Reactions and Rates Several activities
By Trish Loeblein

I use *Reactions and Rates* throughout the school year to help my students with understanding how the model of molecular collisions is applied in several topics. I have included a basic scope of my HS course topics and how I use PhET simulations. The editable versions are available on the PhET Interactive Simulations website and I have included links. I included 2 versions for Equilibrium Introduction, one excludes the use the sim for the students, but we used the clicker questions and a guided discussion; the second version was used in an honors class.

Activity 1: http://phet.colorado.edu/en/contributions/view/2984
Activity 2: http://phet.colorado.edu/en/contributions/view/3208
Activity 3: http://phet.colorado.edu/en/contributions/view/2928
Activity 4: http://phet.colorado.edu/en/contributions/view/3210

All of my activities are posted under the Creative Commons - Attribution license (http://creativecommons.org/licenses/by/3.0/), so please acknowledge that they were developed by Trish Loeblein and PhET Team, and provide a link back to the main phet website (http://phet.colorado.edu).

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Non-obvious controls:

- Be sure to try all the different tabs at the top of the simulation. The concepts increase in difficulty as you move to the right tabs.
- You can **Pause** the sim and then use **Step** to incrementally analyze.
- If you are doing a lecture demonstration, set your screen resolution to 1024x768 so the simulation will fill the screen and be seen easily.

Important modeling notes / simplifications:

- This simulation is designed to help students visualize reversible reactions, but the number of particles is small, so quantitative data is not a reasonable expectation.
- When you use the launcher in the straight shot mode, only the shot is straight on. The particles do not follow a linear path strictly.
- The total energy displayed represents the sum of kinetic + potential. If two particles collide, but at grazing angles or one from behind the other, not all of the kinetic energy is available to go into the reaction so there may not be enough for a reaction even though the total energy is greater than the barrier height.
- The collision model is simplified to be a basic elastic collision with the change in potential energy accounted for immediately after collision by appropriately adjusting the kinetic energy.
- When you add/remove energy using the PhET heater/cooler, the energy change is instantaneously seen in the particles. In real-life, the container would change temperature and then the particles would change energy through collisions, radiation, and convection. In this simulation, the simplification is made because the learning goals are focused on reactions and rates and not on energy transfer.
- The particle size is not part of the calculations. Different colors and sizes were used to help student' visualization.
- If you want to have students use a molecular model to calculate equilibrium constants, use *Salts and Solubility* where the data is more consistent and the values can be verified using a literature search,

Insights into student use / thinking:

- There is a comprehensive list of learning goals from the design team published in the Teaching Ideas and Activities http://phet.colorado.edu/en/contributions/view/2980

Suggestions for sim use:

- For tips on using PhET sims with your students see: **Guidelines for Inquiry Contributions** and **Using PhET Sims**
- The simulations have been used successfully with homework, lectures, in-class activities, or lab activities. Use them for introduction to concepts, learning new concepts, reinforcement of concepts, as visual aids for interactive demonstrations, or with in-class clicker questions. To read more, see **Teaching Physics using PhET Simulations**
- For activities and lesson plans written by the PhET team and other teachers, see: **Teacher Ideas & Activities**

Learning goals for Reactions and Rates simulation: The numbered items are measurable learning goals that the development team wrote. Some hints for the teacher are provided under the bullets items.

First panel, Single Collision

1. **Describe reactions in terms of a simple molecular model.**
    - For this goal, I want the students to use the model presented on the **Simple Collision** tab. This is not a model that is presented in texts, but the PhET team thought that a 1D model might help students focus on just a few things: not all collisions result in a new substance and reactions are reversible. Reactions are the result of collisions and the products may collide and react to give reactants

2. **Explain how the simulation model relates to test tube size experiments**
    - Real reaction vessels don't have a molecular shooter, what is it modeling? Explain how you used it to test your ideas about how reactions occur.
    - When you pull out the shooter, it acts like stretching a spring so the molecule gets elastic potential energy; when you let go, the energy is converted to Kinetic energy and gives the molecule speed just like heating the container would.
    - The shooter could represent pouring the substances together and stirring with variable vigor.

3. **Students will describe on a microscopic level, what contributes to a successful reaction. (Include illustrations)**

    - Make sure your students pull the shooter a variety of distances and change the angle
    - Reactions are the result of collisions between molecules. Whether a collision leads to products or not is determined by both the speed (energy) and angle of the collision. It may be difficult for the students to see the effect of the angle, but if you have the shooter on an angle and pull it out so that the Total energy is above the activation energy, the collisions produce a reactant only if the angle is appropriate.
    - Reactions are reversible and they can experiment forward and reverse by selecting a different species to shoot.
    - Students may describe things they discover about the reaction coordinate here too. See the note in #3

4. **Students will describe what would enable a reaction proceed or slow its progress with references to the reaction coordinate**.

    - Based on the reaction coordinate and the energy of the reactants, students should be able to predict if a collision with a given energy will lead to products.
    - For reactants that do not have enough energy to react, students should be able to propose how they could make the reaction happen through changes in temperature or use of a catalyst. They can't add anything that looks like a

catalyst, but they can change the activation energy by selecting Design your Own. Alternately, in order to stop a reaction from happening, they could propose how they could slow down or stop the reaction through changes in temperature or use of a catalyst.

- Reactions can proceed at lower temperatures if the activation energy is lowered. In a real reaction, this is done with catalyst.
- For the reaction to occur, reactant molecules must have sufficient energy to overcome the activation energy. Heating and cooling molecules will change their energy, and as a result will change the probability of successful collisions.

5. **Students will use the potential energy diagram to determine**
   - The activation energy for the forward and reverse reactions,
   - The difference in energy between reactants and products.
   - The relative potential energies of the molecules at different positions on a reaction coordinate

6. **The reaction coordinate shows how potential energy changes with the separation of reactants and products.**
   - The reaction coordinate shows the relative potential energies of the reactants, products, and the transition state.
   - Different chemical reactions will have different reaction coordinates.

Second Panel, Many Collisions

1. **Describe reactions in terms of molecular models with illustrations.**
   - The description should include: A chemical reaction given in the form A+BC↔ AB+ C or AB+CD ↔ AD +CB represents a large number of particles colliding and reorganizing to make new substances; Not every collisions results in a reaction; reactions are reversible.

2. **Use the molecular model to explain why reactions are not instantaneous.**
   Reactions are the result of collisions and that takes time. They may observe that rates vary, but since I don't plan to have them open the Reaction coordinate, they may not have an explanation for the observations.
3. **Use the molecular model to explain why reactions have less than 100% yields.**
   Since reactions are reversible, even though products are being formed, they are reacting to make reactants, so there may not be 100% yield. We will have done a lab where they make rice crispy bars and I want to make sure that their explanations include more than a physical explanation that some reactants may stick to the container and not be able to collide. They may observe that rates vary, but since I don't plan to have them open the Reaction coordinate, they may not have an explanation for the observations.
3. **Students will sketch how the number of reactants and products will change as a reaction proceeds**

4. **Students will be able to determine the number of reactants or products from the experiment graph.**

5. **Convert number to concentration**

    - Estimate the size of the container from the number of atoms across a side. Make an assumption for the depth of the container, the only parameter of the volume that isn't visible. From your estimate of the volume, and the number of atoms or molecules present, calculate the concentration.

6. **Students will relate changes observed in the rate of reaction for a system of many molecules to changes at the molecular level, such as changes in the energy of molecules, or in the potential energy along the reaction coordinate.**

    - Just as heating and cooling will change the probability of a single reaction happening, heating and cooling will change the rate at which multiple reactant molecules proceed to form products.

Equilibrium concepts that could be achieved in either the second or third panel:

1. **Students will explain how they know that a system has reached equilibrium from a graph of number of reactants and products versus time.**
2. **Students will predict how raising or lowering the temperature will affect a system in the equilibrium position.**
3. **Students will describe the relative sizes of the forward and reverse rates at equilibrium.**
4. **Students will explain what effects whether the equilibrium position favors the products or the reactants.**
5. **Students can predict how addition of a reactant or product will affect the forward and reverse reaction rates, and once this new system reaches equilibrium how the reactant and product concentrations will compare to the original system at equilibrium.**

Third Panel, Rate Experiments

1. **Students can calculate a rate coefficient from concentration and time data.**

2. Students can determine how a rate coefficient changes with temperature from concentration vs. time data collected at different temperatures.

3. Students should be able to compare graphs of concentration vs. time to determine which represents the fastest or slowest rate.

Lesson plan for *Reactions and Rates* 1: Introduction to reactions
2 50 minute periods

Learning Goals: *I have put notes in italics after the learning goals to explain my thinking and also describe what might be included in an acceptable answer.*

Students will be able to:

1. **Describe reactions in terms of a simple molecular model.** *For this goal, I want the students to use the model presented on the* ***Simple Collision*** *tab. This is not a model that is presented in texts, but the PhET team thought that a 1D model might help students focus on just a few things: not all collisions result in a new substance and reactions are reversible. Reactions are the result of collisions and the products may collide and react to give reactants (This tab can be used to help simplify the relationships between reactions and the energy diagrams, but this is not a learning goal for this activity)*
2. **Describe reactions in terms of molecular models with illustrations.** *The description should include: A chemical reaction given in the form A+BC↔ AB+ C or AB+CD ↔ AD +CB represents a large number of particles colliding and reorganizing to make new substances; Not every collisions results in a reaction; reactions are reversible.*
3. **Differentiate between dissolving and reacting.** *The Salts simulation doesn't show water, so the students will not see the agent or process for dissolving. I have not tested this goal, so I'll see if they can use the simulations to differentiate. The difference is that the substance is unchanged; the ions can organize into groups (crystals) or break apart (hydrate). In reactions, the particles combine with different particles to make different substances.*
4. **Use the molecular model to explain why reactions are not instantaneous.** *Reactions are the result of collisions and that takes time. They may observe that rates vary, but since I don't plan to have them open the Reaction coordinate, they would not have an explanation for the observations.*
5. **Use the molecular model to explain why reactions have less than 100% yields.** *Since reactions are reversible, even though products are being formed, they are reacting to make reactants, so there may not be 100% yield. We will have done a lab where they make rice crispy bars and I want to make sure that their explanations include more than a physical explanation that some reactants may stick to the container and not be able to collide. They may observe that rates vary, but since I don't plan to have them open the Reaction coordinate, they would not have an explanation for the observations.*

Background: We will have used *Salts and Solubility* simulation in the activity titled: Activity 1 Introduction to Salts-Understanding ionic formulas. Therefore my students will be a little familiar with molecular illustrations; also my students used the Kinetic Molecular theory in physics the preceding year. My students have not had a chemistry course previously. I plan to use this activity before using the introduction to chemical reactions in the text. This in introduced in Chemistry 6th edition by Zumdahl Balancing equations (3.6 & 3.7).

Teaching note: This is a complex simulation and I have other activities that use this simulation for Rates and Thermodynamics.

Lesson:

This lesson starts with a demonstration of iron chloride and potassium thiocyanate and uses the simulation and a power point presentation projected to facilitate a class discussion. I do not plan to give them the reaction, but just say chemical 1 mixes with chemical 2. I am not concerned that this is a complicated reaction; I just wanted to use one that had only color change. I would have enough prepared to repeat the experiment; I usually mix them at least twice. Large test tubes work nicely for a vessel in my classroom, which has only 30 students.

Then the students will use the simulation in an inquiry activity to complete the learning goals. My students use a computer lab and work in pairs. On #1 of the directions, I will ask them to make their drawings by hand because I have found that if they use the computer, the step takes too much class time.

