspect this happens in other units as well.

I was surprised at how many students had difficulty with the final question about their friend who had carbon monoxide poisoning. I thought it might be too easy to say they should breathe more oxygen, since that seems like an obvious response. Some students said to take the friend to the doctor, which is good advice, but did not really help me assess whether they understood equilibrium. Some re-wording of the test item may be needed to clarify that their answer should address their learning about equilibrium.

Desired Changes

As our district has changed course requirements to ensure all performance expectations in the Iowa Core are accessible to each graduate, Physical Science I, a one-semester course, now covers the same performance expectations as Chemistry, a year-long course. The distinction between these courses will likely come from additional topics and more rigorous math inclusion in the year-long course. Both are typically taught at the junior level. Maxwell-Boltzmann distributions may be worth exploring in the year-long course, both earlier in the year when states of matter and kinetic molecular theory are introduced, and again in this unit to help explain why some particles can react, even at low temperatures. However, these topics go beyond the scope of the semester-based course and standards. Another topic that may be applicable and helpful to students in the year-long course is learning about reaction mechanisms. If they see a reactant is in a step that is already happening quickly, it can explain why increasing the concentration of that

reactant may have no impact on the rate of the overall reaction. It also reinforces collision theory, since each step describes one collision.

Since this unit was first taught, I used an activity where students use nuts and bolts to represent reactants in an equilibrium reaction instead of M&Ms to demonstrate reactions. I like the nuts and bolts model more because it better models chemical changes as “bonds” that are made and broken when the nut and bolt are physically put together or taken apart. The downside is the data is more difficult to interpret. It is typically a faster process for students to remove the nut from the bolt than it is to add it, so starting with all separate does not show much change during the reaction. On the other hand, sometimes the number spikes or dips sharply from one trial to the next. Since all groups follow the same rules for moving M&Ms, the data is very neat and ends up staying exactly the same once it reaches equilibrium. This makes it easier for students to recognize and describe. I may try to develop a combination of the two activities in the future.

On the assessment, some students were able to say that she should get more oxygen but were not able to appropriately explain why that would improve their friend’s health other than “oxygen is good for people”. To help students successfully respond to this type of question, I believe I need to start early in the year helping students generate claims with appropriate and adequate evidence and reasoning and practice it often. In addition, I would change the prompt in the assessment to “Given what you have learned about equilibrium and the equation provided, what is the best course of action to help your friend (other than calling for medical assistance)? Explain how this will help.” This will help clarify the expectations for the student response.

Continued Learning

Since the creation and implementation of this unit, I learned about the use of phenomenon, storylines, and driving question boards. I feel like using a storyline and student developed driving question board to better arrange the learning progression and help students take ownership could strengthen the unit and increase student engagement. The demonstrations used in the unit are good lesson-level phenomenon, but a cohesive storyline with an anchoring phenomenon will improve the unit.

One possible phenomenon might be causes of tooth decay (Bleam, et al., 2015), which could include some interdisciplinary health components. We could start with a photo of someone's mouth that shows signs of decay. Students could learn about conditions that increase the rate of decay, how tooth enamel exists in an equilibrium state and how it is affected by acidic beverages and fluoride. This storyline would likely require the addition of some learning on topics like structure and health of teeth, acidity and pH. Students may be surprised to learn that while brushing is good for teeth, care should be taken about when to brush. A local dentist and dental assistant could speak to the class about some career options in their field. In place of a traditional test at the end of the unit, they could create a product that helps to educate the public about good choices for oral health, including in their explanations the concepts of rates and equilibrium in their preferred format (for example, a brochure, news article, video, or mock interview). All of this would help students see the real-world relevance in another context and create a purpose for the learning and assessment beyond the requirements of school.

There are a variety of other phenomena that could be equally fruitful. They might inform the community of the procedures their city is taking to prevent lead contamination in our local water supply so we can avoid a crisis like the one in Flint, Michigan.

Students who have an interest in horticulture could be motivated to learn about changing colors of hydrangea and develop educational materials for a local garden center. Ideally, students could choose from a menu of phenomena, based on interest, and collaborate to explore it in smaller groups, but I am not sure I am ready to take on that level of chaos yet. At this point, I will choose one phenomena I think will be most intriguing for students and try to use it well.

Professional Growth and Impact

Through this project, I have learned so much about curriculum design, NGSS, and science instructional strategies. Before I knew about backward design, I would often wait to create an assessment until nearly the end of the unit, and its contents depended on what I had taught in the previous weeks, not specific learning targets I had set for students before the unit started. While my teaching was aligned with standards, my assessments were not always high quality. I could read the standards and comprehend what was expected, but I have gained a deeper understanding of how the three dimensions can be taught explicitly and how to incorporate the crosscutting concepts and science and engineering practices into assessments.

While completing this project, I have also had the opportunity for professional growth in a teacher leadership position for science curriculum in my district. I still get to teach, but I also have time to collaborate with teachers and lead professional learning around the performance expectations and instructional shifts. I am so grateful for this

opportunity, and I feel qualified because of what I learned over the course my work to earn this degree.

Although I learned a great deal, I now see how much more I still must do to improve my own curriculum and practices and better lead our district science curriculum efforts. This is one unit with two performance expectations, leaving many more to grapple with. To create well-aligned curriculum, significant time and resources must be invested. There are some good resources available commercially, however, they always seem to need some supplementation, and while materials may change at the next adoption, the standards will not. I have learned that collaboration with colleagues makes this process go much faster and we create higher quality products together than we can alone. I have recently started to learn more about Open Educational Resources and how valuable they are, as they are available for free use, modification, and distribution. My district is also planning for all middle and high school students to have devices starting in 2019-2020, so I will need to do some learning about how to better incorporate technology, while avoiding the overdependence on technology. I know I will continue to pursue learning opportunities because of the desire I have to continually improve my practice and the practices of my colleagues.

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Appendix A: Curriculum Topic Study Summary

I. Adult Content Knowledge

From Science for All Americans, Chapter 4, Structure of Matter, p. 46-47:

- The rates at which reactions occur in large collections of atoms depend largely on how often the reactants encounter one another—and so depend on the concentration of reactants and on how fast they are moving (that is, on temperature). Reaction rates can be affected dramatically by very small concentrations of some atoms and molecules which link to the reactants in a way that positions them well to link to each other, or which have an excited state that can transfer just the right amount of energy for the reaction to occur. In particular, reactions occurring in water solution may be affected significantly by the acidity of the solution (AAAS, 1990).

From Science for All Americans, Chapter 11, Constancy and Change, p.172-179:

- The ultimate fate of most physical systems, as energy available for action dissipates, is that they settle into a state of equilibrium. Forces are balanced, and all change appears to have stopped. If something new is done to the system, it will settle into a new equilibrium (AAAS, 1990).
- The idea of equilibrium can also be applied in situations of continual change, as long as they counterbalance each other. From a molecular viewpoint, equilibrium states belie a continual activity of molecules (AAAS, 1990).
- Some processes are not readily reversible, eventually leading to static rather than dynamic equilibrium (as the reactants are completely used up). A system can remain in equilibrium through small disturbances, but not larger ones (AAAS, 1990).
- Many systems include feedback subsystems to keep an aspect of the system constant or within a narrow range. These can fail if conditions become too extreme (AAAS, 1990).
- Patterns of change are of special interest in the sciences. Descriptions can predict what will happen; analysis can help understand and make

predictions; control is essential for design of technological systems. Patterns can be steady (progress in one direction), cyclic (happening over and over), or irregular (AAAS, 1990).

- In spite of the unpredictability of details, however, the summary behavior of some large systems may be highly predictable. Changes in the pressure and temperature of a gas in equilibrium can often be predicted with great accuracy, despite the chaotic motion of its molecules and the scientist's inability to predict the motion of any one molecule (AAAS, 1990).

From Science Matters, Chapter 6, Elements in Combination:

- Chemists make their living by trying to create new and useful mixtures of atoms, or by trying to manufacture established useful chemicals in new ways. Almost every aspect of modern life – food and clothing, transportation, and communications, sports and entertainment – depends on the discoveries of chemistry (Hazen & Trefil, 2009, p. 96).

From Science Matters, Chapter 15, Enzymes:

- Enzymes sole task is to help other molecules interact with each other. They remain unchanged. In inorganic molecules, they are called catalysts. They are generally specific to linking two molecules only (Hazen & Trefil, 2009, p.254).

From A Framework for K-12 Science Education, PS1.B: pp 109-111

- “Collision theory” provides a qualitative model for explaining the rates of chemical reactions. Higher rates occur at higher temperatures because atoms are typically moving faster and thus collisions are more frequent; also, a larger fraction of the collisions have sufficient energy to initiate the process (NRC, 2011).
- Although a sample may be at a constant chemical composition, chemical reactions may be occurring within it that are balanced in opposite directions at equal rates (NRC, 2011).

From A Framework for K-12 Science Education, Stability and Change pp 98-101

- Stability denotes a condition in which some aspects of a system are unchanging, at least at the scale of observation (NRC, 2011).
- A system with steady inflows and outflows is said to be at dynamic equilibrium (NRC, 2011).

II. Instructional Implications – *Big ideas that span across grade levels, grade-level concepts and ideas important for understanding the topic, suggestions for effective instruction, misconceptions, learning difficulties, developmental considerations*

From Benchmarks for Science Literacy, 11C, Constancy and Change, p.271-275

- When change occurs in a variable, a major issue is the rate at which change occurs. Students have to make sense of a constant rate of change before they consider increasing or decreasing rates (AAAS, 1993).
- Understanding rate of change is not as simple as it seems; graphs help, but slopes are puzzling to most children (AAAS, 1993).
- The theme of change should be brought up at every opportunity in the context of science, mathematics, or technology. Encourage students to describe it, and then look for patterns of change in the abstract (AAAS, 1993).
- Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change (AAAS, 1993).

From National Science Education Standards, 9-12, Standard B essay, p.177

- The relationship between properties of matter and structure requires three levels of thinking: macroscopic observations of properties, microscopic structure of molecules, atoms and subatomic particles, and symbolic and mathematical use of formulas, symbols, and equations (NRC, 1996).
- Connection between particles and symbols that represent them is not always clear (NRC, 1996).

From National Science Education Standards, K-12, Unifying Concepts and Processes, p.115-116

- Help students realize that models are developed and tested by comparing with observations of reality (NRC, 1996).
- The world is too large and complex to analyze all at once, so we designate systems (NRC, 1996).
- Laws of nature allow us to make predictions about that identify or explain in advance what is expected (NRC, 1996).

III. Concepts and Specific Ideas – *Specific science ideas in the goal statements, technical terminology used in the goal statements, what is important vs. what can be eliminated or less emphasized*

From Benchmarks for Science Literacy, 4D, Structure of Matter p. 76-80:

- The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials. Some atoms and molecules are highly effective in encouraging the interaction of others (AAAS, 1993).

From Benchmarks for Science Literacy, 11C Constancy and Change, p.272-275

- Much of science and mathematics has to do with understanding how change occurs in nature and in social and technological systems, and much of technology has to do with creating and controlling change (AAAS, 1993).
- Constancy, often in the midst of change, is also the subject of intense study in science (AAAS, 1993).
- Equilibrium, steady states, and conservation might all be thought of as showing symmetry – another kind of constancy or invariance in the midst of change (AAAS, 1993).
- A system in equilibrium may return to the same state of equilibrium if the disturbances it experiences are small. But large disturbances may cause it to escape that equilibrium and eventually settle into some other state of equilibrium (AAAS, 1993).

National Science Education Standards, 9-12, Standard B, Structure and Properties of Matter, p.178-179, Chemical Reactions, p.179

- Chemical reactions may release or consume energy. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog (NRC, 1996).
- Chemical reactions can take place in time periods from a few femtoseconds to billions of years. Rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties – including shape – of the reacting species (NRC, 1996).
- catalysts, such as metal surfaces, accelerate chemical reactions. Reactions in living systems are catalyzed by protein molecules called enzymes (NRC, 1996).

National Science Education Standards, K-12, Constancy, Change, and Measurement, p.117-118

- Rate involves comparing one measured value with another (NRC, 1996).

National Science Education Standards, K-12, Evolution and Equilibrium, p119

- Equilibrium is the physical state in which forces and changes occur in opposite and off-setting directions. Balance and homeostasis are forms of equilibrium (NRC, 1996).

National Science Education Standards, 9-12, Standard A, Formulate and Revise Scientific Explanations and Models Using Logic and Evidence and Recognize and Analyze Alternative Explanations and Models, p. 175

- Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation (NRC, 1996).

- Emphasize critical abilities of analyzing an argument to decide which explanations and models are best. Not all explanations have equal weight (NRC, 1996).

From A Framework for K-12 Science Education, PS1.B: pp 109-111

- The rates of chemical processes can be understood in terms of the collisions of molecules. (NRC, 2011)
- Dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (NRC, 2011)

IV. Research on Student Learning – *misconceptions or alternative ideas, important prerequisites*

Benchmarks for Science Literacy 11C, Constancy and Change, p357-358

- Fourth-graders' representations of changes over time are "data-driven" in the sense that the particular data in the problem are the most important. This contrasts with "system-driven" representations in which the emphasis is on overall patterns. Unfortunately, students are typically introduced to system-driven representations while they still think it is a wrong or meaningless way to convey information (AAAS, 1993).

Making Sense of Secondary Science: Research Into Children's Ideas, Chapter 10,
Chemical Change, p.85-91

- Students must first understand concepts of particulate nature of matter and chemical change. Must appreciate that there is mutual interaction of particles and conservation of matter through change. The role of energy in a chemical change must be understood (Driver, Squires, Rushworth, & Wood-Robinson, 1994).

V. Coherency and Articulation – *Connections between ideas that provide clarification for the content, prerequisite ideas*

Atlas of Science Literacy, Chemical Reactions, p. 60-61

- In 3-5, students should learn that many kinds of changes occur faster under hotter conditions (Project 2061, 2001).
- In 6-8, students should learn that increased temperature means greater average energy of motion and that temperature and acidity of a solution influence reaction rates. Substances dissolved in water may facilitate the reaction (Project 2061, 2001).

Atlas of Science Literacy, Describing Change, p. 120-121

- In 3-5, students should learn that some features may stay the same even when other features change. Tables and graphs can be good ways to track changes (Project 2061, 2001).
- In 6-8, students should learn that rates of change can be computed from differences in quantity and vice versa (Project 2061, 2001).
- In 9-12, students should learn that things can change in detail but remain the same in general and that sometimes the more of something there is, the more rapidly it may change. Sometimes the rate of change of something depends on how much there is of something else (Project 2061, 2001).

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Appendix B: Understanding by Design Template, Stage 1

NGSS Performance Expectations										
<p>HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.</p> <p>HS-PS1-6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.</p>										
<p>Established Goals</p> <p>Students will be able to explain collision theory and identify factors that affect reaction rate.</p> <p>Students will be able to apply Le Châtelier's principle to make changes to an equilibrium system.</p>	Transfer									
	Students will be able to independently use their learning to alter reaction conditions in order to optimize a reaction.									
	Meaning									
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left; padding: 5px;">ESSENTIAL QUESTIONS</th> <th style="text-align: left; padding: 5px;">UNDERSTANDINGS</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">How can we improve our quality of life by optimizing reactions to fit our needs?</td> <td style="padding: 5px;">Reactions are influenced by many variables, including temperature and concentration.</td> </tr> <tr> <td style="padding: 5px;">How can we solve real-world problems by optimizing reactions?</td> <td style="padding: 5px;">We can alter these conditions to make a reaction respond in a predictable way.</td> </tr> <tr> <td style="padding: 5px;">How does our body use enzymes and equilibrium to keep us healthy?</td> <td></td> </tr> </tbody> </table>	ESSENTIAL QUESTIONS	UNDERSTANDINGS	How can we improve our quality of life by optimizing reactions to fit our needs?	Reactions are influenced by many variables, including temperature and concentration.	How can we solve real-world problems by optimizing reactions?	We can alter these conditions to make a reaction respond in a predictable way.	How does our body use enzymes and equilibrium to keep us healthy?		
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Acquisition										
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Appendix C: Reaction Kinetics and Chemical Equilibrium Learning Targets

Skill	Level 1: Limited	Level 2: Developing	Level 3: Proficient	Level 4: Advanced
I can explain collision theory and can identify factors that affect reaction rate.	I can describe collision theory.	I can describe collision theory and can usually identify how changes in temperature, particle size, concentration, or the addition of a catalyst/inhibitor affect reaction rate.	I can describe collision theory and can explain how and WHY changes in temperature, particle size, concentration, or the addition of a catalyst/inhibitor affect reaction rate.	I can do everything in Level 3 and can use rate data to predict a rate for a given set of conditions.
I can apply Le Châtelier's principle to make changes to an equilibrium system.	I can identify which direction equilibrium will shift if changes are made to a system at equilibrium.	I can describe a system at equilibrium and identify which direction equilibrium will shift when changes are made to a system at equilibrium.	I can describe a system at equilibrium and apply Le Châtelier's principle to identify how concentrations of reactants and products will be affected when a change is made to concentration or temperature.	I can do everything in Level 3 and can identify how concentrations of reactants and products will be affected when there's a change in pressure or volume.

Did You Get It?

- | | | | |
|---|---------------------------------------|---|---------------------------------------|
| Can you tell how changing the temperature will affect the rate of a reaction? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you tell how changing the concentration of a reactant will affect the rate of a reaction? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you tell how changing the reactant particle size will affect the rate of a reaction? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you use collision theory to explain why changing any of these variables or adding a catalyst or inhibitor will change the rate of a reaction? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you explain what is going on in a reaction that is at equilibrium? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you explain how the reaction will shift if changes are made to concentration or temperature of the system? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |
| Can you make a plan to optimize the amount of a specific substance produced in an equilibrium reaction? | <input type="checkbox"/> I've got it. | <input type="checkbox"/> I need practice. | <input type="checkbox"/> I need help. |

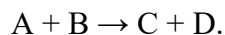
Appendix D: Summative Assessment

Kinetics and Equilibrium Assessment

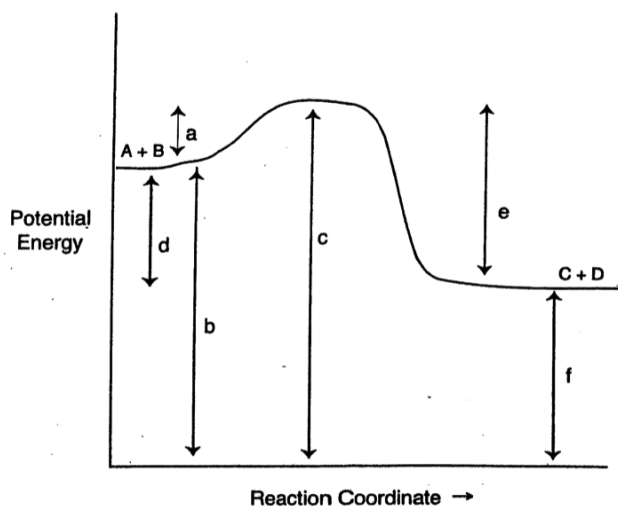
- Collision theory states: (Circle ALL that apply.)
 - Particles must collide with proper orientation for a reaction to occur
 - Reactions happen only when particles collide.
 - Every collision leads to a reaction
 - Particles must collide with enough energy to react
- Which of the following usually increase reaction rate? (Circle ALL that apply.)

a. Decreasing the concentration of reactants	e. Decreasing temperature
b. Increasing the concentration of reactants	f. Increasing particle size
c. Adding a catalyst	g. Decreasing particle size
d. Increasing temperature	
- Iron combines with oxygen in a slow, exothermic reaction, as shown below. Because it happens so slowly, we don't notice the heat being produced. By speeding it up, we can use this reaction to keep us warm in the winter. What are two changes that you could make to speed it up? Explain, including details about collision theory, why those changes will make the reaction happen faster. $4 \text{ Fe} + 3 \text{ O}_2 \rightarrow 2 \text{ Fe}_2\text{O}_3 + \text{heat}$

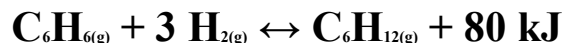
Respond to questions 4-8 by using letters "a" through "f" from the potential energy diagram for the reaction



- Which letter represents the potential energy of the reactants?
- Which letter represents the potential energy of the products?
- Which letter represents the overall energy change in the reaction (ΔH)?
- Which letter represents the activation energy of the reaction?
- Which letter(s) would change if a catalyst were added?
- Does this diagram represent an endothermic or exothermic reaction?

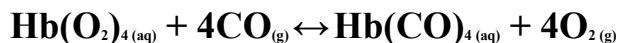


10. What is true about chemical equilibrium? (Circle ALL that apply.)
- The concentrations of the reactants and the products are always equal at equilibrium
 - The rates of the forward and reverse reactions are equal at equilibrium
 - Both forward and reverse reactions can continue once equilibrium is reached
11. For the following reaction, determine how the indicated change in conditions affects the reaction. Show how the equilibrium shifts and how the concentration of each substance is affected by filling in the blanks in the chart. For shift, write "right" or "left." For concentrations, write "I" for increase and "D" for decrease.



Stress	Equilibrium Shift	$\Delta[\text{C}_6\text{H}_6]$	$\Delta[\text{H}_2]$	$\Delta[\text{C}_6\text{H}_{12}]$
temperature decrease				
$[\text{H}_2]$ increase				
volume increase				

12. Your friend's house had high levels of carbon monoxide and she has a headache and dizziness. Luckily, their carbon monoxide alarm went off and everyone made it out of the house safely. Carbon monoxide is dangerous, because it replaces oxygen as it binds to hemoglobin (represented by Hb) in the blood, as shown in the reaction below.



What should be done to reverse the effects and make your friend feel better? Explain why this is the best treatment and how it will work.

Appendix E: Understanding by Design Template, Stage 3

Code	Pre-Assessment Summative Assessment as Pre-Test	
Students will be able to explain collision theory and identify factors that affect reaction rate.	<p>Learning Events</p> <p>Engage: Students will engineer a clock reaction to happen to the tune of a song of their choosing, varying temperature or concentration and noting the effects on the time for the color change.</p> <p>Explore: Students will use a computer simulation to observe the relationship between the types of particle collisions and the success of collisions in leading to chemical change.</p> <p>Explain: Start with some demonstrations, including burning powdered milk to introduce surface area effects on reaction rate and elephant toothpaste to introduce the use of a catalyst. Then summarize the factors that affect reaction rate and how collision theory can be used to explain the observed changes in rate.</p> <p>Elaborate: Students have conversation around collision theory and potential energy diagram practice questions. Catalytic Converters article to read and questions.</p> <p>Evaluate: Students present engineering challenge to song and explain the factor(s) used to manipulate the rate and why those factors led to the desired changes.</p> <p>Elaborate: Analysis of rate data for cause and effect relationships. Do the first few examples with students and then let them continue in small groups. Emphasis on utilization of data, controlled variables, and proportions. Students do not need to derive rate expressions.</p> <p>Engage: Elicit student preconceptions while demonstrating LeChatelier's principle with various reactions.</p> <p>Explore: Students will use M&M's to model reactants and products in a reaction at equilibrium, confronting common misconceptions about equilibrium.</p> <p>Explain: Students read the ChemMatters article, "What's So Equal About Equilibrium?", which defines equilibrium and applications in climate science.</p>	<p>Progress Monitoring</p> <p>As students work on testing and engineering their reaction, I will monitor their work.</p> <p>Before beginning computer simulation, they will discuss and write down ideas for why reactions happened faster when the temperature or concentration was higher. We will then return to these explanations to see how they changed after learning more about collision theory.</p> <p>This evaluation will allow me to know which students need more help.</p> <p>Monitor student responses in small group work. Provide additional guidance as needed.</p> <p>Lessons may need to be adjusted to confront alternative ideas. Provide feedback to student responses to equilibrium follow-up questions.</p>

	<p>Evaluate: Bailing water analogy – Set up two dishpans with water, and two beakers. Students are going to transfer the water from their pan into the other as efficiently as they can, using only their beaker. What will happen to the levels of water in the two dishpans? How does this model equilibrium? What factors might change the water levels once they have reached equilibrium?</p> <p>Explain: Online virtual equilibrium lab connects rates and Le Châtelier’s Principle. Then practice applying Le Chatelier’s principle.</p> <p>Elaborate: Students will learn about one way that predictable change in equilibrium was used to solve a real-world problem in the Le Chatelier’s Principle, Coupled Equilibrium, and Egg Shells article.</p> <p>Evaluate: Summative Assessment</p>	<p>After the analogy: Ask students to jot down their ideas about what would happen if one student were given a larger beaker than the other. Give students feedback – maybe just follow-up questions to consider.</p> <p>Analyze student responses to questions and practice problems and provide written feedback.</p> <p>Students who are not proficient on summative assessment will be required to complete intervention and reassess.</p>
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Appendix F: Teacher's Notes

Day 1: Introduce Engineering Activity

The teacher should start with the hook that there will be a new musical based on the Harry Potter series! The director would like special effects as part of the production and need a special effects expert to make some potions “magically” change color to the tune of the song. Students should be shown the iodine clock reaction and note that the reaction doesn't happen immediately when the reactants are mixed. Students will prove their abilities to the director by setting this reaction in sequence to a song of their choosing. If desired, students can be shown an example (and added level of challenge) by watching a YouTube video of Stanford students setting a reaction to the [William Tell Overture](#).

Questions for teacher to ask:

- “What is the problem that we are trying to solve?” Students should identify that this is a problem of changing how quickly a reaction occurs.
- “How might this problem apply in other situations?” Students might find alternative contexts like medicine, cooking, or cleaning that the rate of a reaction might need to be manipulated.
- “What variables might we test that would produce the desired effect and help us design a solution?” Students should identify temperature and concentration, but other variables may also be tested.
- “What are some constraints that must be considered?” Students may need the term constraints to be defined, depending on previous experiences. They might identify the materials available and time to design a solution.