Postlesson: I plan to use Magnesium reacting with hydrochloric acid as another demonstration of a reaction and this time use a proper balanced equation. I will also have some salts, white and colored, in solid form and in solution to mix with water. One thing that my students have difficulty with is recognizing dilution color change vs chemical color change. There are some slides included for the post-lesson.

Lesson plan for *Reactions and Rates* 2: Introduction to Reaction Kinetics with Single Collisions Revised for College Chemistry

Background: I teach a dual credit chemistry course using Chemistry 6th Edition Zumdahl Houghton Mifflin, NY, 2003. The students in my class are taking their first high school chemistry course and receive credit for the first semester of college chemistry and credit for the corresponding lab. I used this lesson as part of introduction to spontaneity. Originally, this was 2 lessons, but I discovered that the students learned more from the first activity than I expected, so I took out some steps. I have written another activity (still called # 4) using the *Reactions and Rates* simulation to be used in the Kinetics unit second semester along with two *Soluble Salt* activities (3 and 4 in the series of 5).

Learning Goals for activity 2 Introduction to reaction kinetics with Single collisions**:** Students will be able to:

- Describe how the **reaction coordinate** can be used to predict whether a reaction will proceed including how the potential energy of the system changes.
- Describe what affects the potential energy of the particles and how that relates to the energy graph. *Answer: distance and type of particle*
- Describe how the reaction coordinate can be used to predict whether a reaction will proceed **slowly, quickly or not at all**.
- Use the potential energy diagram to determine:
    - The *approximate* activation energy for the forward and reverse reactions.
    - The *sign* difference in energy between reactants and products.
- Draw a potential energy diagram from the energies of reactants and products and activation energy.

***Reactions and Rates* Introduction:** I did have to remind many students to select "view" to display the graphs on the right side which they need to fully meet the goals.

Lesson for Activity 2:
Demonstration**:** Mix solutions of iron (III) nitrate and sodium thiocyanide. This is nice because it forms a complex instead of a precipitate

My students work in pairs and use the lab sheet for guidance. I predict that it will be important to check that the students discover that the shooter can be used to get low energy and they may have trouble understanding the difference between potential and total energy. The activity took most of my college chemistry students one 50 minute period, but some had to finish outside of classtime.

First panel, Single Collision

1. Students will describe on a microscopic level, what contributes to a successful reaction. (Include illustrations)

    - Make sure your students pull the shooter a variety of distances and change the angle
    - Reactions are the result of collisions between molecules. Whether a collision leads to products or not is determined by both the speed (energy) and angle of the collision. It may be difficult for the students to see the effect of the angle, but if you have the

shooter on an angle and pull it out so that the Total energy is above the activation energy, the collisions produce a reactant only if the angle is appropriate.
- Reactions are reversible and they can experiment forward and reverse by selecting a different species to shoot.
- Students may describe things they discover about the reaction coordinate here too. See the note in #3

2. Describe how the reaction coordinate can be used to predict whether a reaction will proceed including how the potential energy of the system changes.

- Based on the reaction coordinate and the energy of the reactants, students should be able to predict if a collision with a given energy will lead to products.
- For reactants that do not have enough energy to react, students should be able to propose how they could make the reaction happen through changes in temperature or use of a catalyst. They can't add anything that looks like a catalyst, but they can change the activation energy by selecting Design your Own. Alternately, in order to stop a reaction from happening, they could propose how they could slow down or stop the reaction through changes in temperature or use of a catalyst.
- Reactions can proceed at lower temperatures if the activation energy is lowered. In a real reaction, this is done with catalyst.
- For the reaction to occur, reactant molecules must have sufficient energy to overcome the activation energy. Heating and cooling molecules will change their energy, and as a result will change the probability of successful collisions.

3. Students will use the potential energy diagram to determine
   1. The activation energy for the forward and reverse reactions,
   2. The difference in energy between reactants and products.
   3. The relative potential energies of the molecules at different positions on a reaction coordinate
- Number 1 and 2 are traditionally in texts and there are usually practice problems. For number 3, students can observe how the distance between the molecules relates to the reaction coordinate. As the particles get close together, the energy increases. This is usually illustrated in texts as well.

5. Students will draw a potential energy diagram from the energies of reactants and products and activation energy.

- The reaction coordinate shows how potential energy changes with the separation of reactants and products.
- The reaction coordinate shows the relative potential energies of the reactants, products, and the transition state.
- Different chemical reactions will have different reaction coordinates.

Lesson plan for *Reactions and Rates* 3*:* **Equilibrium** Introduction

(Macroscopic Description, Q, Temperature, and Reaction Coordinate)

Time for activity: 90 minutes of class and some homework

Learning Goals: Students will be able to:

- Use a physical experiment to model chemical equilibrium
- Sketch how the number of reactants and products will change as a reaction proceeds
- Predict how changing the initial conditions will affect the equilibrium amounts of reactants and products. *(Amounts of chemicals, temperature which also effects K)*
- Predict how the shape of the reaction coordinate will affect the equilibrium amounts of reactants and products.

Background:

Reactions and Rates activity 1 was done in September, #2 was done in December, 3 and 4 will be done in the same unit in March.

I used Amy Jordan's activity http://phet.colorado.edu/en/contributions/view/3055 in 2009 and decided to make some changes based on my students' comments. One thing that my students said are that they wished they had more time to explore with the water exchange equilibrium and that they felt that they could do the PhET part for homework, so I put the water experiments first. This version is a combination of Amy's lab and my changes to the PhET directions.

Amy Jordan wrote to me after she used her activity: "*I think it was successful in working through the students' misconceptions about equilibrium, and how temperature affects equilibrium position. For one thing, almost all students predicted that when temperature was raised to above the activation energy bump, there would be all product and no reactants left*---*then they learned that temperature does affect equilibrium position, but not in the way they thought!"*

Reactions and Rates **Introduction:** My students had used the simulation and did not need help figuring out how to use the third panel. They commented that the PhET part could be done outside of class. The simulation is meant for qualitative concept development. There is much variation in values because of the small number of particles. I experimented with just using different amounts of reactants only and only 2 temperatures (the default and a value that would be just above the activation energy). The results give qualitative data that supports literature expectations. If you want to get quantitative values for the equilibrium constant, K, use the simulation called *Salts and Solubility*; the data for K_{sp} are easily verified in solubility tables.

Lesson:

There is an experiment that precedes the use of the simulation. After Part A Step 4, I think it would be helpful to talk to students about whether they think this situation represents a new type of reaction or just new initial conditions. I think that some students thought that the new conditions represented a new reaction coordinate partly because they used the sim before they did the lab. I have not decided how to best address question 8, but I think we should at least have a class discussion about that there could be a way to optimize the initial conditions.

For Part B, question 2, I will assign groups different reactions (one reaction per group) and we will share our results on another day. I hope to arrange for this to happen in class if I can get the computer lab.

Post-Lesson: There are some clicker questions.

Lesson plan for *Reactions and Rates* 4*:* **Equilibrium LeChatlier**

Includes the use of *Salts and Solubility* and *Phases of Matter*

This was adapted from an activity by Amy Jordan

Time for activity: I plan to use this as a homework

Learning Goals:

Students will be able to:

- Explain how to make an equilibrium system change and predict what changes will happen. *I have included guiding questions so that the students will have to use both macroscopic and molecular ideas. I use that wording often in the learning goals, and I don't want them to become too repetitive, so I left it off the student directions.*
- Compare and contrast salt-solution, phase, and chemical equilibriums.

Teaching notes: The basic goal of this activity is for students to build their own understanding of how to use LeChatelier's Principle to predict equilibrium changes caused by concentration and temperature, but I tried to write the goals and questions in "student language". They can explore concentration effects with *Salts and Solubility* and *Reactions and Rates*. I decided to constrain the salt solution equilibrium to the amount of water, because I wanted to make the assignment a reasonable length and not too redundant. Students can see temperature effects using *States of Matter* and different energy curves in *Reactions and Rates*, (but not with *Salts and Solubility)*. I was hoping to use *States of Matter*, to investigate the effects of pressure, but it didn't work out because the temperature rise as work is being done is difficult to counteract.

I think a good lab that could be done to help with understanding about how temperature effects salt solution equilibrium would include using a salt that has an endothermic dissolving process and one that is exothermic. My plan is to have a class discussion as opposed to doing a lab.

Background: I plan to use this activity in combination with labs.

My students will have done the following activities which are linked to the location on the PhET site: the first two Salts and Solubility, the first three *Reactions and Rates*, and *States of Matter*-phase change and diagrams

They will have done *Reactions and Rates #3* just days before.

Lesson:

I will have a test tube, some salt and water available and do a demo by just putting enough salt in the test tube that I expect some to be undissolved. Ask a student volunteer to draw a "test tube" and "close up view" of what is going on at the board. ***I will emphasize that this is an inquiry introduction to equilibrium not a "learn it all" experience.*** Have the students use the lab sheet for guidance.

Simulation Introduction: You may want to ask a student demonstrate "saturated solution" in *Salts and Solubility* to help students differentiate between unsaturated, saturated and a solution with undissolved crystal. Have another student, demonstrate "reaction equilibrium" using *Reactions and Rates.* Discuss that one represents a "Physical system" and the other "Chemical System." I have found that if you use a total of around 180 particles, the data is more consistent. My students will have used these sims, so I don't anticipate any other verbal directions or projected explanations.

Answers to Instructions:

Lesson plan for *Reactions and Rates* 4: **Equilibrium LeChatlier**

Includes the use of *Salts and Solubility* and *Phases of Matter*

This was adapted from an activity by Amy Jordan

Time for activity: I plan to use this as a homework

1. Research "LeChatelier's Principle" and then write the principle in your own words. ***Le Chatlier's Priciple says that if an external stress is applied to a system at equilibrium, the system will adjust itself to minimize that stress.***

2. Investigate salt solution equilibrium by talking with partner about a-d and using *Salts and Solubility* simulation….

   a. If you had a salt solution with some undissolved salt….***more particles will dissociate***

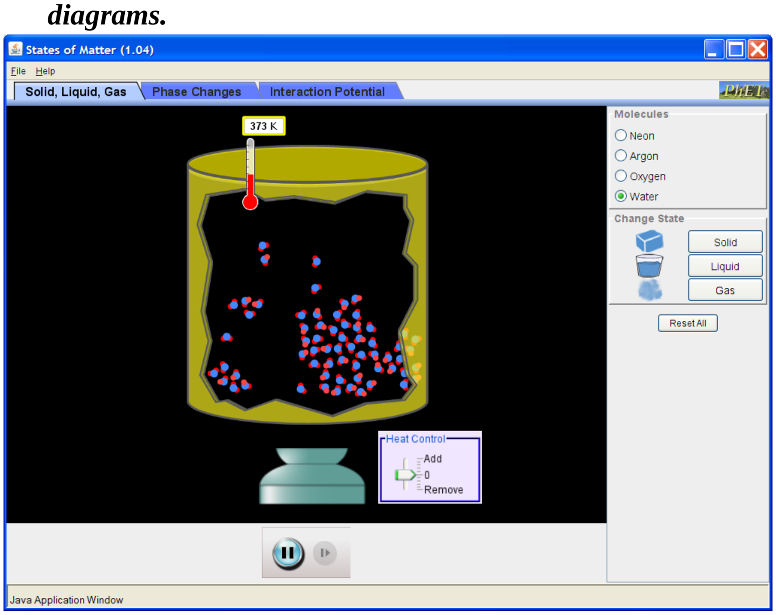
   b. How would your answers change for an unsaturated solution… ***no more particles will dissociate, but will just spread out***

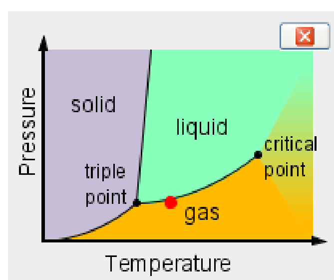
   c. Test to see how letting out water affect saturated ***(from an earlier activity, the students should be able to produce a saturated solution)*** and unsaturated solutions…***for a saturated solution particles will begin to crystallize, for an unsaturated solution, if particles crystallize will depend on the ratio of ions/water and solubility.***

   d. If you had a real salt solution, what are some other ways that you could reduce the amount of water? ***Let evaporate slowly or boil off some water***

3. Explain using LeChatelier's Principle what happens to saturated and unsaturated solutions when the amount of water is varied. Illustrate your explanations with "test tube" size drawings and "close-up" views to show the ions and crystals. ***This should just be a paragraph form of the answers for a-d with pictures like seen in the clicker questions for [Salts and Solubility]***

4. In *States of Matter* simulation, what are ways that equilibriums are displayed? Use images from both the first two tabs. ***Any of the default states on the first tab demonstrate mono-phase equilibrium. Students can also change the temperature to see two phases. Here's an example from the first tab, where energy was added until the temperature is at boiling; there is some liquid and gas present. In the second tab, the students could also use cues from the phase diagrams.***





6. How would you identify a chemical equilibrium? What can you do to change it? Does it matter which reaction you are testing? ***The number of reactants***

and products will be varying only a little. You can change initial amounts, temperature and you can add chemicals after the experiment has started.

7. Describe how chemical equilibriums are similar to physical equilibriums and identify areas where the chemical systems are more complicated. ***I am going to be looking for thoughtful answers, but I am not expecting exact correlation to problems that the students will be doing from the text. I will emphasize that this is an inquiry introduction to equilibrium not a "learn it all" experience. Dilution or concentration (reduction of solvent) changes the salt equilibrium. I am not sure that they will be able to determine the effects of lower overall concentration of reactants, but they should be able to see that using more of one does affect the outcome. I am hoping that they will see that introducing products affects the equilibrium state. For phase systems, it should be easy to see that increasing temperature enables more particles to have the speed to more up the phase diagrams and vise versus. I hope that they see that for reactions, general statements like this cannot be made because some reactions are endothermic, some exothermic, some have high activation energy, and some have products and reactants that are similar in energy.***

Post lesson:
Discuss how temperature effects salt solution equilibrium would include using a salt that has an endothermic dissolving process and one that is exothermic. My plan is to have a class discussion as opposed to doing a lab. Urea 108 g/100 ml(20°C)) 733g/100 mL (100 °C). $CaCl_2$ 74.5 g/100mL (20 °C) 159 g/100 mL (100 °C). Notice that urea which is an endotherimic dissolving process dramatically increases solubility with temperature, but that the difference is not so great for calcium chloride which is exothermic.

I plan to move to the text book and discuss the examples and assign practice.
I have written Clicker questions that could be used as review or divided to use some for pre-lesson and some for post lesson.

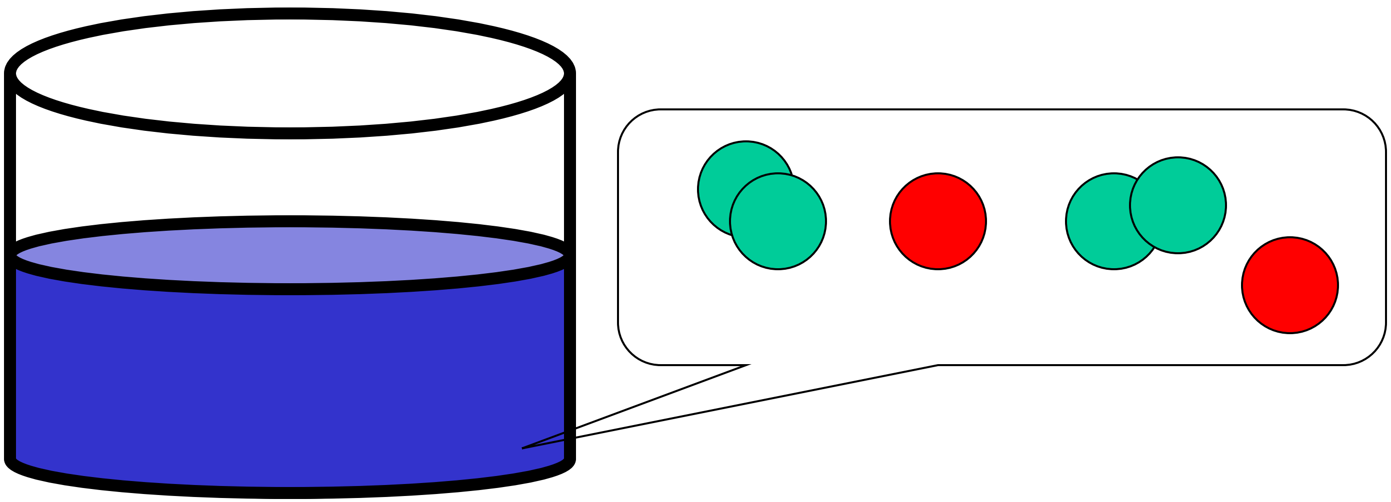
Reactions and Rates

Activity 1:
Introduction to reactions

Trish Loeblein
PhET

Learning Goal

1. Describe reactions in terms of a simple molecular model.

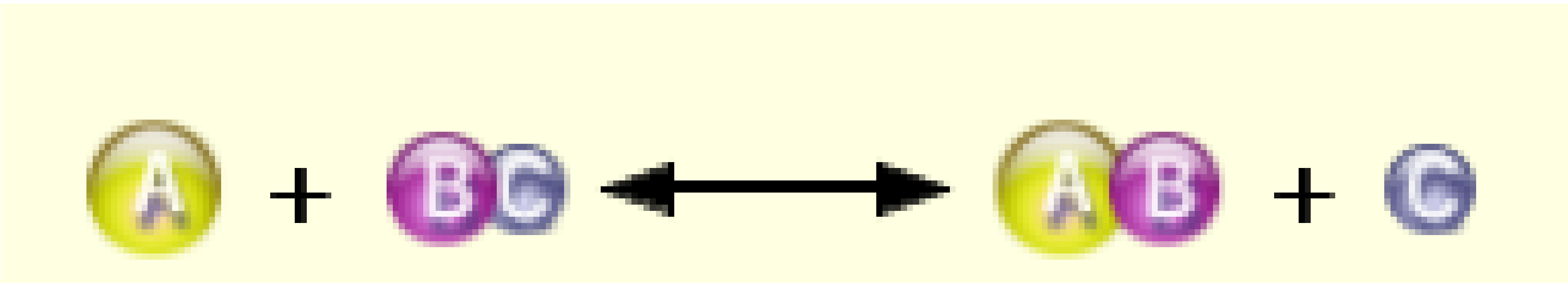


Observe this reaction

What makes you think that there was a reaction?

Draw what you think is happening on a molecular scale

Describe what you think this means:



Observe the model:

1. How does your idea compare to the model?
2. What does “reaction” mean to you?
3. Does a “reaction” always occur?

What do you think the programmer was trying to show by using different colors?

Students will be able to:

2. Describe reactions in terms of molecular models with illustrations.
3. Differentiate between dissolving and reacting
4. Use the molecular model to explain why reactions are not instantaneous.
5. Use the molecular model to explain why reactions have less than 100% yields.

Use the **Many Collisions** tab of *Reactions and Rates*

Post lesson slides follow

Observe the reaction:

What makes you think that there was a reaction?

Magnesium+hydrochloric acid ↔ magnesium chloride+hydrogen gas

Draw what you think is happening on a molecular scale

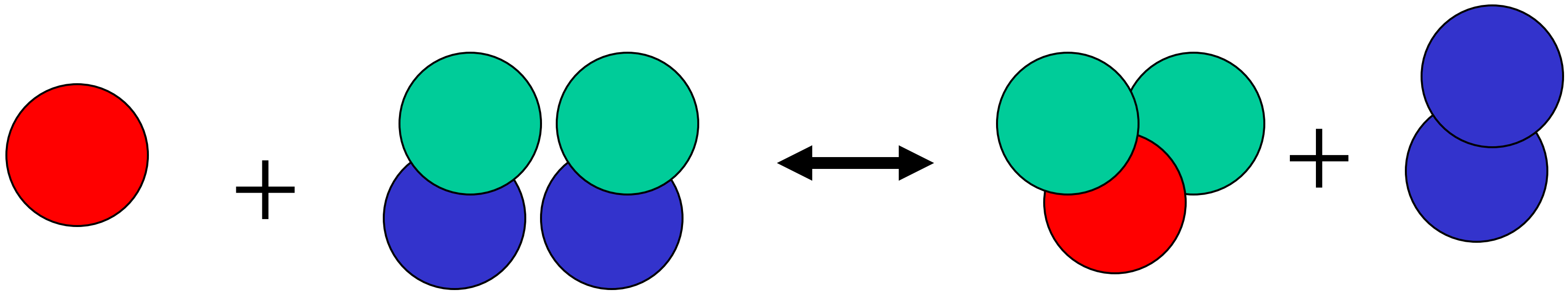
The actual reaction looks like this:

$$Mg + 2HCl \leftrightarrow MgCl_2 + H_2$$

Draw what you think could be happening.

Like this, but many more "balls":

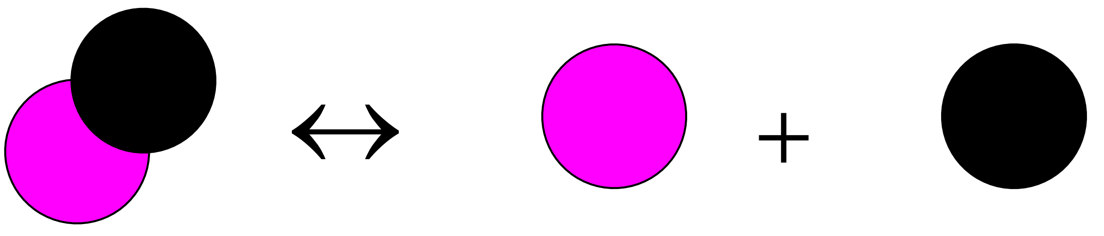
$$Mg + 2HCl \leftrightarrow MgCl_2 + H_2$$

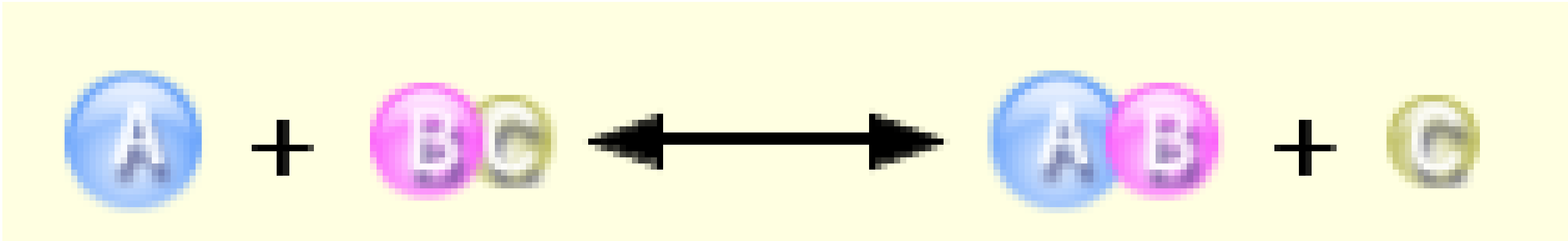


Observe the demonstrations and identify which are reactions.