- “Why should only one variable be tested at a time?” Students have hopefully been asked this question before, but it bears repeating. They should be able to identify that we can only draw cause and effect conclusions when we isolate one variable to change and one dependent variable to measure.
- “How might graphing your results help in designing a solution?” This might be a question you save until students have collected some data and are conversing with individual groups. Students might be able to see that if they can find a trend line, they can then determine the approximate conditions that will make a reaction happen at the desired times.

The design brief handout should be given to students at this time. This and all other handouts are provided in Appendix G. I would recommend groups of four students and it may be helpful to give students a position within their group. Groups may collaborate with each other and the teacher can check in with the communication officer to check progress.

1. Manager: This person makes sure everyone contributes to the group, keeps the group on task, and keeps track of time/constraints.
2. Recorder: This person will keep notes, data, and observations from your group’s work. This person is also in charge of the actual writing of the final presentations, though the entire group will contribute to its contents.
3. Communication/Resource officer: This person obtains and gets all the materials and resources the group need. This includes seeking information/resources from other groups if desired. The resource officer from another group should be approached when seeking to share information.

4. Lab Technician: This person sets up lab equipment, performs the experiment. Others can be directed to help with any experimentation, but the lab technician should direct them.

The rest of the class can be given to students to plan for the following day and brainstorm ideas for their song choice.

Days 2-4: Experimentation

During planning, testing, and optimization, the teacher should be available as a resource and monitor students' progress. While students are planning, ask them what information they will need to record and how they will go about collecting this data. If students are attempting to test more than one variable at a time, you may need to help them realize that this information will not be as useful as testing only one independent variable at a time.

Day 5: Collision Theory PhET

Provide students with devices to access the PhET website and the handout (provided in Appendix G) to lead them through using the Rates of Reaction simulation. As students work, walk around and check in on student thinking. Collect handouts and read and comment on the summarizing question with asterisk.

Day 6: Reaction Rate Demonstrations and Notes

Use [powdered milk](#) or lycopodium powder to compare the flame that you get when trying to burn a spoonful of powder to the flame that you get when you sprinkle the same spoonful of powder over a flame. Note that the sprinkling can create quite a large fireball, so be prepared to perform this demonstration safely with goggles and proper distance. Avoid areas of the room with smoke/heat detectors to prevent a false alarm.

Then set up the [elephant toothpaste demonstration](#), mixing two parts of 30% hydrogen peroxide with one part dish soap in a graduated cylinder inside of a container to aid in cleanup. Let student observe that there isn't much happening, because the reaction is happening very slowly. Then add a small amount of a catalyst such as potassium iodide solution and watch the foam quickly form and push out the top of the graduated cylinder. Both demonstrations are entertaining for students, but also do a great job demonstrating how greater surface area exposure and catalysts speed up a reaction. After completing these demonstrations, summarize the learning and add an explanation of a reaction diagram in students' notes (an outline is provided in Appendix G). Allow students to provide explanations and definitions in their own words, asking clarifying questions as needed. Once notes are complete, let small groups discuss the questions that follow, and check for understanding as you walk around to each group. Questions 3 and 5 are good questions to listen for student explanations in their discussions. If students are stuck or disagree, ask some leading questions that help them arrive at an answer they can support with collision theory.

Day 7: Practice and Application

Students should be given some time to practice interpreting reaction diagrams and answering questions utilizing collision theory as an explanation in the handouts (Appendix G). Again, move around the room and monitor student conversations and work. Provide feedback and guidance as needed. Once they finish, they can read the article about how catalytic converters work and answer the questions about the article (see Appendix G). You can print the article or direct them to the website on electronic

devices. Collect question responses and provide feedback or further questions for students to consider.

Day 8: Presentations

Now that students understand collision theory, give them about 20 minutes to prepare solutions for their song presentation. I chose to video record presentations to look back at later and share with colleagues. After presentations, ask students to explain what variable(s) they chose to manipulate and why that was an effective way to change the time to fit the reaction. You can have them do this orally or in writing. I prefer to ask each student to write their own explanation so that one student doesn't answer for an entire group. When reading these explanations, look for the cause and effect relationships between variables to be identified, evidence that supports that relationship, and references to collision theory in their reasoning. Provide feedback and separate explanations or make a list of those students who need additional instruction.

Day 9: Analysis of Rate Data

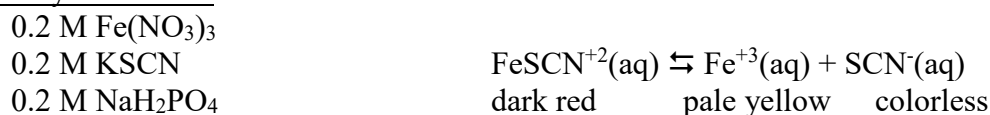
While rate expressions are beyond the performance expectations, I wanted my chemistry students to look at some numerical data and draw conclusions about the relationships. I didn't use terms like first or second order. We used more general descriptions, such as, "If the concentration is doubled, the rate increases by a factor of four and if the concentration is 4 times higher, the rate increases by a factor of 16. The pattern is that the change in concentration is squared to find the change in the rate." Or "If the concentration is doubled, the rate is also doubled. This suggests if the concentration was tripled, the rate would also be tripled" If students identify the difference between experimental data instead of factors, take the time to explore that data

and look for patterns. Once that data proves fruitless in making any predictions and they see how useful factors are, they will accept that it is a better way to analyze the rate data in general. An emphasis was on identifying which data pieces could help us find the relationships (by controlling all other variables).

Day 10: Le Chatelier's Demonstrations

This lesson is meant to engage students in figuring out why the changes they observe are happening and elicit their ideas. Students should take notes about what happens so that they can later use their understanding of Le Chatelier's principle to explain the changes. Instructions for possible demonstrations/videos/simulations follow:

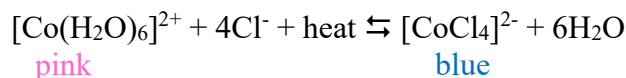
Iron Thiocyanate demo¹



- 1) add Fe⁺³
- 2) add SCN⁻
- 3) remove Fe⁺³ ($\text{Fe}^{3+}(\text{aq}) + \text{H}_2\text{PO}_4^{-}(\text{aq}) \rightarrow \text{Fe}(\text{H}_2\text{PO}_4)_3(\text{s})$)

Cobalt chloride demo²

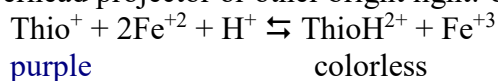
Three tubes of solution. One at room temperature, one in ice bath, one in hot water.



Thionin demo³

10 mL thionin solution (Make thionin fresh: 0.0115 g of thionin in 50 mL water)
 100 mL – 1M H₂SO₄
 ~500 mL distilled water
 2 g FeSO₄·7H₂O

Mix chemicals in 1L beaker and place on overhead projector or other bright light. Use foil to block light from half.



¹Adapted from Flinn Scientific: <https://www.flinnsci.com/overhead-equilibrium/vel5004/>

²I purchased the solution pre-made from Flinn: <https://www.flinnsci.com/hot-and-cold-equilibrium---lechateliers-principle---chemical-demonstration-kit/ap5938/>

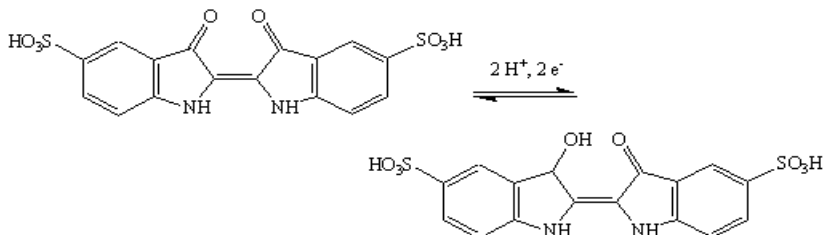
³Adapted from Flinn Scientific: <https://www.flinnsci.com/thionin---the-two-faced-solution/dc0815/>

Traffic light demo⁴

3g dextrose, dissolved completely before adding
5g sodium hydroxide

Once these are both dissolved, dilute to 250 mL Add 10 mL of indigo carmine, stopper and let sit for at least 10 minutes. (Make indigo carmine fresh: 0.1 g in 50 mL of water)

The changing levels of oxygen cause the color change. Dextrose reaction consumes the oxygen to change back.



⁴Adapted from Flinn Scientific: <https://www.flinnsci.com/stop-n-go-light/dc0402/>

Videos (sound off to avoid students hearing explanation):

http://www.youtube.com/watch?v=DA_wiqieC5s Effects of Pressure on Gases

<http://www.youtube.com/watch?v=0XQVXFL4uoo&feature=related> Temperature

Simulation:

http://phet.colorado.edu/new/simulations/sims.php?sim=Reversible_Reactions

Day 11: M&M Equilibrium

To prepare for this lesson, count out 40 M&Ms into a small paper cup and find the mass. Put approximately that mass in separate cups for each group. Before beginning, ask each student to respond to the true false statements at the top of the sheet. Take a moment to discuss some student ideas about what equilibrium means. Warn students that they need to completely finish the activity before they begin eating any M&Ms. The movement of M&Ms from one side of the sheet of paper to the other represents them reacting to make a new substance. After each round, students need to count and record the number of M&Ms on each side of the paper. Many of them start to notice that there is a point where the same number go from reactants to products as go from products to reactants even before graphing. At this point, the number recorded stays the same. They should be able to draw some conclusion about how this model represents what is

happening at equilibrium and refine their initial conceptions about what it means to be at equilibrium. Look for correct thinking and give students feedback on the final conclusions on the last page of the activity.

Day 12: Bailing Water and Equilibrium

Use the analogy of bailing water to demonstrate the changes in matter at equilibrium. Have two student volunteers bail water from their container into the other's container. This can get sloppy, so it is a good idea to set some ground rules about keeping the water in the containers. Start with all the water in one container and add a little food coloring to make it easier for the rest of the class to see. Give each of the students a small plastic cup (about 5 ounces). Their objective is to transfer the water to the other student's container as fast as they can. The rules are that they cannot block the other student from pouring water into their container, and they should try not to spill water everywhere. They both start bailing water, and the competition is paused periodically to prompt student observations of what is happening to the water levels and explanations about why that stability or change is occurring. Early on, the student with water can bail more than the student with the empty tub, so the matter is shifting towards the empty container. Later, they are exchanging about equal amounts, so the water levels stay relatively constant, but not necessarily at equal levels. Once they have reached equilibrium, tell them that you want to help one of the students out and give them a larger plastic cup. Ask them to predict how this change will affect the water levels and why. Let them start bailing again to test the predictions, and again pause to discuss the changes and eventual new equilibrium levels. They should articulate that the student with the larger cup had the ability to transfer more water, but as the water level decreased, it was difficult to fill the

cup. Discuss how that relates to reactions slowing as reactants are consumed. Ask the student with the larger cup pull out some water and pour it into the smaller cup, showing that the amount that both cups could “scoop” was approximately equal, leading to the equilibrium that is observed. Have students read the article, “[What’s So Equal about Equilibrium?](#)” (Tinnesand, 2005) with a partner. Stress that the RATES of the forward and reverse reaction is what is equal.

Day 13: Virtual Equilibrium Lab

Make sure students have access to computer/tablet devices, either individually or in pairs. Have students use the ChemVLab virtual lab investigation to learn more about what causes shifts in equilibrium and how to predict those shifts. They will likely need help using the lab bench, so that may be something you want to explain before getting started. This doesn’t seem to work in the Chrome browser, but we had success in Firefox and Internet Explorer with Java installed. It shows the color change in both the macroscale and microscale. After finishing the lab, there are a few questions for students to respond to that will allow for assessing learning and give you an opportunity to provide further feedback.

Day 14: Practice Using Le Chatelier’s Principle

Students should first go back to their observations of the Le Chatelier’s demonstrations and discuss with a partner what caused the color changes they observed. Model making some predictions about changes in equilibrium. Then they can work together to make predictions about what will result if changes are made to systems at equilibrium using the handout provided.

Day 15: Chicken Equilibrium Article

Students should read the article about how equilibrium can be used to solve the problem of hot chickens making weak eggs by providing carbonated water. They can then discuss and brainstorm other possible applications or cross-curricular connections (population equilibrium, for example). As practice for the assessment, the teacher could provide the scenario of a grandmother who wants a particular color hydrangea and a simplified equation for the color change. What do they need to do to help grandma get her flowers the correct color? Model an appropriate answer for the scenario to set students up for success. What makes that a good response? What are non-examples of a good response?

Day 16: Summative Assessment

Students should be seated separately and work individually to respond to the items on the formative assessment. When grading, look at each set of responses as a whole to determine the level of proficiency of a student. If a student doesn't experience success, allow opportunities for additional instruction and practice and reassess that student later.