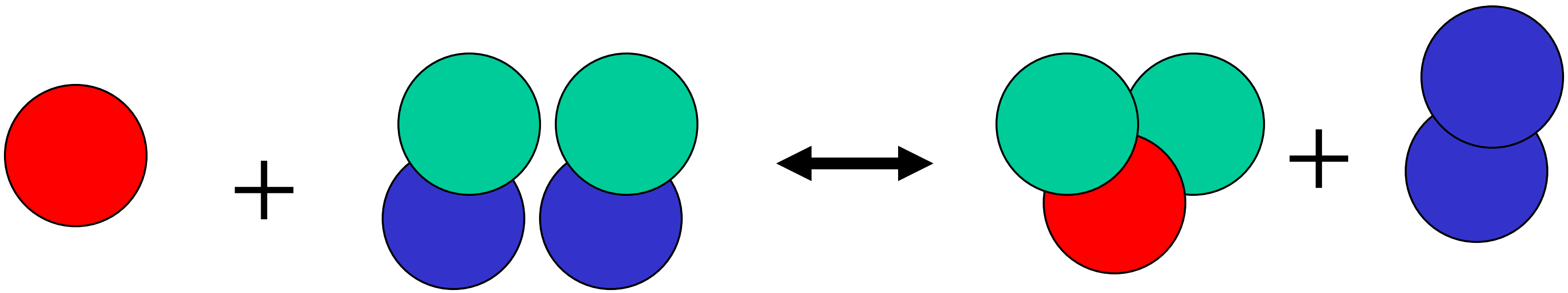
Sketch what is happening on a molecular level.

$$NaCl_{(s)} \leftrightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

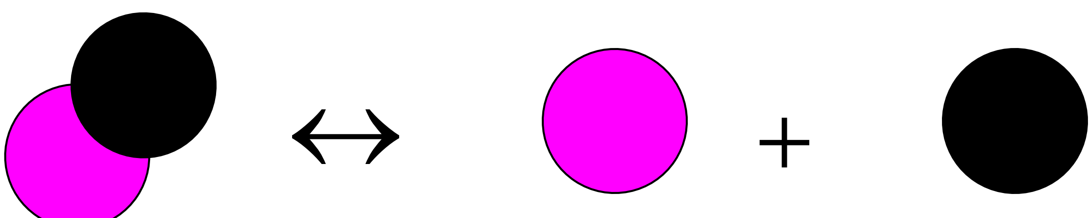




$$Mg + 2HCl \leftrightarrow MgCl_2 + H_2$$



$$NaCl_{(s)} \leftrightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$



Compare models

Student directions ***Reactions and Rates*** **activity 1**: Introduction to reactions

Learning Goals: Students will be able to:

- **Describe reactions in terms of a simple molecular model.**
- **Describe reactions in terms of molecular models with illustrations.**
- **Differentiate between dissolving and reacting**
- **Use the molecular model to explain why reactions are not instantaneous**
- **Use the molecular model to explain why reactions have less than 100% yields.**

1. Use the **Many Collisions** tab to test ideas you might have about reactions on a molecular level. After your tests, type a summary. Add illustrations by drawing on a separate sheet with labels; include references to these drawings in your summary.

2. Explore the ***Salts and Solubility*** simulation again**.** ***(****It is about dissolving not chemical reactions.)* Check that your summary differentiates between dissolving and reacting. Make changes to your summary or drawings and then print.

3. Form a review committee by getting with a group that you do not sit near. Compare your summary and drawings and hand-write additions or changes as necessary. Have your "reviewers" sign your paper.

4. Talk about how you could the simulation to figure out **"why reactions are not instantaneous"**. Run tests and summarize your findings.

5. Talk about what **"reactions have less than 100% yields"** means. When we did the Carbohydrate Chewies lab, some ingredients were lost during the process, now we want to ignore loss of materials to surroundings. Use the simulation to help you understand on a molecular level, then write a description with illustrations.

Student directions *Reactions and Rates* : Introduction to reaction kinetics
Revised for College Chemistry November 2008
Learning Goals: Students will be able to:

- Describe how the **reaction coordinate** can be used to predict whether a reaction will proceed including how the potential energy of the system changes.
- Describe what affects the potential energy of the particles and how that relates to the energy graph.
- Describe how the reaction coordinate can be used to predict whether a reaction will proceed **slowly, quickly or not at all**.
- Use the potential energy diagram to determine:
  - The *approximate* activation energy for the forward and reverse reactions.
  - The *sign* difference in energy between reactants and products.
- Draw a potential energy diagram from the energies of reactants and products and activation energy.

Directions:

1. Talk with your partner about what you think is happening on a microscopic level when the iron (III) nitrate and sodium thiocyanide mix.
   a. Draw pictures that would help you describe the process.
   b. Make a list of what things that might make the color change happen faster and explain your reasoning.
   c. Make a list of what things might make more of the colored complex form and explain your reasoning.

2. Run experiments using **Single Collisions** to determine on a simplest level what contributes to a successful reaction. Make sure that you use the **Energy view** and **Separation view** to help you explain how the energy changes in a reaction can help you make predictions.
   a. Explain the difference between total energy and potential energy. Describe how each can be changed.
   b. How does the **Separation view** help you?
   c. Make sketches of energy graphs to help describe how the energy diagram can be used to predict if the reaction will occur or not.

3. Run experiments using **Many Collisions** to determine what contributes to a **successful** reaction and what affects the **speed** of the reaction.
   a. Describe how this model relates to the single collision model.
   b. Make a table to demonstrate that you have thoroughly used all the simulation features.

4. Sketch the energy graph could look like for the forward reaction to be an exothermic reaction.
   a. What would the sign for ΔH be for the forward reaction? and reverse reaction?
   b. Select the Design Your Own Reaction to make your own exothermic reaction.
   c. Run tests to see if your ideas for number 3 still work. Make changes if necessary.
   d. Explain how the Activation energy for the forward and the one for the reverse reaction are similar and how they differ.

5. Sketch the energy graph could look like for the forward reaction to be an endothermic reaction.
   a. What would the sign for ΔH be for the forward reaction? and reverse reaction?
   b. Select the Design Your Own Reaction to make your own exothermic reaction.
   c. Run tests to see if your ideas for number 3 still work. Make changes if necessary.
   d. Explain how the Activation energy for the forward and the one for the reverse reaction are similar and how they differ.

For practice:

6. Sketch the energy graphs for the following situations.
   a. The reactants have a lower potential energy than the products.
   b. The activation energy of the reverse reaction is greater than the forward reaction
   c. The products have a lower potential energy than the reactants.
   d. The forward reaction has a positive ΔH.
   e. The reverse reaction has a negative ΔH.

Student Directions for*:* Introduction to **Equilibrium**

Learning Goals: Students will be able to:

- Understand what conditions indicate equilibrium of a system
- Use a physical experiment to model chemical equilibrium
- Sketch how the number of reactants and products will change as a reaction proceeds
- Predict how changing the initial conditions will affect the equilibrium amounts of reactants and products.

PART 1: Done in pairs in class
Materials: 4 beakers: 100 mL and 50 mL and **two** 1000 mL beakers,

Directions: **Read a-e, make an appropriate data table, and then begin.**

a) Label the 1000 ml beakers A and B
b) Put about 700 ml water in the large beaker "A". Leave the other beaker "B" empty.
c) Record the volume of water in the beakers in your table.
d) Transfer water between the large beakers using the following "rules"
   - Use the 100 mL beaker to transfer water from A to B;
   - Use the 50 mL beaker transfer water from B to A.
   - Fill the small beakers as full as possible **without tipping the large beakers** in any way.
   - One cycle consists of one A → B transfer and one B → A transfer.
   - **For each cycle**, record the volume of water in beakers A and B.
e) Continue cycles and recording the volumes, until the level of water in beakers A and B are **unchanging**.

Analysis:

1. Graph the volumes of water in beakers A and B per cycle.
2. Look up what equilibrium means and describe in your own words how the water exchange is like a system and how the final results demonstrate "equilibrium".
3. What is the ratio of the volume in Beaker B to Beaker A at equilibrium? _____

Experiment 2

4. What do you think would be different and same if the water transfers were repeated with the beaker A initially half full?
5. Repeat the directions a-e above but start with Beaker A with 500 ml and beaker B empty.
   a. Make a table again and then, graph, and state the ratio of B to A to show your results. (like 1-3 of Analysis)
   b. Explain how your ideas from question 4 were supported or need to be corrected.

Experiment 3

6. What do you think would be different and same if the water transfers were repeated with the beaker B initially with 700 ml and beaker A empty?
7. Repeat the directions a-e above but start with Beaker B with 700 ml and beaker A empty.
   c. Make a table again and then, graph, and state the ratio of B to A to show your results. (like 1-3 of Analysis)
   d. Explain how your ideas from question 6 were supported or need to be corrected.

Conclusion:

8. Explain what equilibrium is for a system and how initial conditions effect it.
9. Describe a real-life of an example like a fish tank with male and female fish with some food available could be used to demonstrate system equilibrium.

Student Directions for *Reactions and Rates* 3*:* Introduction to **Equilibrium**

Learning Goals: Students will be able to:

- Use a physical experiment to model chemical equilibrium
- Sketch how the number of reactants and products will change as a reaction proceeds
- Predict how changing the initial conditions will affect the equilibrium amounts of reactants and products.
- Predict how the shape of the reaction coordinate will affect the equilibrium amounts of reactants and products.

PART 1: Done in pairs in class

Materials: 4 beakers: 100 mL and 50 mL and **two** 1000 mL beakers,

Directions: **Read a-e, make an appropriate data table, and then begin.**

a) Label the 1000 ml beakers A and B
b) Put about 700 ml water in the large beaker "A". Leave the other beaker "B" empty.
c) Record the volume of water in the beakers in your table.
d) Transfer water between the large beakers using the following "rules"
    - Use the 100 mL beaker to transfer water from A to B;
    - Use the 50 mL beaker transfer water from B to A.
    - Fill the small beakers as full as possible **without tipping the large beakers** in any way.
    - One cycle consists of one A → B transfer and one B → A transfer.
    - **For each cycle**, record the volume of water in beakers A and B.
e) Continue cycles and recording the volumes, until the level of water in beakers A and B are unchanging.

Analysis:

1. Graph the volumes of water in beakers A and B per cycle.

2. Describe in your own words how this experiment relates to chemical reaction equilibrium.

3. What is the ratio of the volume in Beaker B to Beaker A at equilibrium? _____When we work with chemical experiments, what do we calculate that is similar?

4. What do you think would be different and same if the water transfers were repeated with the beaker A initially half full?

5. Repeat the directions to test your ideas. Use a table, graph, and ratio of B to A to show your results. Explain how your ideas were supported or need to be corrected.

6. Sketch what you think the graph will look like if you repeated the directions starting with beaker A empty and beaker B with 700ml? ***Remember that a "cycle" is using the 100ml beaker to take from A and the 50ml beaker to take from B.***

7. Repeat the directions to test your ideas. Use a table, graph, and ratio of B to A to show your results. Explain how your ideas were supported or need to be corrected.

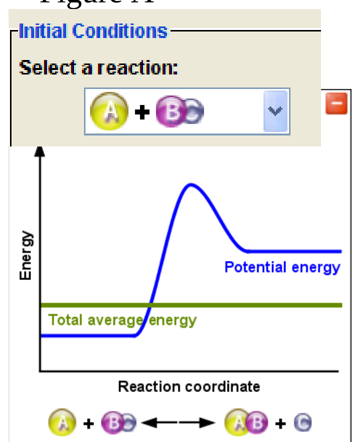
8. If you wanted to optimize the final ratio of B volume to A volume, without changing the cycle definition "***using the 100ml beaker to take from A and the 50ml beaker to take from B"*** how might you change the experimental design?

PART B: Done for homework; may be done with your partner from PART A

1. Open **Reaction and Rates,** using the Rate Experiments tab, design experiments and <u>provide evidence</u> to answer the following. Use the default reaction as shown in Figure A.

   a. With the water exchange experiment, Beaker A water represented reactants and Beaker B represented the products; how does this chemical reaction sim compare?
   b. How do you know when equilibrium has been reached?
   c. How does changing the initial amounts of the reactants affect the amount of product?
   d. How does changing the initial temperature of the reactants affect the amount of product?

Figure A



2. Each team will be assigned one of the other reactions to test. Be prepared to share your results with the class.

Student directions *Reactions and Rates* 4: LeChatlier's Principle

50 minutes untested

Learning Goals: Students will be able to

- Explain how to make equilibrium systems change and predict what changes will happen.
- Compare and contrast salt-solution, phase, and chemical equilibriums.

Instructions:

1. Research "LeChatelier's Principle" and then write the principle in your own words.

Part A Physical Equilibrium

2. Investigate salt solution equilibrium by <u>talking</u> with partner about a-d and <u>using</u> *Salts and Solubility* simulation. *You will be using your ideas to answer question 3.*

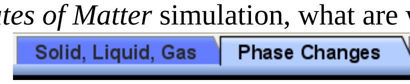
   a. If you had a salt solution with some undissolved salt, what should happen if you add water? Talk about how LeChatelier's Principle might be used to explain what happens. Make sure to test your ideas using the *Salts and Solubility* simulation.

   b. How would your answers change for an unsaturated or saturated solution? Don't forget to test!!

   c. Test to see how letting out water affect salt solutions (undissolved salt, unsaturated or saturated). Talk about how LeChatelier's Principle might be used to explain what happens.

   d. If you had a real salt solution, what are some other ways that you could reduce the amount of water?

3. Explain using LeChatelier's Principle what happens to salt solutions when the amount of water is varied. Illustrate your explanations with "test tube" size drawings and "close-up" views to show the ions and crystals.

4. In *States of Matter* simulation, what are ways that equilibriums are displayed? Use ideas from both  tabs.

5. Explain <u>on a molecular level</u> how you can change the phase equilibrium and what changes happen. Try to relate Kinetic Molecular Theory and LeChatelier's Principle.

Part B Chemical Equilibrium: use ***Reactions and Rates***,  tab

6. How would you identify a chemical equilibrium? What can you do to change it? Does it matter which reaction you are testing? Make a data table that demonstrates that you have thoroughly explored the possibilities. *If you use a total of about 180 particles, the data is more consistent.*

7. Describe how chemical equilibriums are similar to physical equilibriums and identify areas where the chemical systems are more complicated.

Reactions and Rates 1 Clicker Questions

Activity 1: Introduction to reactions

Trish Loeblein

PhET Activity

Learning Goals

Students will be able to:

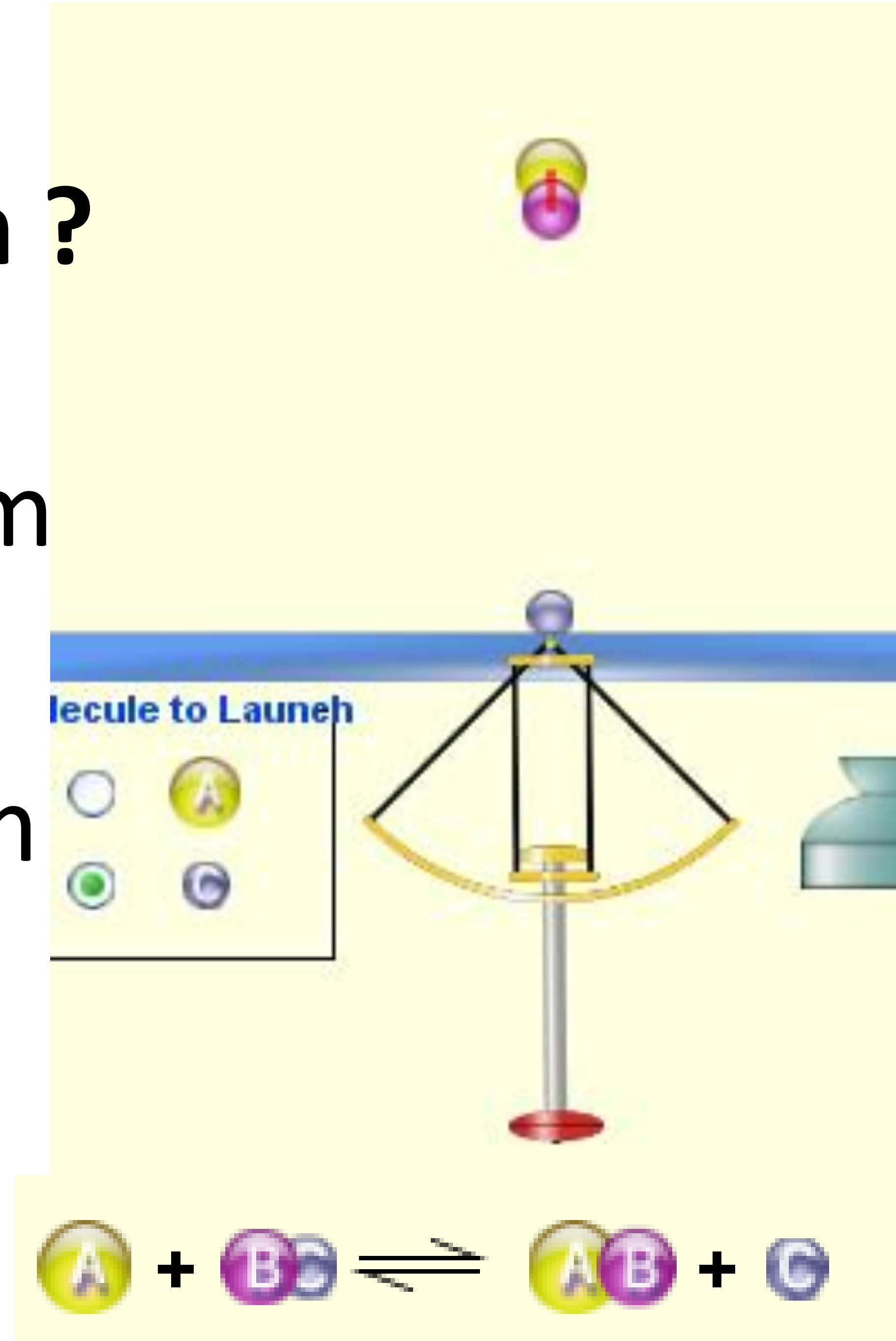
1. Describe reactions in terms of a simple molecular model.
2. Describe reactions in terms of molecular models with illustrations.
3. Differentiate between dissolving and reacting
4. Use the molecular model to explain why reactions are not instantaneous.
5. Use the molecular model to explain why reactions have less than 100% yields.

What will <u>probably</u> immediately happen ?

A  will form

B  will form

C No reaction

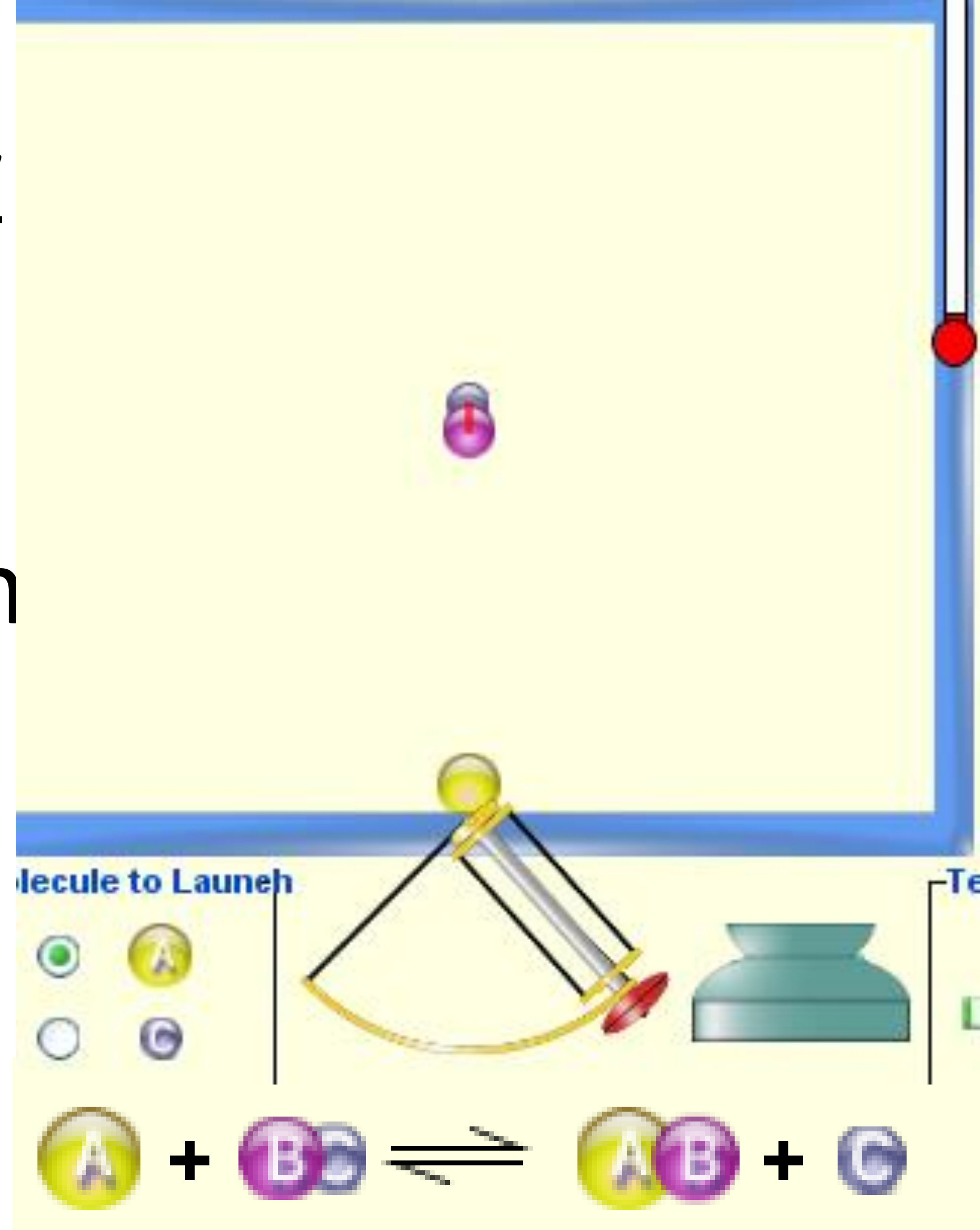


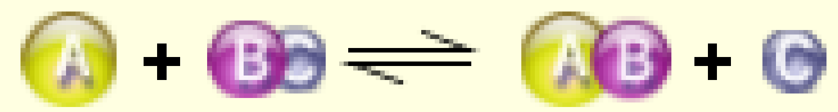
What will probably happen ?