Appendix G: Student Handouts

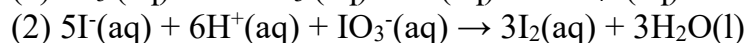
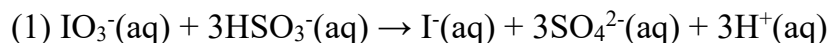
Design Brief: Stage Wizardry

Rates of Reaction

Context:

The rate of a chemical reaction is the time required for a given quantity of reactant(s) to be changed to product(s). Reaction rate is usually expressed in moles per unit time. This rate is affected by several factors, including the nature of the reactants, concentration of the reactants, temperature, pressure, and presence of catalysts. In this experiment, we will study the effects of two of these factors – temperature and concentration. A chemical reaction is the result of effective collisions between particles of reactants.

In this experiment, two solutions will be mixed, and the completion of the reaction will be marked by a color change. One solution contains the iodate ion (IO_3^-). The other contains the hydrogen sulfite ion (HSO_3^-) and soluble starch. The entire reaction takes place in two stages. The ionic equations for these stages are:



In the presence of starch molecules (not shown above), molecular iodine (I_2) produces a characteristic blue color. The rate of the entire reaction can be determined by timing the interval between the time the two solutions are mixed and the appearance of the blue color. By varying the concentration of one of the reactants (at constant temperature) and then varying the temperature of a constant concentration, the effects of these two factors on reaction rate can be observed and recorded.

This experiment should provide a better understanding of reaction rates and the factors that affect these rates. This information will be helpful in solving your problem.

Challenge:

You have the opportunity to audition for the position of special effects engineer for a stage production of *Harry Potter: The Musical*. The task you have been given is to make the reaction described above happen in a series of beakers to the tune of a song. To complete this task, you will need to study the effect of changing the concentration of a reactant and the temperature at which a reaction takes place on the rate of a chemical reaction. Design a solution for the problem, applying this knowledge to make the reaction happen to the tune of a song after pouring the chemicals together at the same time.

Resources:

You may use all materials that have been provided by your instructor. You may also make requests for other materials, but it is possible that those requests will not be approved.

- Solution A (0.04 M KIO_3) - 0.25 L per group
- Solution B (with HSO_3^- ion and soluble starch) - 0.25L per group
- safety goggles
- beakers and test tubes
- graduated cylinders
- thermometers
- timer (cell phone or stopwatch)
- distilled water
- ice cubes
- hot plates
- graph paper

Constraints:

You will have two complete class periods to test and design your solution. The next class period, you will have 20 minutes to prepare and then you will show your solution to the class. You will need to send a cued song to the teacher prior to this day to play during your demonstration. It could be from YouTube, a CD, or another electronic device.

Evaluation Summary:

Your team will be evaluated based on the presentation you make to the rest of the class. The score you receive depends on your ability to find a solution to the problem, explain the relationship of the variables, work safely in lab, collaborate, and provide feedback for the other groups. The grading rubric is found below.

Learning Target	Not Shown	Developing	Successful
I can find a solution for the problem using the resources available.	The reaction does not remotely match the tune.	The reactions match the tune of the song in one or two separate containers.	The reactions match the tune of the song in at least three separate containers.
I can explain the relationship between the variables tested and how that informed the design of the solution.	I can't accurately describe the relationship between variables.	I can explain the relationship but have trouble with how that lead me to the solution.	I can explain the relationship and how that led me to the solution presented.
I can work well in a group and fulfill my role.	I don't actively participate in the activity.	I actively participate in the activity.	I actively participate in the activity and fulfill all duties of my position.
I can work safely in lab.	I frequently need to be reminded to wear goggles and clean up after myself.	I wear goggles most of the time, but I am not as careful as I should be.	I wear goggles the entire time and use care when handling chemicals.
I can give constructive feedback to other groups to help improve their project.	I don't have any feedback to offer other groups to improve their presentation.	I have at least one piece of feedback for another group that would strengthen their presentation.	I have at least two pieces of feedback for other groups that would strengthen their presentation.

Collision Theory PhET Simulation

Collision theory says that particles must collide to react. This seems logical. But not every collision leads to a reaction. Today we will investigate what makes a successful collision, and therefore, what can be done to increase those collisions and the overall speed of a reaction.

Go to the site www.phet.colorado.edu, click on “Play with Sims”. Go to the “chemistry” tab on the left side of the page, and then scroll down to the simulation labeled “Reactions & Rates”. Click on it, and then choose the green button labeled “Run Now”.

Single Collision Tab

1. This simulation uses a pinball launcher as a model for reacting particles. Particle A is in the launcher, and particle BC is in the middle of the reaction chamber. What changes as you begin to pull the launcher back?
2. Pull the launcher back all the way and release. What do you observe?
3. Click “Reload Launcher” and try it again, but only pull the launcher back halfway. What does this change about our model? What do you observe that is different as a result?
4. Reload the launcher again, and set the Launcher Options button to “Angled shot”. Change the angle of the launcher so that it will still hit the particle in the middle of the screen. Pull it all the way back and release. How is this model different than the first one? What changes as a result?
5. What factors seem to be important to get particles to react in the model?

Many Collisions Tab

1. Switch to the tab labeled Many Collisions at the top of the screen. Add about 5 particles of A and 5 particles of BC. What do you observe in the reaction chamber?
2. According to what you saw in the single collisions, what could you do to make the particles react?
3. What else could you do to make more particles react?
4. What are some “rules” for reacting particles?

Another Model¹

In this model, a baseball bat represents Reactant A and a baseball represents Reactant B. A reaction will only be successful if the batter hits a homerun. If the batter does not hit a homerun, the reaction will be considered a failure.

Now, read the four scenarios and answer the questions.

Scenario 1: The pitcher throws a fastball down the middle of the plate. The batter takes a mighty swing and totally misses the ball. The umpire yells, “Strike one!”

Scenario 2: The pitcher throws an off-speed pitch, and the batter checks his swing. The batter just barely makes contact with the ball and it dribbles down in front of the batter’s feet into foul territory. The umpire yells, “Foul ball; strike two!”

Scenario 3: The pitcher throws a curveball that looks like it might catch the outside corner of the plate. The batter swings with all his strength, but the bat grazes the underside of the ball and the ball skews off to the right, flying into the crowd. The umpire yells, “Foul ball; still two strikes!”

Scenario 4: The pitcher throws another fastball down the center of the plate. The batter swings and wallops the ball high into the air and the ball clears the center field wall that reads 410 feet. The umpire yells, “Homerun!”

1. Did a reaction happen in scenario 1? Why or why not? Explain in terms of the nature of the collision.

2. Did a reaction happen in scenario 2? Why or why not? Explain in terms of the nature of the collision.

3. Did a reaction happen in scenario 3? Why or why not? Explain in terms of the nature of the collision.

4. Did a reaction happen in scenario 4? Why or why not? Explain in terms of the nature of the collision.

5. What is needed for an effective collision?

*6. Complete the following sentence: Collision theory states that a reaction is most likely to occur if...

¹Horan, B. (2006). *Collision theory – impact for a chemical reaction*. POGIL. Stony Brook University. http://69.195.198.240/uploads/media_items/collision-theory.original.pdf

Rates of Reaction Notes

Reaction rate:

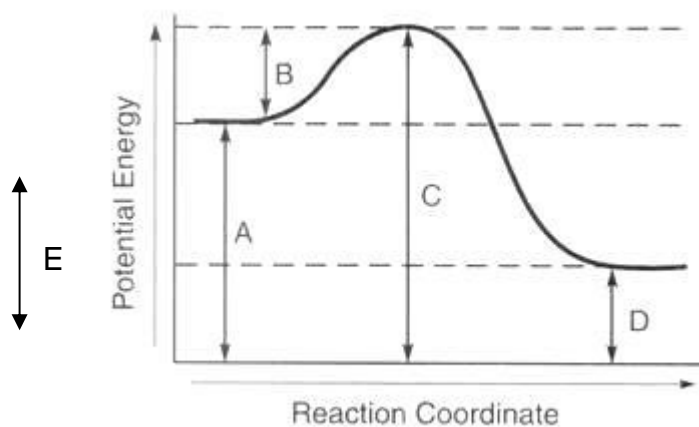
Collision Theory:

Rate depends on:

- 1.
- 2.
- 3.

Activation Energy:

Activated Complex: (also known as _____):



Potential Energy Diagrams

A:

B:

C:

D:

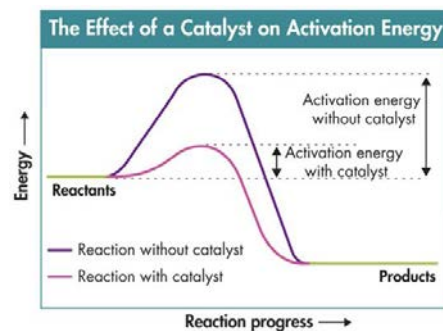
E:

Is this reaction endothermic or exothermic?

Factors affecting reaction rates:

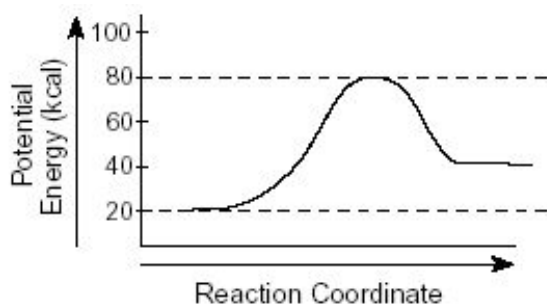
- 1.
- 2.
- 3.
- 4.

What is the opposite of a catalyst?



Questions:

- Does every collision between reacting particles lead to products? Explain.
- Suppose a thin sheet of zinc containing 0.5 mol of the metal is completely changed in air to zinc oxide (ZnO) in one month. How could you express the rate of conversion of the zinc?
- *Why does refrigerated food stay fresh for much longer periods than food stored at room temperature?
- How do catalysts speed up a reaction? (Hint: it may be useful to draw a diagram)
- *When the gas to a stove is turned on, the gas does not burn until it is lit by a flame or spark. Once lit, however, it continues to burn until it is turned off. Explain why this happens and the purpose of the flame or spark.
- Use the potential energy diagram to answer the following:



Endothermic or exothermic?

Potential energy (PE) of reactants?

PE of products?

PE of activated complex?

Activation energy of forward reaction?

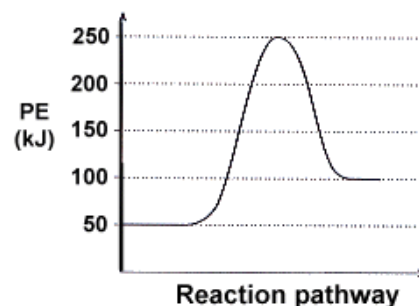
Activation energy of reverse reaction?

Collision Theory and Potential Energy Diagrams

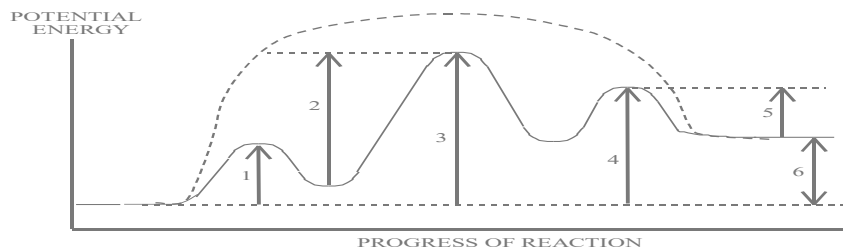
- 1) *Explain why all reactions have an activation energy, using your knowledge of collision theory.
- 2) *Describe how the activation energy of a reaction affects the overall rate of the chemical reaction.
- 3) *It has been observed that more gas station fires occur on hot days than on cold days. Explain this phenomenon using your knowledge of collision theory. (Hint: It's not just the temperature increase that causes this!)

- 4) *Answer the following questions based on the potential energy diagram shown here:

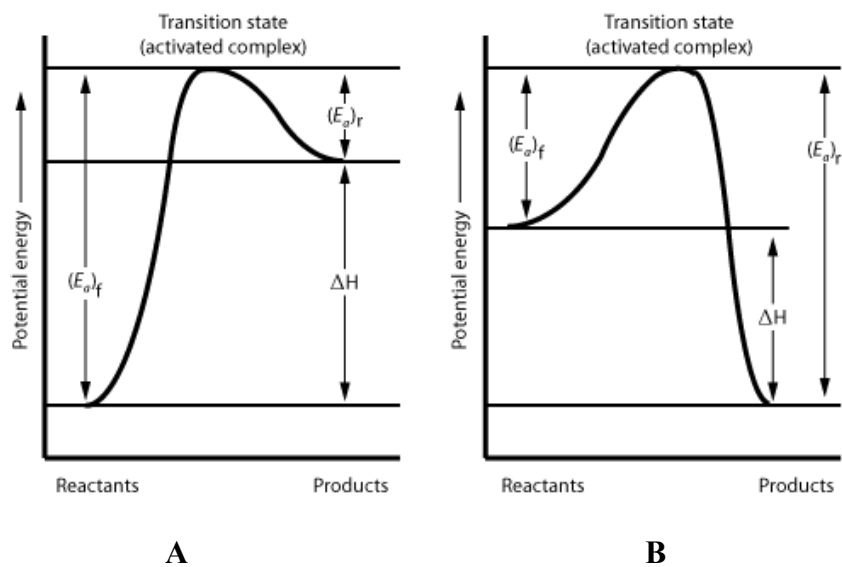
- a. Does the graph represent an endothermic or exothermic reaction?
- b. Label the position of the reactants, products, and activated complex.
- c. Determine the activation energy, E_a for this reaction.
- d. How much energy is released or absorbed during the reaction?