A  will form

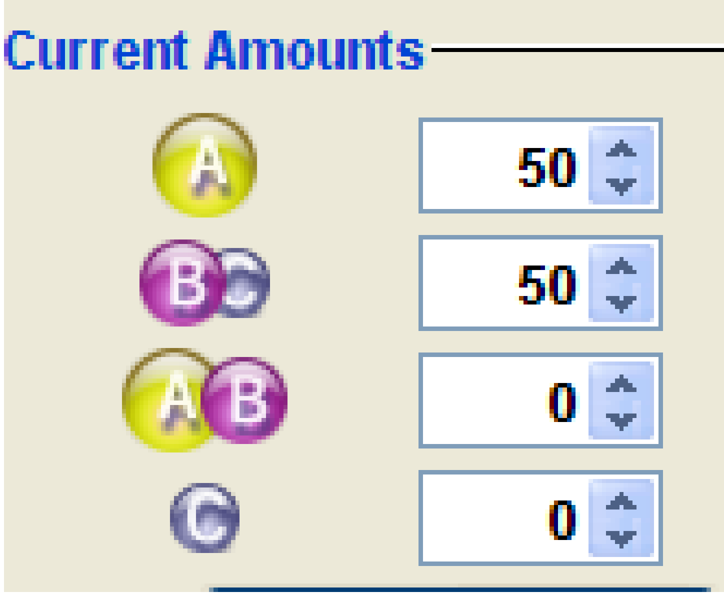
B  will form

C No reaction





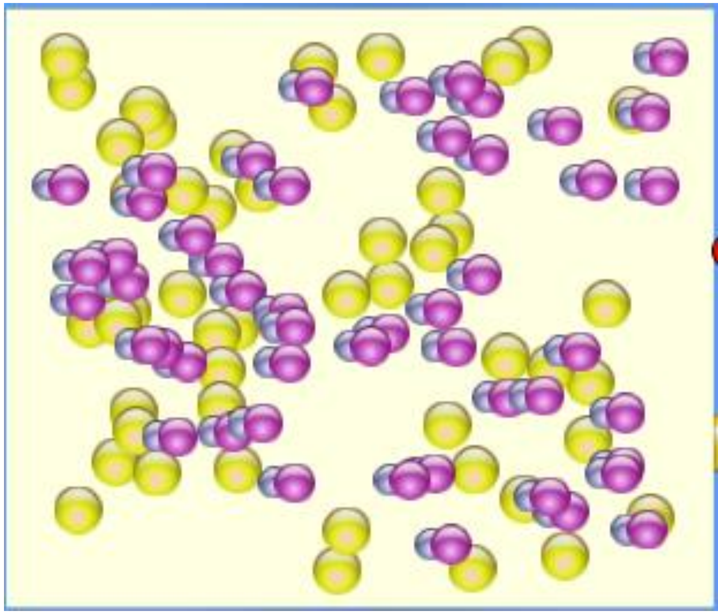
What will <u>probably</u> immediately happen ?

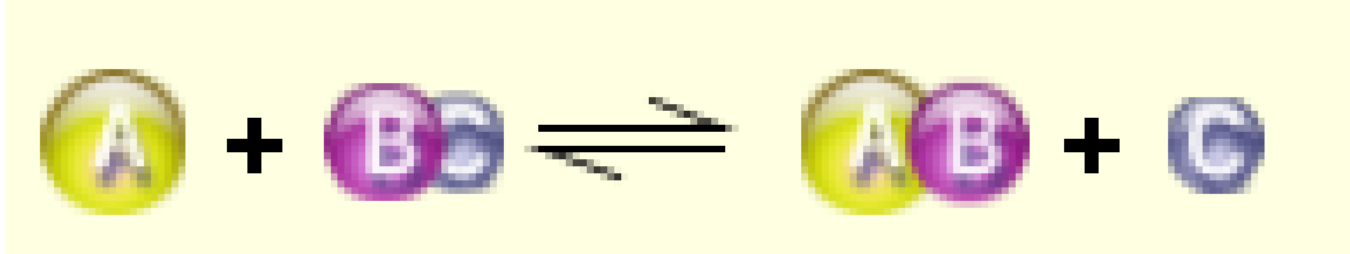


A  will form

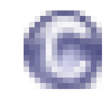
B  will form

C No reaction





What will <u>most likely</u> be in the container after several minutes have passed ?

A. Container will have only  & 
B. Container will have only  & 
C. Container will have a mixture of all four

Reactions and Rates 2 Clicker Questions

Activity 2: Introduction to reaction kinetics

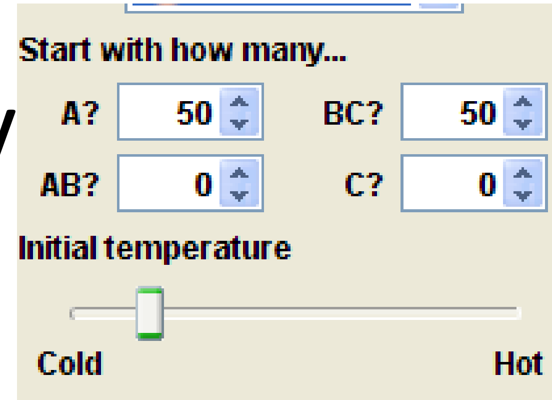
Trish Loeblein
PhET

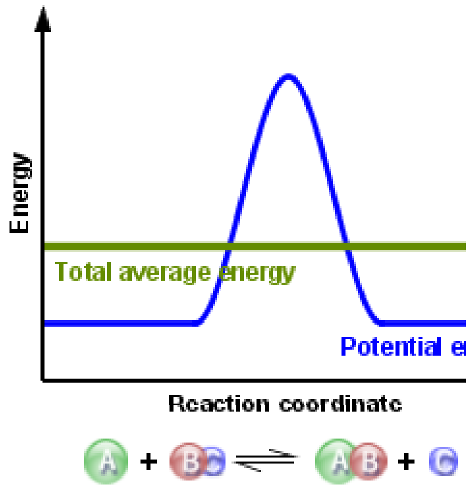
Learning Goals

Students will be able to:

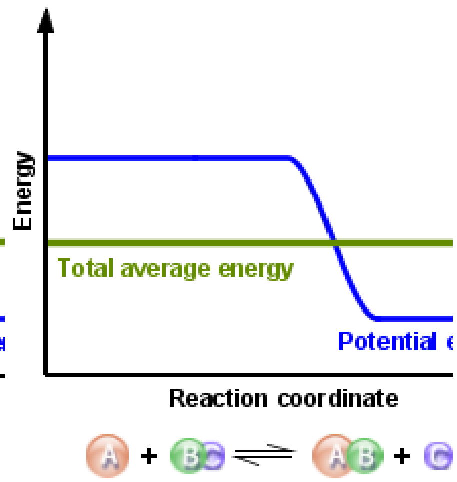
- Describe how the **reaction coordinate** can be used to predict whether a reaction will proceed including how the potential energy of the system changes.
- Describe what affects the potential energy of the particles and how that relates to the energy graph.
- Describe how the reaction coordinate can be used to predict whether a reaction will proceed **slowly, quickly or not at all**.
- Use the potential energy diagram to determine:
  - The *approximate* activation energy for the forward and reverse reactions.
  - The *sign* difference in energy between reactants and products.
- Draw a potential energy diagram from the energies of reactants and products and activation energy.

Which reaction would probably appear to be quickest?