- 5) Given the following *Potential Energy Diagram* for a 3 step reaction, answer the questions below it:



- a) Which arrow indicates the *activation energy* for the *first* step of the reverse reaction?
- b) Which arrow indicates the *activation energy* for the *first* step of the forward reaction?
- c) Which arrow indicates the *activation energy* for the *second* step of the forward reaction?
- d) Which arrow indicates the *enthalpy change* (ΔH) or "*enthalpy change*" for the *overall forward* reaction?
- e) Which arrow indicates the *enthalpy change* (ΔH) or "*enthalpy change*" for the *overall reverse* reaction?



- 6) Use the above Potential Energy Diagrams to answer the following questions:
- a) Compare the activation energy shown on graph A to the activation energy shown on graph B. Which reaction is more favorable? Why?
 - b) Which reaction is endothermic? How do you know?
- 7) Sketch your own potential energy diagram for an **exothermic reaction**. Label X-axis, Y-axis, Reactants, Products, Activation Energy, Activated Complex, Overall Energy Change.

Catalytic Converter Article

Read the article, "[How Catalytic Converters Work](#)" (Nice & Bryant, 2000) to learn how reaction rate chemistry is used in designing parts to a vehicle.

Answer the following questions about the article. Try to make connections to collision theory.

1. Why is it important to have a catalytic converter in all vehicles?
2. Notice the location of the catalytic converter in the diagram of the car. What is the advantage of moving the catalytic converter to be as close to the engine as possible?
3. What is the design advantage to using a tiny honeycomb pattern or ceramic beads coated with the catalyst as opposed to just passing through the pipe?

Analyzing Effects on Rate

1. Consider the following data for the reaction $A \rightarrow B$.

	Initial [A] (M)	Initial rate (M/s)
Experiment 1	0.05	3.0×10^{-4}
Experiment 2	0.10	12×10^{-4}
Experiment 3	0.20	48×10^{-4}

- How did the concentration of substance A change from experiment 1 to 2?
 - How did that change affect the rate?
 - How did the concentration of substance A change from experiment 2 to 3?
 - How did that change affect the rate?
 - How did the concentration of substance A change from experiment 1 to experiment 3?
 - How did that change affect the rate?
 - What is the pattern for the relationship between a change in concentration of substance A and the change in rate?
2. Consider the following data for the reaction $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$.

	Initial [N_2O_5] (M)	Initial rate (M/s)
Experiment 1	0.010	4.8×10^{-6}
Experiment 2	0.020	9.6×10^{-6}

- How did the concentration of N_2O_3 change from experiment 1 to 2?
 - How did this change affect the rate?
 - What is the relationship between the change in concentration and the change in rate for this reaction?
3. Consider the following data for the reaction $A + B \rightarrow C$.

	Initial [A] (M)	Initial [B] (M)	Initial rate (M/s)
Experiment 1	0.050	0.050	4.0×10^{-3}
Experiment 2	0.10	0.050	8.0×10^{-3}
Experiment 3	0.050	0.10	1.6×10^{-2}

- What is the dependent variable in these experiments?
- What independent variable was changed between experiment 1 and 2?
- What variable was held constant between experiment 1 and 2?
- How did the change in concentration affect the rate from experiment 1 to 2?
- What is the relationship between concentration of substance A and the rate?
- Which set of experiments should be considered to gauge the effects of a change in the concentration of substance B?
- What is the relationship between concentration of substance B and the rate?

4. Consider the following data for the reaction $\text{OCl}^-(\text{aq}) + \text{I}^-(\text{aq}) \rightarrow \text{OI}^-(\text{aq}) + \text{Cl}^-(\text{aq})$.

	$[\text{OCl}^-]$ (M)	$[\text{I}^-]$ (M)	Initial rate (M/s)
Experiment 1	0.0040	0.0020	4.8×10^{-4}
Experiment 2	0.0020	0.0040	4.8×10^{-4}
Experiment 3	0.0020	0.0020	2.4×10^{-4}

- What is the effect of concentration of OCl^- on the rate of this reaction?
 - *Which two experiments did you consider to reach this conclusion? Why did you choose those two experiments?
 - What is the effect of concentration of I^- on the rate of this reaction?
 - *Which two experiments did you consider to reach this conclusion? Why did you choose those two experiments?
5. Consider the following data for the reaction $\text{NO}_2^- + \text{NH}_4^+ \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$.

	Initial $[\text{NO}_2^-]$ (M)	Initial $[\text{NH}_4^+]$ (M)	Initial rate (M/s)
Experiment 1	0.010	0.200	5.4×10^{-7}
Experiment 2	0.020	0.200	10.8×10^{-7}
Experiment 3	0.040	0.200	21.5×10^{-7}
Experiment 4	0.200	0.0202	10.8×10^{-7}
Experiment 5	0.200	0.0404	21.6×10^{-7}
Experiment 6	0.200	0.0808	43.3×10^{-7}

- What is the effect of changing the concentration of NO_2^- on the rate of this reaction?
- *Which experiments did you choose to analyze to reach this answer, and why?
- What is the effect of changing the concentration of NH_4^+ on the rate of this reaction?
- *Which experiments did you choose to analyze to reach this answer, and why?

M&M Equilibrium Lab

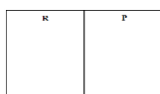
First, please decide whether you believe the following statements are true or false.

- T** or **F** At equilibrium, there are equal concentrations of reactants and products.
- T** or **F** The reaction stops once equilibrium has been reached.
- T** or **F** Equilibrium will be the same whether you start with reactants, products, or a mixture of both.

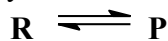
Materials: 40 M&M candies for each group and 1 blank sheet of paper

Introduction:

For this lab, we will be using M&M candies to represent chemical compounds undergoing a reaction. In groups of two, draw a line down the middle of a sheet of paper. Label the left side of the paper “R” for reactants and the right side “P” for products.



You will be performing all of your reactions on this paper according to the following equation:



To represent molecules that are reactants, you will put M&M’s on the reactant side of the paper; products will be M&M’s on the product side of the paper. Reactions will be represented by moving an M&M from one side of the paper to the other.

Part I

For this part, one person should take care of moving M&M’s from the reactant side and the other should move products to reactants. It is key to do this simultaneously.

1. Start with 40 M&M’s on the reactant side of the paper.
2. Each round, you will be exchanging M&M’s between R and P.
3. For each round, **R should move half of his/her M&M’s to the P side. P should move one fourth of theirs to the R side.** (If you end up with a decimal for the number to exchange, you should round up.)
4. At the end of each round, count the M&M’s on each side of the paper and keep track of the numbers in a table.

Round	R	P
0	40	0
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

5. At the end of 10 rounds, calculate the ratio of products to reactants. (ratio = P/R)

Part II

6. Part two is the exact same as part one except for the starting amounts of reactants and products. Choose a number of M&M's to put in the reactant side and put the rest in the products side.
7. Start exchanging the M&M's by following the same rules from step 3 in part one. Keep track of the number of candies on each side after each transaction in another table.

Round	R	P
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

8. At the end of 10 rounds, calculate the ratio of products to reactants.

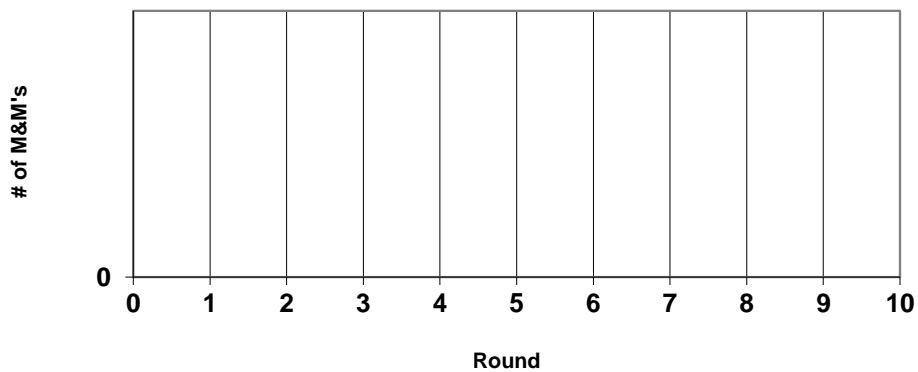
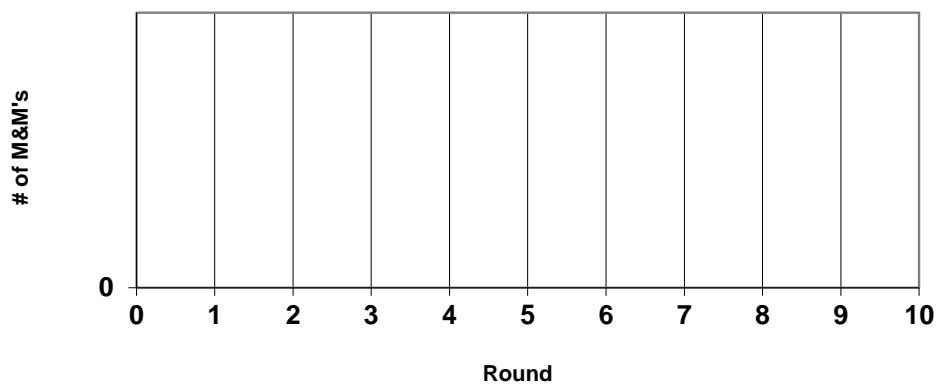
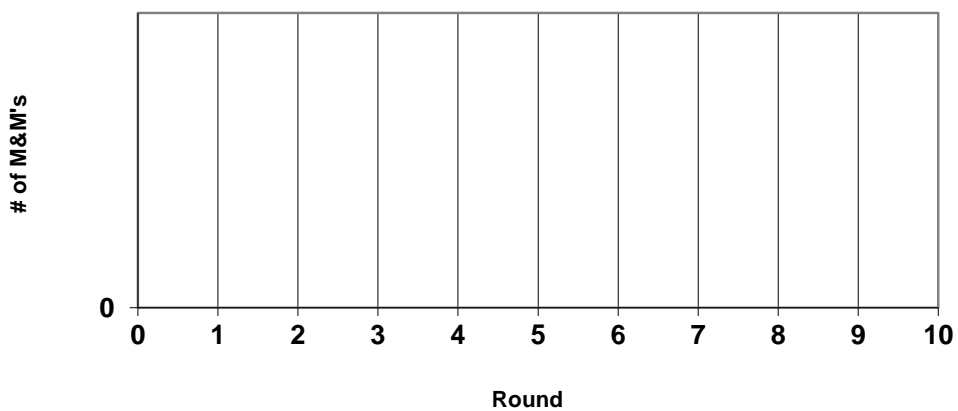
Part III

9. Part three follows the same rules as parts one and two. Except you will need to join up with another group for this part because it requires more total M&M's. Start with 0 reactants and 40 products.
10. Exchange for five rounds and calculate the ratio of products to reactants.
11. After the fifth round, add another group's candies to the reactant side of the equation and continue to exchange for another 5 rounds.

Round	R	P
0	0	40
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

12. At the end of the last round, calculate the ratio of products to reactants.

Graph the reaction progress for each of the three parts of this activity. Use a different color or symbol for reactants and products and connect the dots for each set.

Part I**Part II****Part III**

Questions: You may eat your M&M's while you work on the questions.

- Q1. How could you tell when your M&M "reaction" had reached equilibrium? What happened after several rounds of reaction in each of the three parts?
- Q2. *At equilibrium, is the concentration of "reactants" and "products" always equal? Explain.
- Q3. *Does the "reaction" stop once equilibrium is reached? Explain.
- Q4. In part III, you added more M&M's to one side of the paper. Think about what happened after you added the M&M's. The word dynamic is defined as: marked by usually continuous and productive activity or change. Why do you think equilibrium is often described as "dynamic"?
- Q5. *At equilibrium, the **rate** of the forward reaction _____ the **rate** of the reverse reaction.
- Q6. Under the same conditions, at equilibrium the concentrations of both reactants and products remain _____.
- Q7. Equilibrium may be approached from different starting points, but at equilibrium the **ratio** of products to reactants will be _____.

Virtual Equilibrium Lab

Go to the website chemvlab.org

Click on “Activities” and then choose the “Equilibrium” activity and push the “Try It!” button. After you have finished the entire activity, the following three questions will show up on the screen. Instead of entering your answers there, write them below.

1. What is happening on the molecular level when the reaction shifts to the left?

2. How can you remove a chemical from a reaction?

3. For these reactions, what does the color of the solution tell you about the equilibrium position of the reaction?

LeChâtelier's Principle

Which direction will equilibrium shift in response to the changes listed?

1. $\text{N}_2 (\text{g}) + 3 \text{H}_2 (\text{g}) \rightleftharpoons 2 \text{NH}_3 (\text{g}) + \text{heat}$
 - a. remove NH_3 gas
 - b. decrease pressure
 - c. add N_2 gas
 - d. increase temperature

2. $2 \text{SO}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons 2 \text{SO}_3 (\text{g}) + \text{heat}$
 - e. increase SO_2 concentration
 - f. increase temperature
 - g. remove O_2

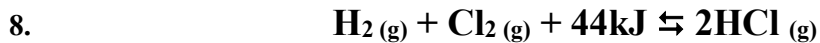
3. $\text{CO}_2 (\text{g}) + \text{C} (\text{s}) + \text{heat} \rightleftharpoons 2 \text{CO} (\text{g})$
 - h. increase temperature
 - i. increase CO concentration
 - j. decrease pressure

4. $\text{H}_2 (\text{g}) + \text{Cl}_2 (\text{g}) \rightleftharpoons 2 \text{HCl} (\text{g}) + \text{heat}$
 - k. increase H_2 concentration
 - l. increase pressure

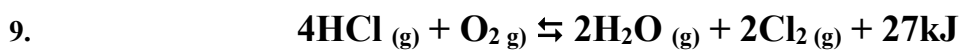
5. $\text{N}_2 (\text{g}) + \text{O}_2 (\text{g}) + \text{heat} \rightleftharpoons 2 \text{NO} (\text{g})$
 - m. decrease O_2 concentration
 - n. add catalyst

6. $\text{PCl}_3 (\text{g}) + \text{Cl}_2 (\text{g}) \rightleftharpoons \text{PCl}_5 (\text{g}) + \text{heat}$
 - o. increase Cl_2 concentration
 - p. decrease pressure

7. $\text{CO}_2 (\text{g}) + \text{H}_2 (\text{g}) + \text{heat} \rightleftharpoons \text{CO} (\text{g}) + \text{H}_2\text{O} (\text{g})$
 - q. decrease pressure
 - r. add a catalyst



Change	Shift	$[\text{H}_2]$	$[\text{Cl}_2]$	$[\text{HCl}]$
Pressure up				
Pressure down				
Temperature up				
Temperature down				
Hydrogen up				
Chlorine up				
Add HCl				



Change	Shift	$[\text{HCl}]$	$[\text{O}_2]$	$[\text{H}_2\text{O}]$	$[\text{Cl}_2]$
Pressure up					
Pressure down					
Temperature up					
Temperature down					
Add HCl					
Take out Oxygen					
Add Water Vapor					

Appendix H: Answer Keys

Collision Theory PhET Simulation

Collision theory says that particles must collide to react. This seems logical. But not every collision leads to a reaction. Today we will investigate what makes a successful collision, and therefore, what can be done to increase those collisions and the overall speed of a reaction.

Go to the site www.phet.colorado.edu, click on “Play with Sims”. Go to the “chemistry” tab on the left side of the page, and then scroll down to the simulation labeled “Reactions & Rates”. Click on it, and then choose the green button labeled “Run Now”.

Single Collision Tab

1. This simulation uses a pinball launcher as a model for reacting particles. Particle A is in the launcher, and particle BC is in the middle of the reaction chamber. What changes as you begin to pull the launcher back? **The temperature increases, as shown on the thermometer.**
2. Pull the launcher back all the way and release. What do you observe?
The atom (A) collides with the molecule (BC), knocking the C atom off and connecting a new molecule, AB. This represents a reaction.
3. Click “Reload Launcher” and try it again, but only pull the launcher back halfway. What does this change about our model? What do you observe that is different as a result? **The atom is shot more slowly. The particles collide, but do not react.**
4. Reload the launcher again, and set the Launcher Options button to “Angled shot”. Change the angle of the launcher so that it will still hit the particle in the middle of the screen. Pull it all the way back and release. How is this model different than the first one? What changes as a result? **The particles collide at an angle instead of a direct hit. As a result, they ricochet off, but do not form any new particles.**
5. What factors seem to be important to get particles to react in the model?
They need to be moving fast enough and at the correct angle to react.

Many Collisions Tab

1. Switch to the tab labeled Many Collisions at the top of the screen. Add about 5 particles of A and 5 particles of BC. What do you observe in the reaction chamber?
The particles bounce around, hitting the walls inside the chamber, sometimes colliding with each other. They do not react.
2. According to what you saw in the single collisions, what could you do to make the particles react?
You could make them move faster so they hit harder. It doesn't seem to allow you to change the angle that they collide.
3. What else could you do to make more particles react? **If we added more particles, they would be crowded closer together and collide more often.**
4. What are some “rules” for reacting particles? **They must have enough energy when colliding, and the proper angle of collision.**

Another Model (from POGIL by Horan, 2006)

In this model, a baseball bat represents Reactant A and a baseball represents Reactant B. A reaction will only be successful if the batter hits a homerun. If the batter does not hit a homerun, the reaction will be considered a failure.

Now, read the four scenarios and answer the questions.

Scenario 1: The pitcher throws a fastball down the middle of the plate. The batter takes a mighty swing and totally misses the ball. The umpire yells, "Strike one!"

Scenario 2: The pitcher throws an off-speed pitch, and the batter checks his swing. The batter just barely makes contact with the ball and it dribbles down in front of the batter's feet into foul territory. The umpire yells, "Foul ball; strike two!"

Scenario 3: The pitcher throws a curveball that looks like it might catch the outside corner of the plate. The batter swings with all his strength, but the bat grazes the underside of the ball and the ball skews off to the right, flying into the crowd. The umpire yells, "Foul ball; still two strikes!"

Scenario 4: The pitcher throws another fastball down the center of the plate. The batter swings and wallops the ball high into the air and the ball clears the center field wall that reads 410 feet. The umpire yells, "Homerun!"

1. Did a reaction happen in scenario 1? Why or why not? Explain in terms of the nature of the collision. **No, because the batter did not make contact. There must be a collision of the bat and ball for a homerun.**
2. Did a reaction happen in scenario 2? Why or why not? Explain in terms of the nature of the collision. **No, because the batter made contact, but not at the right angle or with enough force. The ball slowly bounced off into foul territory as a result. The collision of the ball and bat must be more direct and harder for a homerun.**
3. Did a reaction happen in scenario 3? Why or why not? Explain in terms of the nature of the collision. **No, because the batter made contact, but again, at the wrong angle. The ball went into foul territory again as a result. He needs to get the timing right for a direct hit to get a homerun.**
4. Did a reaction happen in scenario 4? Why or why not? Explain in terms of the nature of the collision. **Yes, the batter hit the ball hard and with the correct timing for direct contact between the ball and bat. The collision sent the ball sailing far over the wall.**
5. What is needed for an effective collision? **proper timing (angle) and energy.**
- *6. Complete the following sentence: Collision theory states that a reaction is most likely to occur if... **the particles collide with enough energy and in the right orientation.**

Rates of Reaction Notes

Reaction rate: **Change in reactants or products over time – provide examples**

Collision Theory: **explanation of reaction rates that assumes successful collision of reacting particles is needed to create products; allows for predictions about the results of changes.**

Rate depends on:

1. **frequency: the more often particles collide, the more likely they will react.**
2. **energy: the faster the particles move, the more often they will collide, and more forceful collisions will be, leading to more reacting particles.**
3. **orientation: if particles are properly aligned when they collide, they are more likely to react to form products.**

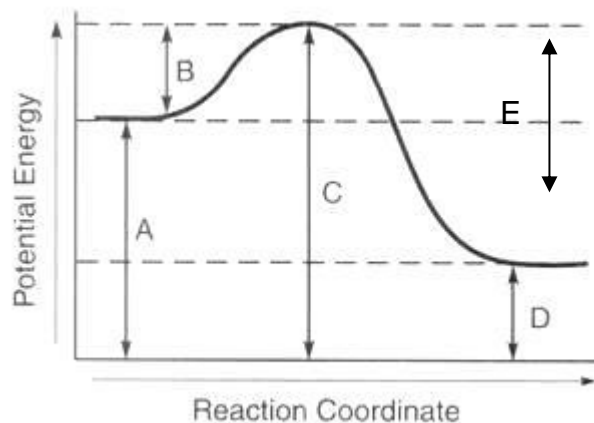
Activation Energy: **the minimum amount of energy that colliding particles need in order to make products.**

Activated Complex: (also known as transition state):

Potential Energy Diagrams

- A: **Potential energy of reactants**
 B: **activation energy, E_a**
 C: **potential energy of activated complex**
 D: **potential energy of products**
 E: **overall change in energy, ΔH**

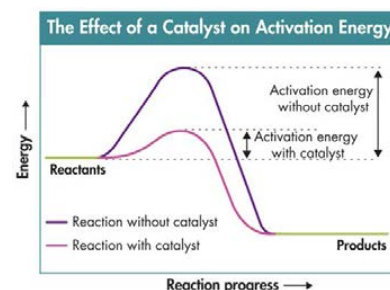
Is this reaction endothermic or exothermic?
Exothermic, since the amount of energy needed is less than the amount of energy that is released.



Factors affecting reaction rates:

1. **concentration: higher concentration, the more closely packed particles are, the more frequent collisions will occur, leading to faster reactions. (includes higher pressure for gases)**
2. **temperature: higher temperature means faster moving particles, greater frequency and energy with which collisions occur, leading to faster reactions.**
3. **catalyst: lowers activation energy, making lower energy collisions able to make products.**
4. **surface area: the smaller the reacting particles are, the more surface area is exposed for collisions**

What is the opposite of a catalyst? **Inhibitor (slows a reaction)**



Questions:

1. Does every collision between reacting particles lead to products? Explain.

No, particles can collide and bounce off, unchanged, if they don't have enough energy or the right alignment.

2. Suppose a thin sheet of zinc containing 0.5 mol of the metal is completely changed in air to zinc oxide (ZnO) in one month. How could you express the rate of conversion of the zinc?

This could be expressed in several ways, including 0.5 mol/month or 6.0 mol/year.

3. Why does refrigerated food stay fresh for much longer periods than food stored at room temperature?

Refrigerated food is colder, and lower temperatures slow reactions since particles have less energy and fewer are able to collide hard enough to react.

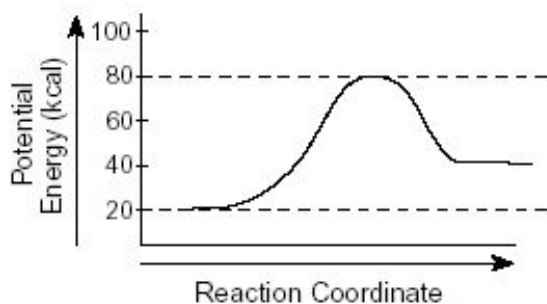
4. How do catalysts speed up a reaction? (Hint: it may be useful to draw a diagram)

Catalysts lower activation energy, making a larger portion of the particles have sufficient energy to react when they collide. Sometimes this is by providing a surface for the reaction to take place, with the proper orientation of the particles. Sometimes, it collides with and temporarily changes one of the reacting particles, which requires less energy to react with the other reactant.

5. When the gas to a stove is turned on, the gas does not burn until it is lit by a flame or spark. Once lit, however, it continues to burn until it is turned off. Explain why this happens and the purpose of the flame or spark.

The spark provides the small amount of extra energy needed for the collisions to turn the gas and oxygen into carbon dioxide and water. That reaction is exothermic, so once it is going, the heat that is released is enough to sustain the reaction until the gasoline is removed.