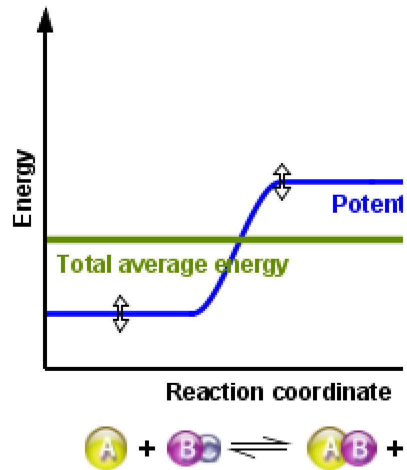




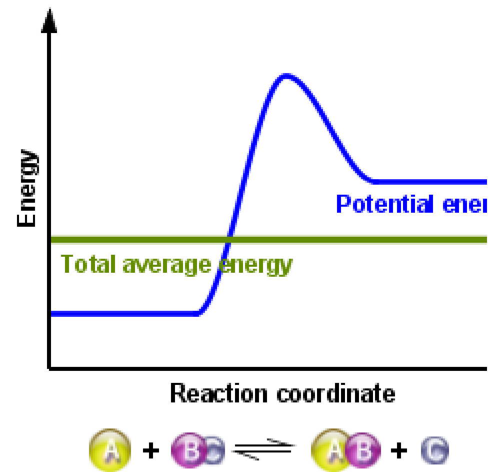
A



B

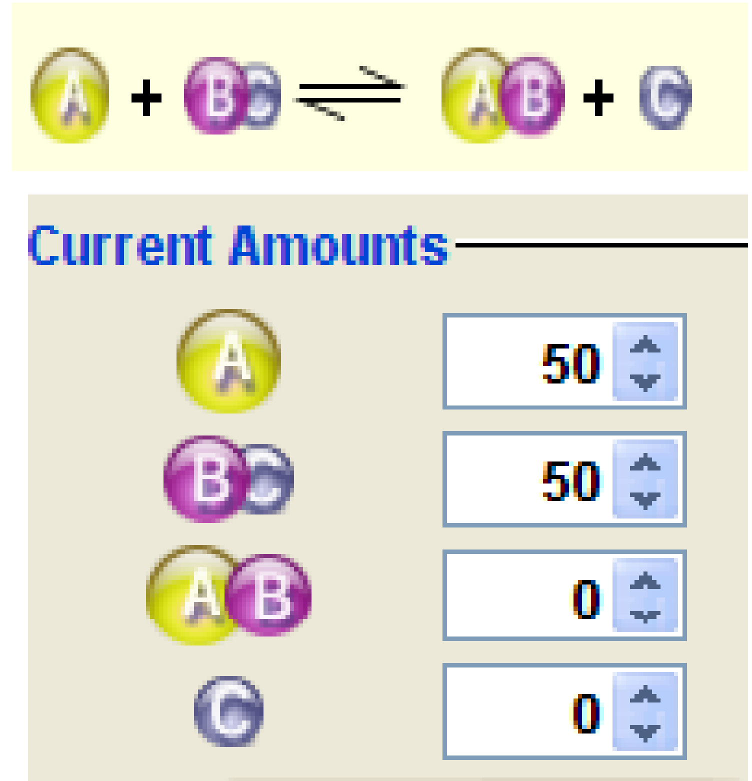


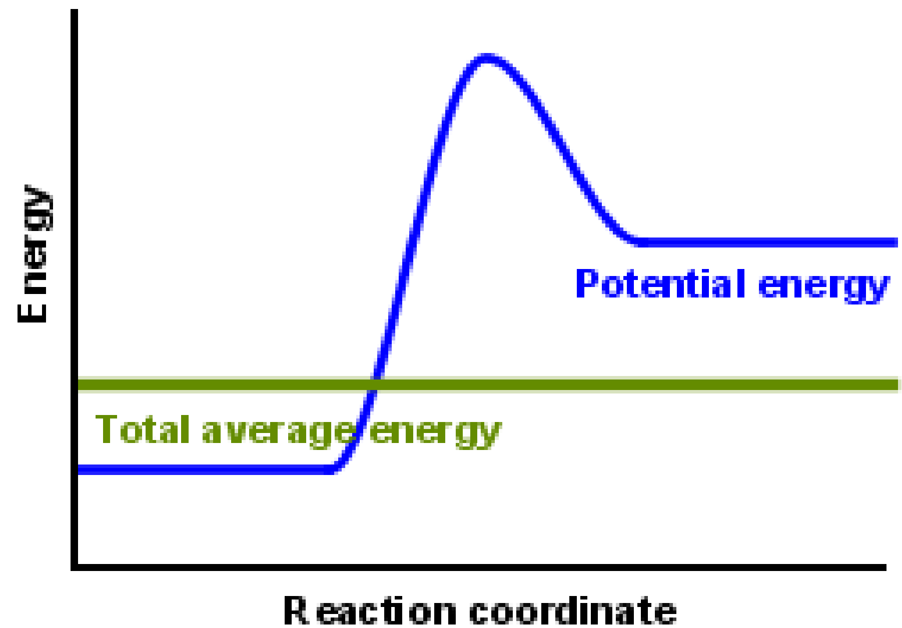
C

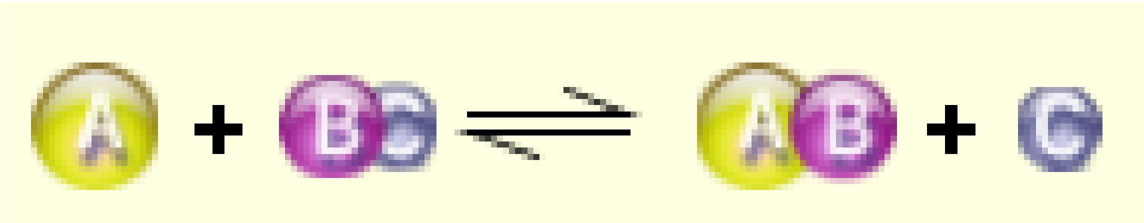


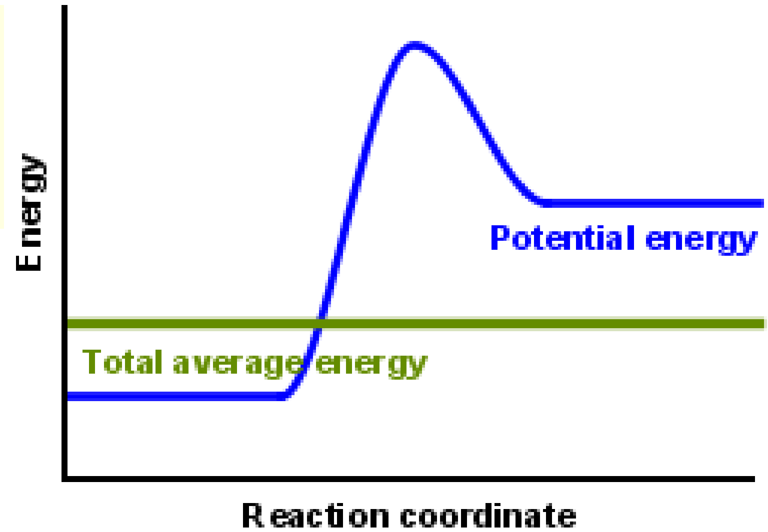
D

What would best describe what is in the container after several minutes have passed ?

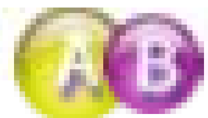
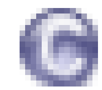


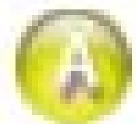


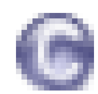


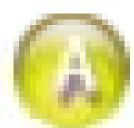


Answer choices

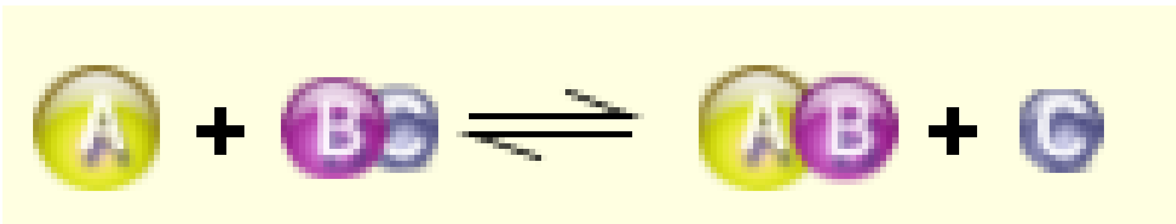
A. Container will have only  & 

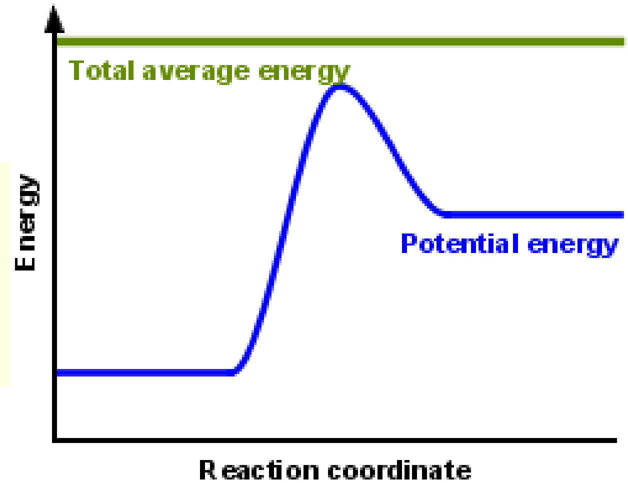
B. Container will have only  & 

C. Container will have a mixture of all four with more  & 

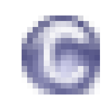
D. Container will have a mixture of all four with more  & 

Using the heater  would



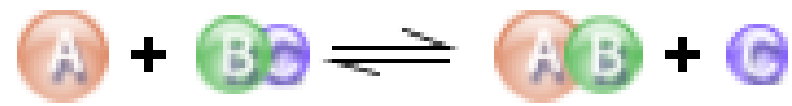


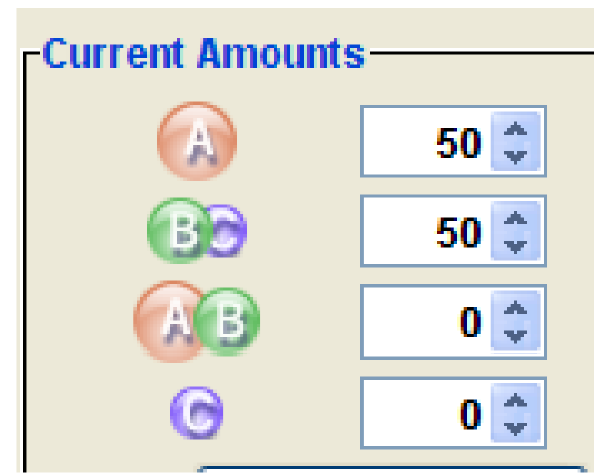
A. Increase the number of  & 

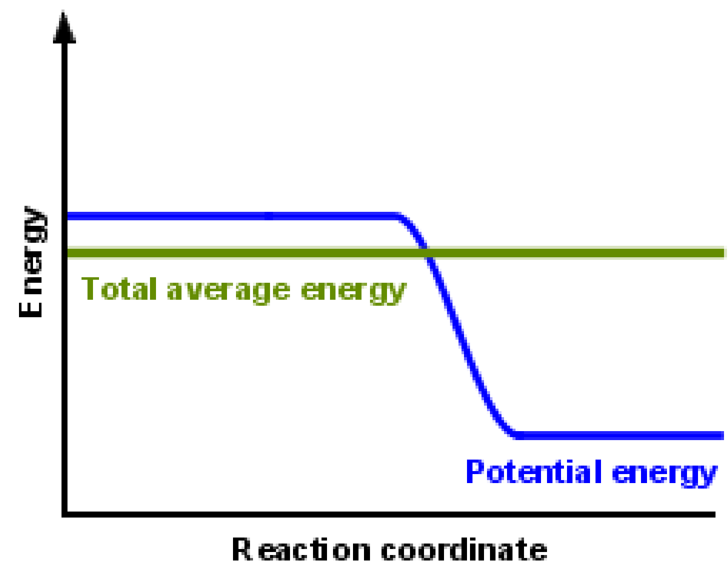
B. Increase the number of  & 

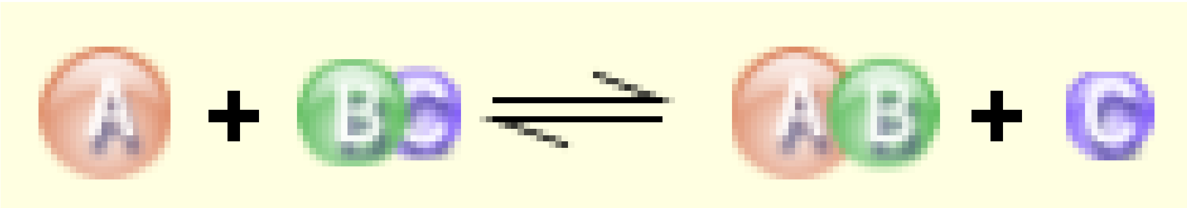
C. Have no effect

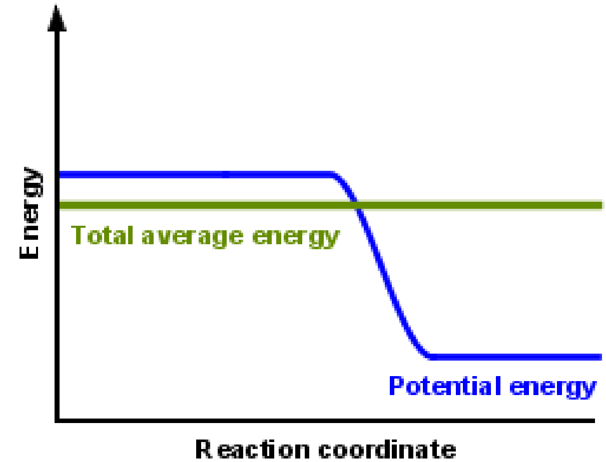
What would best describe what is in the container after several minutes have passed ?



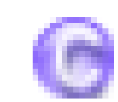


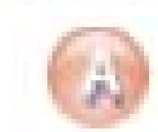


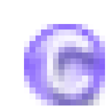


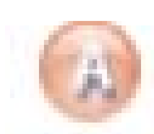
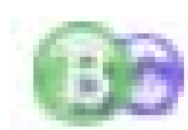