6. Use the potential energy diagram to answer the following:



Endothermic or exothermic? **endothermic**

Potential energy (PE) of reactants? **20 kcal**

PE of products? **40-45 kcal**

PE of activated complex? **80 kcal**

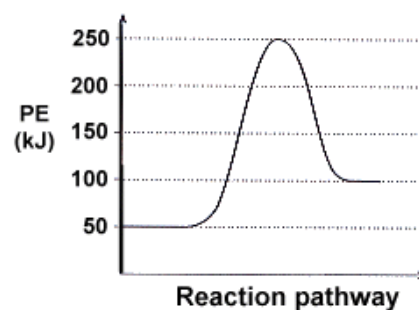
Activation energy of forward reaction? **60 kcal**

Activation energy of reverse reaction? **40-45 kcal**

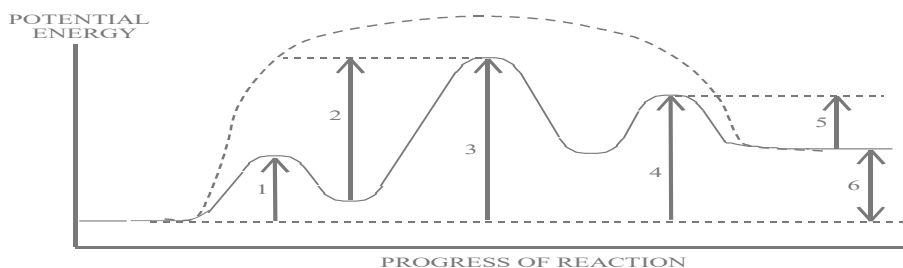
Collision Theory and Potential Energy Diagrams

- 1) *Explain why all reactions have an activation energy, using your knowledge of collision theory. **No matter what particles are colliding, they will not react if they bump into each other too softly. The amount of energy needed changed, but there is always a minimum amount of energy needed.**
- 2) *Describe how the activation energy of a reaction affects the overall rate of the chemical reaction. **The greater the activation energy, the less frequently collisions will have enough energy to react, and the slower the reaction will occur.**
- 3) *It has been observed that more gas station fires occur on hot days than on cold days. Explain this phenomenon using your knowledge of collision theory. (Hint: It's not just the temperature increase that causes this!) **The particles at higher temperature have more energy, leading to more frequent successful collisions between the gasoline and oxygen particles. In addition, higher temperature means more particles will evaporate to become gas, increasing the surface area for the gasoline and oxygen to collide.**
- 4) *Answer the following questions based on the potential energy diagram shown here:

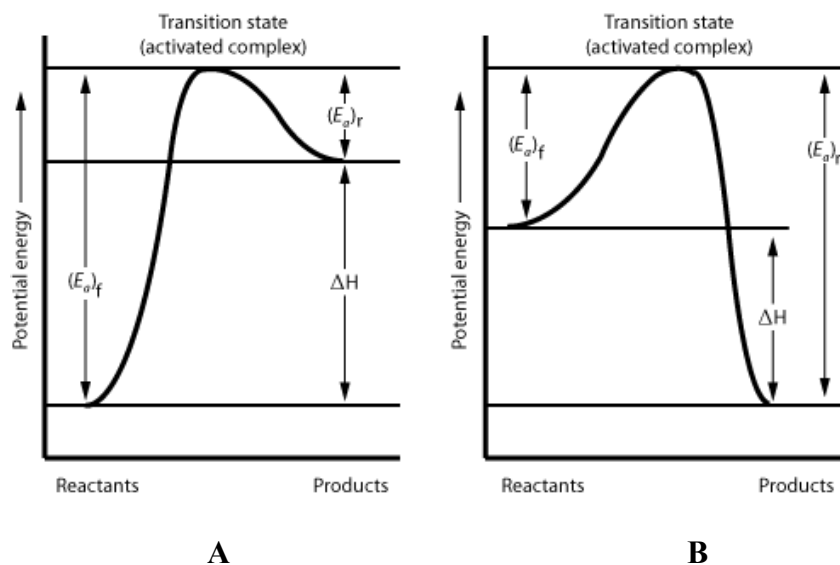
- a. Does the graph represent an endothermic or exothermic reaction? **endothermic**
- b. Label the position of the reactants, products, and activated complex.
- c. Determine the activation energy, E_a for this reaction. **200 kJ**
- d. How much energy is released or absorbed during the reaction? **50 kJ is absorbed**



- 5) Given the following *Potential Energy Diagram* for a 3-step reaction, answer the questions below it:



- a) Which arrow indicates the *activation energy* for the *first* step of the reverse reaction? **5**
- b) Which arrow indicates the *activation energy* for the *first* step of the forward reaction? **1**
- c) Which arrow indicates the *activation energy* for the *second* step of the forward reaction? **2**
- d) Which arrow indicates the *enthalpy change* (ΔH) or "*enthalpy change*" for the *overall forward* reaction? **4**
- e) Which arrow indicates the *enthalpy change* (ΔH) or "*enthalpy change*" for the *overall reverse* reaction? **6**



- 6) Use the above Potential Energy Diagrams to answer the following questions:
- Compare the activation energy shown on graph A to the activation energy shown on graph B. Which reaction is more favorable? Why? **B is more favorable, because it has a much lower activation energy.**
 - Which reaction is endothermic? How do you know? **A is endothermic because it takes in more energy than it releases as the reaction progresses.**
- 7) Sketch your own potential energy diagram for an **exothermic reaction**. Label X-axis, Y-axis, Reactants, Products, Activation Energy, Activated Complex, Overall Energy Change.

Answers will vary, but the diagram should have more potential energy for the reactants than the products and all parts should be labeled properly.

Catalytic Converter Article

Read the article, "[How Catalytic Converters Work](#)" to learn how reaction rate chemistry is used in designing parts to a vehicle.

Answer the following questions about the article. Try to make connections to collision theory.

1. Why is it important to have a catalytic converter in all vehicles? **The catalytic converter reduces the amount of harmful gas emissions that leave a vehicle. It is important to create less air pollution so that we have clean air to breathe.**
2. Notice the location of the catalytic converter in the diagram of the car. What is the advantage of moving the catalytic converter to be as close to the engine as possible? **The closer it is to the engine, the faster it will warm up, which increases the rate of the conversion of the gases, leading to fewer emissions.**
3. What is the design advantage to using a tiny honeycomb pattern or ceramic beads coated with the catalyst as opposed to just passing through the pipe? **The design provides greater surface area for the collision of gas particles with the catalyst on the surface. This increases the proportion of the gas particles that are converted and reduces the emission of those gases.**

Analyzing Effects on Rate

1. Consider the following data for the reaction $A \rightarrow B$.

	Initial [A] (M)	Initial rate (M/s)
Experiment 1	0.05	3.0×10^{-4}
Experiment 2	0.10	12×10^{-4}
Experiment 3	0.20	48×10^{-4}

- How did the concentration of substance A change from experiment 1 to 2? **doubled**
 - How did that change affect the rate? **quadrupled**
 - How did the concentration of substance A change from experiment 2 to 3? **doubled**
 - How did that change affect the rate? **quadrupled**
 - How did the concentration of substance A change from experiment 1 to experiment 3? **Four times greater**
 - How did that change affect the rate? **16 times greater**
 - What is the pattern for the relationship between a change in concentration of substance A and the change in rate? **The change in concentration squared is equal to the change in rate.**
2. Consider the following data for the reaction $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$.

	Initial [N_2O_5] (M)	Initial rate (M/s)
Experiment 1	0.010	4.8×10^{-6}
Experiment 2	0.020	9.6×10^{-6}

- How did the concentration of N_2O_3 change from experiment 1 to 2? **doubled**
 - How did this change affect the rate? **doubled**
 - What is the relationship between the change in concentration and the change in rate for this reaction? **The rate changes by the same factor as the concentration.**
3. Consider the following data for the reaction $A + B \rightarrow C$.

	Initial [A] (M)	Initial [B] (M)	Initial rate (M/s)
Experiment 1	0.050	0.050	4.0×10^{-3}
Experiment 2	0.10	0.050	8.0×10^{-3}
Experiment 3	0.050	0.10	1.6×10^{-2}

- What is the dependent variable in these experiments? **rate**
- What independent variable was changed between experiment 1 and 2? **Initial [A] (M) was doubled.**
- What variable was held constant between experiment 1 and 2? **Initial [B] (M)**
- How did the change in concentration affect the rate from experiment 1 to 2? **It doubled.**
- What is the relationship between concentration of substance A and the rate? **The rate is changed by the same factor as the concentration of A.**
- Which set of experiments should be considered to gauge the effects of a change in the concentration of substance B? **Experiment 1 and 3, because concentration of B changes while concentration of A stays constant.**
- What is the relationship between concentration of substance B and the rate? **The change in the rate is the same factor as the change in the concentration's factor squared.**

4. Consider the following data for the reaction $\text{OCl}^-(\text{aq}) + \text{I}^-(\text{aq}) \rightarrow \text{OI}^-(\text{aq}) + \text{Cl}^-(\text{aq})$.

	$[\text{OCl}^-]$ (M)	$[\text{I}^-]$ (M)	Initial rate (M/s)
Experiment 1	0.0040	0.0020	4.8×10^{-4}
Experiment 2	0.0020	0.0040	4.8×10^{-4}
Experiment 3	0.0020	0.0020	2.4×10^{-4}

- What is the effect of concentration of OCl^- on the rate of this reaction? **The rate is changed by the same factor as the concentration of OCl^- .**
 - *Which two experiments did you consider to reach this conclusion? Why did you choose those two experiments? **Experiments 1 and 3, because the concentration of OCl^- changed while the concentration of I^- stayed constant.**
 - What is the effect of concentration of I^- on the rate of this reaction? **The rate is changed by the same factor as the concentration of I^- .**
 - *Which two experiments did you consider to reach this conclusion? Why did you choose those two experiments? **Experiments 2 and 3, because the concentration of OCl^- stayed constant while the concentration of I^- changed.**
5. Consider the following data for the reaction $\text{NO}_2^- + \text{NH}_4^+ \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$.

	Initial $[\text{NO}_2^-]$ (M)	Initial $[\text{NH}_4^+]$ (M)	Initial rate (M/s)
Experiment 1	0.010	0.200	5.4×10^{-7}
Experiment 2	0.020	0.200	10.8×10^{-7}
Experiment 3	0.040	0.200	21.5×10^{-7}
Experiment 4	0.200	0.0202	10.8×10^{-7}
Experiment 5	0.200	0.0404	21.6×10^{-7}
Experiment 6	0.200	0.0808	43.3×10^{-7}

- What is the effect of changing the concentration of NO_2^- on the rate of this reaction? **The rate is changed by the same factor as the concentration of NO_2^- .**
- *Which experiments did you choose to analyze to reach this answer, and why? **Experiments 1, 2, and 3, because the concentration of NO_2^- changed while the concentration of NH_4^+ stayed constant.**
- What is the effect of changing the concentration of NH_4^+ on the rate of this reaction? **The rate is changed by the same factor as the concentration of NH_4^+ .**
- *Which experiments did you choose to analyze to reach this answer, and why? **Experiments 4, 5, and 6, because the concentration of NH_4^+ changed while the concentration of NO_2^- stayed constant.**

M&M Equilibrium Lab

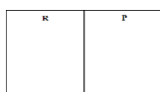
First, please decide whether you believe the following statements are true or false.

- T** or **F** At equilibrium, there are equal concentrations of reactants and products.
- T** or **F** The reaction stops once equilibrium has been reached.
- T** or **F** Equilibrium will be the same whether you start with reactants, products, or a mixture of both.

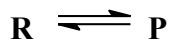
Materials: 40 M&M candies for each group and 1 blank sheet of paper

Introduction:

For this lab, we will be using M&M candies to represent chemical compounds undergoing a reaction. In groups of two, draw a line down the middle of a sheet of paper. Label the left side of the paper “R” for reactants and the right side “P” for products.



You will be performing all of your reactions on this paper according to the following equation:



To represent molecules that are reactants, you will put M&M’s on the reactant side of the paper; products will be M&M’s on the product side of the paper. Reactions will be represented by moving an M&M from one side of the paper to the other.

Part I

For this part, one person should take care of moving M&M’s from the reactant side and the other should move products to reactants. It is key to do this simultaneously.

1. Start with 40 M&M’s on the reactant side of the paper.
2. Each round, you will be exchanging M&M’s between R and P.
3. For each round, **R should move half of his/her M&M’s to the P side. P should move one fourth of theirs to the R side.** (If you end up with a decimal for the number to exchange, you should round up.)
4. At the end of each round, count the M&M’s on each side of the paper and keep track of the numbers in a table.

Round	R	P
0	40	0
1	20	20
2	15	25
3	14	26
4	14	26
5	14	26
6	14	26
7	14	26
8	14	26
9	14	26
10	14	26

5. At the end of 10 rounds, calculate the ratio of products to reactants. (ratio = P/R) **1.86**

Part II

6. Part two is the exact same as part one except for the starting amounts of reactants and products. Choose a number of M&M's to put in the reactant side and put the rest in the products side.
7. Start exchanging the M&M's by following the same rules from step 3 in part one. Keep track of the number of candies on each side after each transaction in another table.

Round	R	P
0	30	10
1	18	22
2	15	25
3	14	26
4	14	26
5	14	26
6	14	26
7	14	26
8	14	26
9	14	26
10	14	26

8. At the end of 10 rounds, calculate the ratio of products to reactants. 1.86

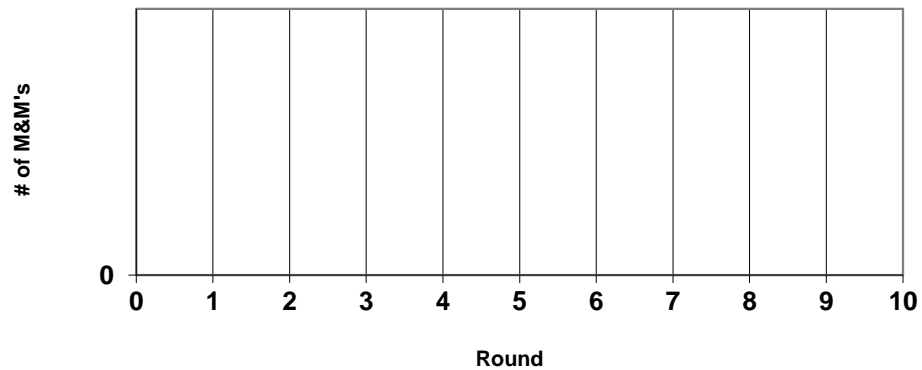
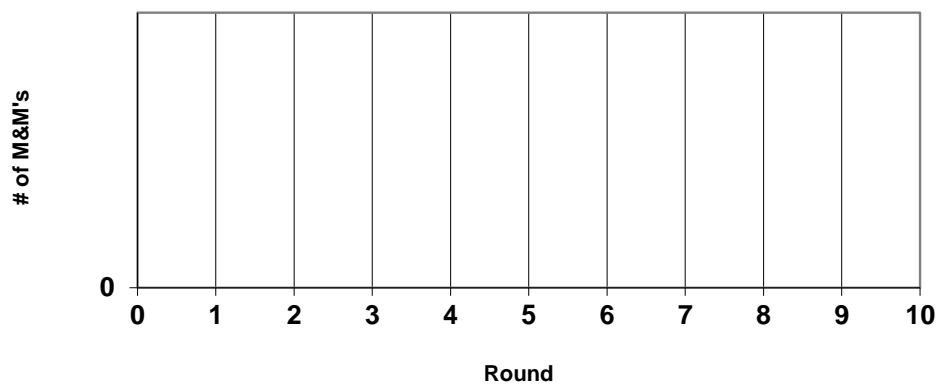
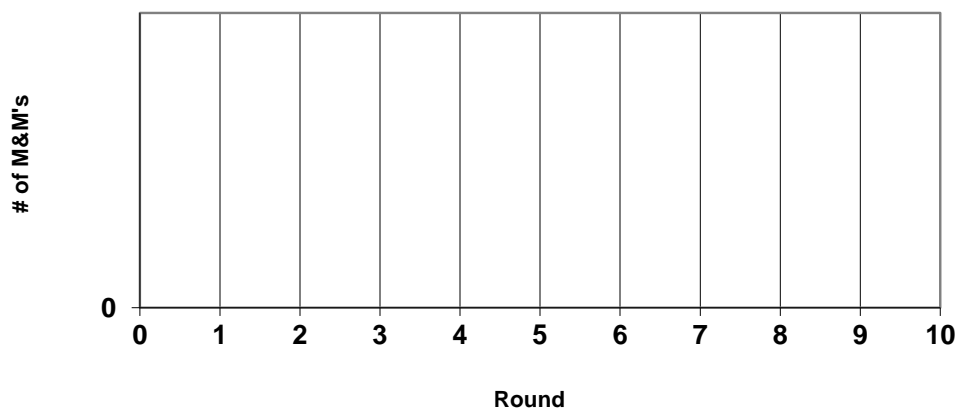
Part III

9. Part three follows the same rules as parts one and two. Except you will need to join up with another group for this part because it requires more total M&M's. Start with 0 reactants and 40 products.
10. Exchange for five rounds and calculate the ratio of products to reactants.
11. After the fifth round, add another group's candies to the reactant side of the equation and continue to exchange for another 5 rounds.

Round	R	P
0	0	40
1	10	30
2	13	27
3	13	27
4	13	27
5	53*	27
6	33	47
7	28	52
8	27	53
9	27	53
10	27	53

12. At the end of the last round, calculate the ratio of products to reactants. 1.96

Graph the reaction progress for each of the three parts of this activity. Use a different color or symbol for reactants and products and connect the dots for each set.

Part I**Part II****Part III**

Questions: You may eat your M&M's while you work on the questions.

Q1. How could you tell when your M&M "reaction" had reached equilibrium? What happened after several rounds of reaction in each of the three parts?

We noticed that the number of M&Ms on each side stayed the same from one round to the next. We were switching the same number of M&Ms.

Q2.* At equilibrium, is the concentration of "reactants" and "products" always equal? Explain.

No, in all the trials, we didn't end up with the same number on the reactant and product side, but the numbers stopped changing. That could happen when they are equal to each other, but it doesn't have to. The thing that was equal is the number of M&Ms being passed each round.

Q3.* Does the "reaction" stop once equilibrium is reached? Explain.

No, the passing of M&Ms represented particles reacting, and that didn't stop once we had reached equilibrium. Even though we were still passing them, the total number on each side stayed the same because we passed the same number in both directions.

Q4. In part III, you added more M&M's to one side of the paper. Think about what happened after you added the M&M's. The word dynamic is defined as: marked by usually continuous and productive activity or change. Why do you think equilibrium is often described as "dynamic"?

The number on that side went down and the other side went up, because the number being passed wasn't equal anymore. Eventually, the number passed became equal again, and the numbers stopped changing on both sides. The ratio was the same as it was before we added M&Ms.

It is called dynamic because there are always particles changing – it doesn't stop reacting.

Q5.* At equilibrium, the **rate** of the forward reaction equals the **rate** of the reverse reaction.

Q6. Under the same conditions, at equilibrium the concentrations of both reactants and products remain constant.

Q7. Equilibrium may be approached from different starting points, but at equilibrium the **ratio** of products to reactants will be constant/unchanging.

Virtual Equilibrium Lab

Go to the website chemvlab.org

Click on “Activities” and then choose the “Equilibrium” activity and push the “Try It!” button. After you have finished the entire activity, the following three questions will show up on the screen. Instead of entering your answers there, write them below.

1. What is happening on the molecular level when the reaction shifts to the left?

When we say that a reaction shifts to the left, we mean more reactant particles are created, as the product particles are used up, so a greater proportion of the particles present are the reactants (shown on the left side of the equation).

2. How can you remove a chemical from a reaction?

A chemical can be removed by reacting it with another substance that will form a precipitate, removing that chemical from solution.

3. For these reactions, what does the color of the solution tell you about the equilibrium position of the reaction?

The color provides evidence of the type of particles that are present, if we know what color each species is. If the two species are pink and blue, then purple is a combination of the two and indicates that both are present. If we see mostly pink, then we know there is a greater proportion of the pink particles.

LeChâtelier's Principle

Which direction will equilibrium shift in response to the changes listed?

1. $\text{N}_2 (\text{g}) + 3 \text{H}_2 (\text{g}) \rightleftharpoons 2 \text{NH}_3 (\text{g}) + \text{heat}$
 - a. remove NH_3 gas **right**
 - b. decrease pressure **left**
 - c. add N_2 gas **right**
 - d. increase temperature **left**

2. $2 \text{SO}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons 2 \text{SO}_3 (\text{g}) + \text{heat}$
 - e. increase SO_2 concentration **right**
 - f. increase temperature **left**
 - g. remove O_2 **left**

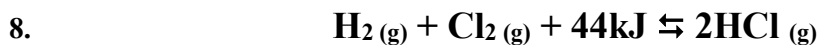
3. $\text{CO}_2 (\text{g}) + \text{C} (\text{s}) + \text{heat} \rightleftharpoons 2 \text{CO} (\text{g})$
 - h. increase temperature **right**
 - i. increase CO concentration **left**
 - j. decrease pressure **no shift**

4. $\text{H}_2 (\text{g}) + \text{Cl}_2 (\text{g}) \rightleftharpoons 2 \text{HCl} (\text{g}) + \text{heat}$
 - k. increase H_2 concentration **right**
 - l. increase pressure **no shift**

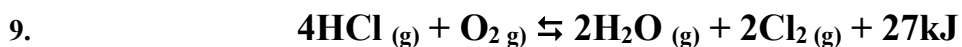
5. $\text{N}_2 (\text{g}) + \text{O}_2 (\text{g}) + \text{heat} \rightleftharpoons 2 \text{NO} (\text{g})$
 - m. decrease O_2 concentration **left**
 - n. add catalyst **no shift**

6. $\text{PCl}_3 (\text{g}) + \text{Cl}_2 (\text{g}) \rightleftharpoons \text{PCl}_5 (\text{g}) + \text{heat}$
 - o. increase Cl_2 concentration **right**
 - p. decrease pressure **left**

7. $\text{CO}_2 (\text{g}) + \text{H}_2 (\text{g}) + \text{heat} \rightleftharpoons \text{CO} (\text{g}) + \text{H}_2\text{O} (\text{g})$
 - q. decrease pressure **no shift**
 - r. add a catalyst **no shift**



Change	Shift	$[\text{H}_2]$	$[\text{Cl}_2]$	$[\text{HCl}]$
Pressure up	no shift	no shift	no shift	no shift
Pressure down	no shift	no shift	no shift	no shift
Temperature up	right	decrease	decrease	increase
Temperature down	left	increase	increase	decrease
Hydrogen up	right		decrease	increase
Chlorine up	right	decrease		increase
Add HCl	left	increase	increase	



Change	Shift	$[\text{HCl}]$	$[\text{O}_2]$	$[\text{H}_2\text{O}]$	$[\text{Cl}_2]$
Pressure up	right	decrease	decrease	increase	increase
Pressure down	left	increase	increase	decrease	decrease
Temperature up	left	increase	increase	decrease	decrease
Temperature down	right	decrease	decrease	increase	increase
Add HCl	right		decrease	increase	increase
Take out Oxygen	left	increase		decrease	decrease
Add Water Vapor	left	increase	increase		decrease

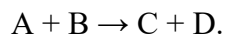
Kinetics and Equilibrium Assessment

- Collision theory states: (Circle ALL that apply.)
 - Particles must collide with proper orientation for a reaction to occur
 - Reactions happen only when particles collide.
 - Every collision leads to a reaction
 - Particles must collide with enough energy to react
- Which of the following usually increase reaction rate? (Circle ALL that apply.)
 - Decreasing the concentration of reactants
 - Increasing the concentration of reactants
 - Adding a catalyst
 - Increasing temperature
 - Decreasing temperature
 - Increasing particle size
 - Decreasing particle size
- Iron combines with oxygen in a slow, exothermic reaction, as shown below. Because it happens so slowly, we don't notice the heat being produced. By speeding it up, we can use this reaction to keep us warm in the winter. What are two changes that you could make to speed it up? Explain, including details about collision theory, why those changes will make the reaction happen faster. $4 \text{ Fe} + 3 \text{ O}_2 \rightarrow 2 \text{ Fe}_2\text{O}_3 + \text{heat}$

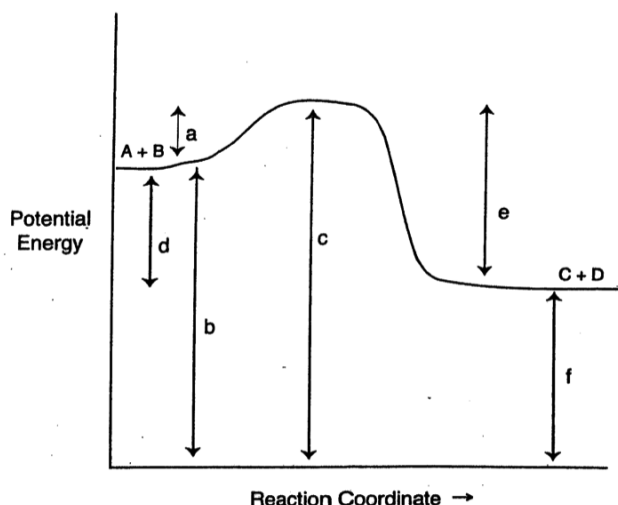
You could grind the iron up into smaller pieces (a powder), since that will create more surface area for the collisions to happen. You could increase the concentration of oxygen so that there are more particles to collide with the iron powder. You could add a catalyst, which will lower the activation energy to make the collisions more likely to be effective.

Although increasing the temperature would make the reaction happen faster, it would defeat the purpose stated in this scenario.

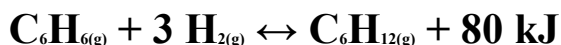
Respond to questions 4-8 by using letters "a" through "f" from the potential energy diagram for the reaction



- Which letter represents the potential energy of the reactants? **b**
- Which letter represents the potential energy of the products? **f**
- Which letter represents the overall energy change in the reaction (ΔH)? **d**
- Which letter represents the activation energy of the reaction? **a**
- Which letter(s) would change if a catalyst were added? **a, c, and e**
- Does this diagram represent an endothermic or exothermic reaction? **Exothermic**

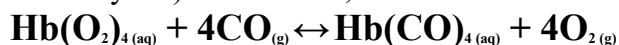


10. What is true about chemical equilibrium? (Circle ALL that apply.)
- The concentrations of the reactants and the products are always equal at equilibrium
 - The rate of the forward and reverse reactions are equal at equilibrium
 - Both forward and reverse reactions can continue once equilibrium is reached
11. For the following reaction, determine how the indicated change in conditions affects the reaction. Show how the equilibrium shifts and how the concentration of each substance is affected by filling in the blanks in the chart. For shift, write "right" or "left." For concentrations, write "I" for increase and "D" for decrease.



Stress	Equilibrium Shift	$\Delta[\text{C}_6\text{H}_6]$	$\Delta[\text{H}_2]$	$\Delta[\text{C}_6\text{H}_{12}]$
temperature decrease	right	D	D	I
$[\text{H}_2]$ increase	right	D		I
volume increase	left	I	I	D

12. Your friend's house had high levels of carbon monoxide and she has a headache and dizziness. Luckily, their carbon monoxide alarm went off and everyone made it out of the house safely. Carbon monoxide is dangerous, because it replaces oxygen as it binds to hemoglobin (represented by Hb) in the blood, as shown in the reaction below.



What should be done to reverse the effects and make your friend feel better? Explain why this is the best treatment and how it will work.

Giving your friend a higher concentration of oxygen will shift the equilibrium to the left, bonding more oxygen to the hemoglobin and causing your friend to breathe the carbon monoxide out.