Answer choices

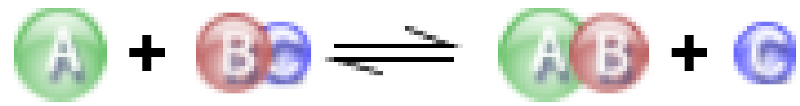
A. Container will have only  & 

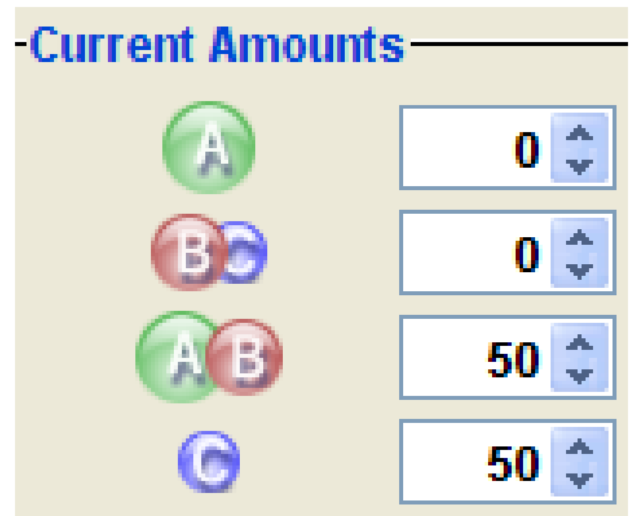
B. Container will have only  & 

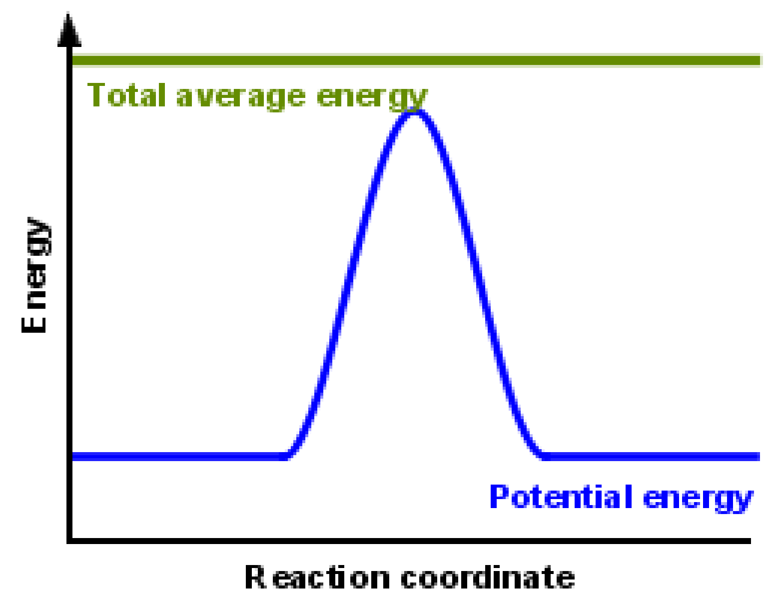
C. Container will have a mixture of all four with more  & 

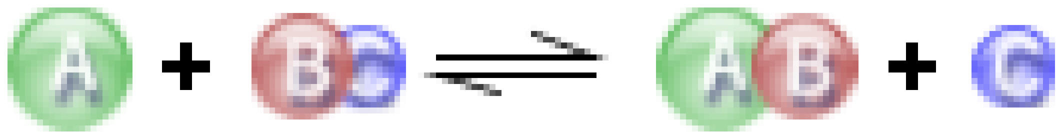
D. Container will have a mixture of all four with more  & 

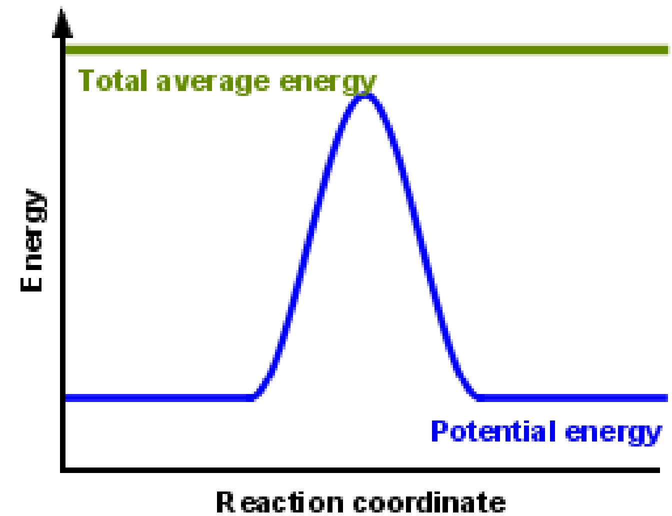
What would best describe what is in the container after several minutes have passed ?





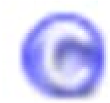






Answer choices

A. Container will have mostly  & 

B. Container will have mostly  & 

C. Container will have a mixture of all four with nearly equal amounts

D. No reaction will occur since the products and reactants have the same energy

Reactions and Rates 3 Clicker Questions

Activity 3: Introduction to **Equilibrium**

Trish Loeblein
PhET

Learning Goals

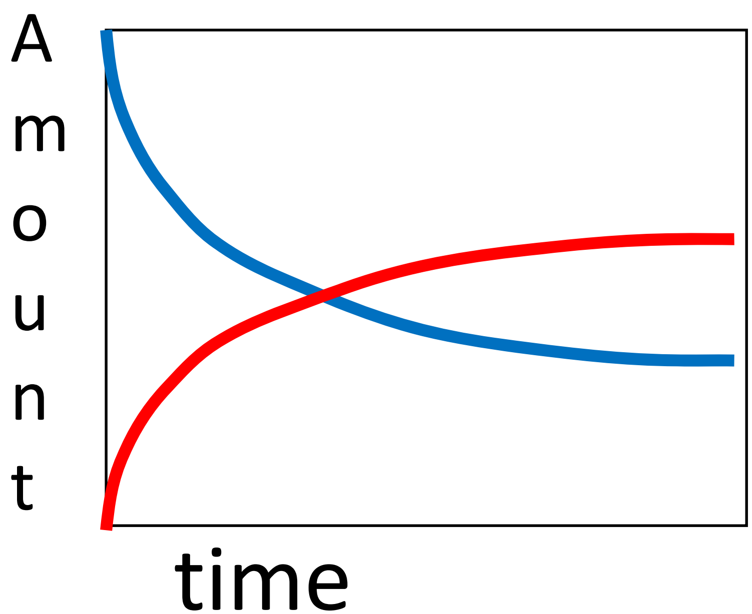
Students will be able to:

- Use a physical experiment to model chemical equilibrium
- Sketch how the number of reactants and products will change as a reaction proceeds
- Predict how changing the initial conditions will affect the equilibrium amounts of reactants and products.
- Predict how the shape of the reaction coordinate will affect the equilibrium amounts of reactants and products.

Which best shows that equilibrium has been reached?

A

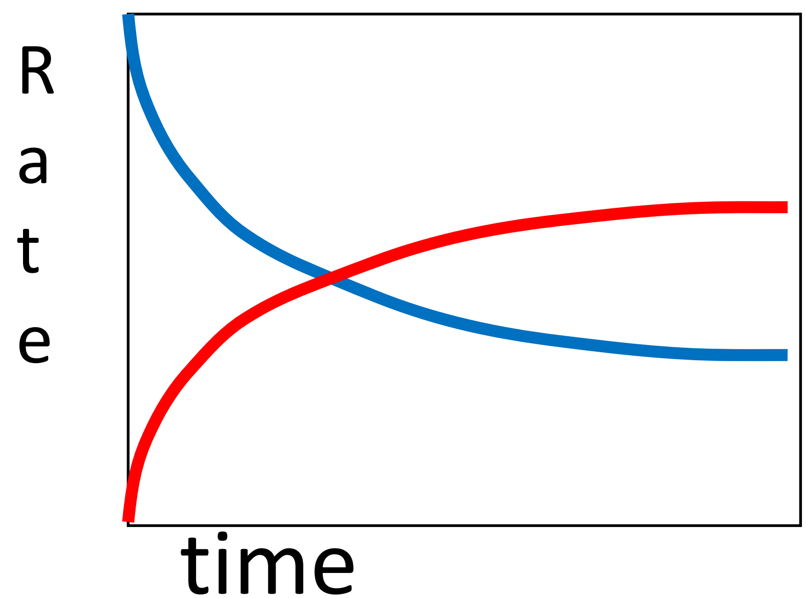
Amount of substance vs time



-Product **-Reactants**

B

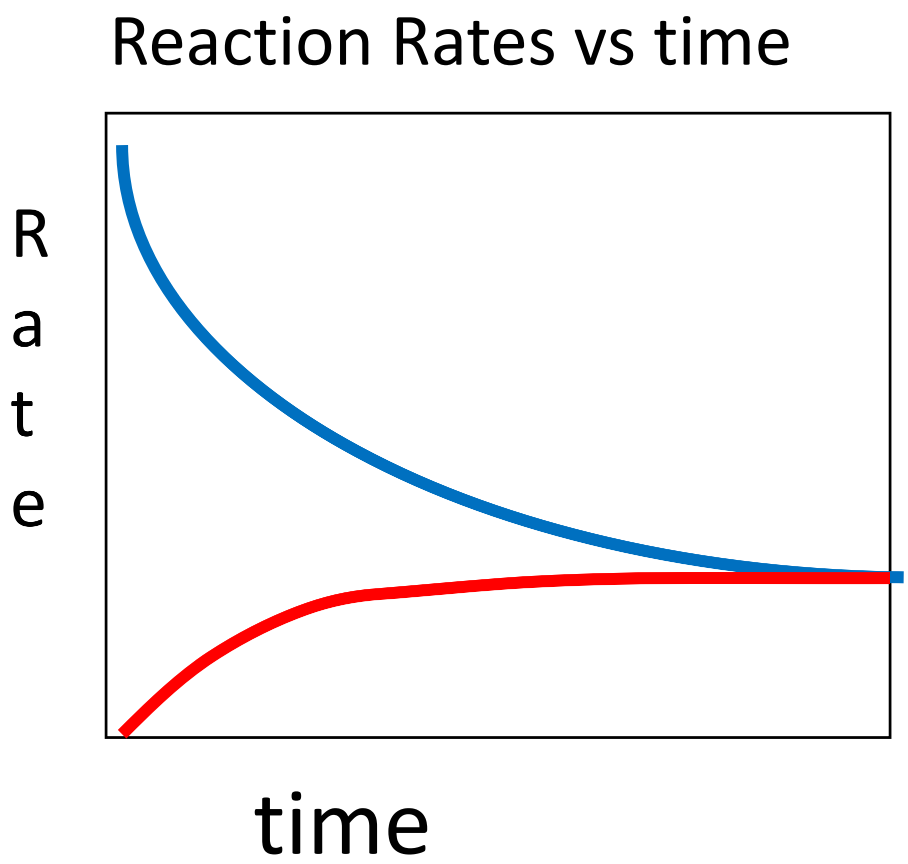
Reaction Rates vs time



-Forward **-Reverse**

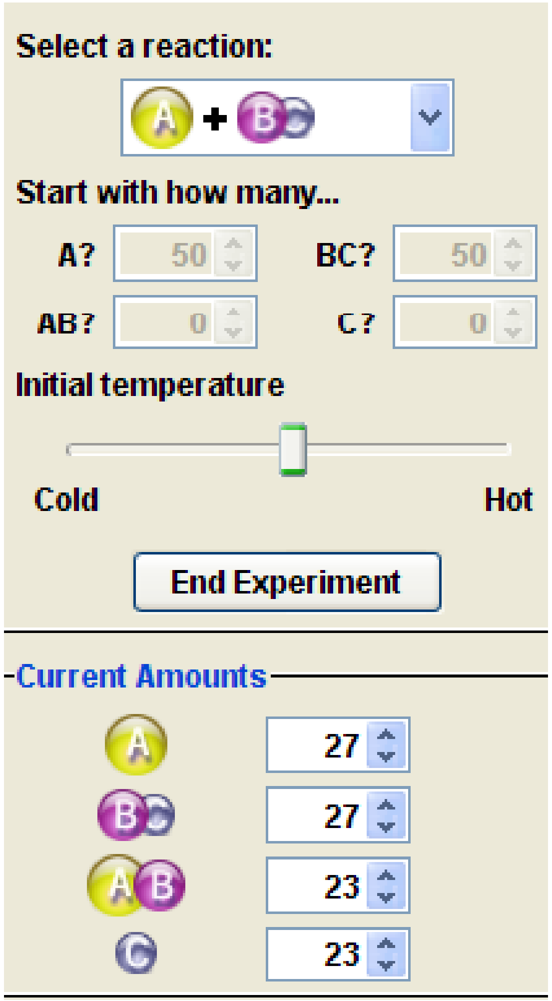
Correct rate graph

Forward reaction rate =Reverse rate

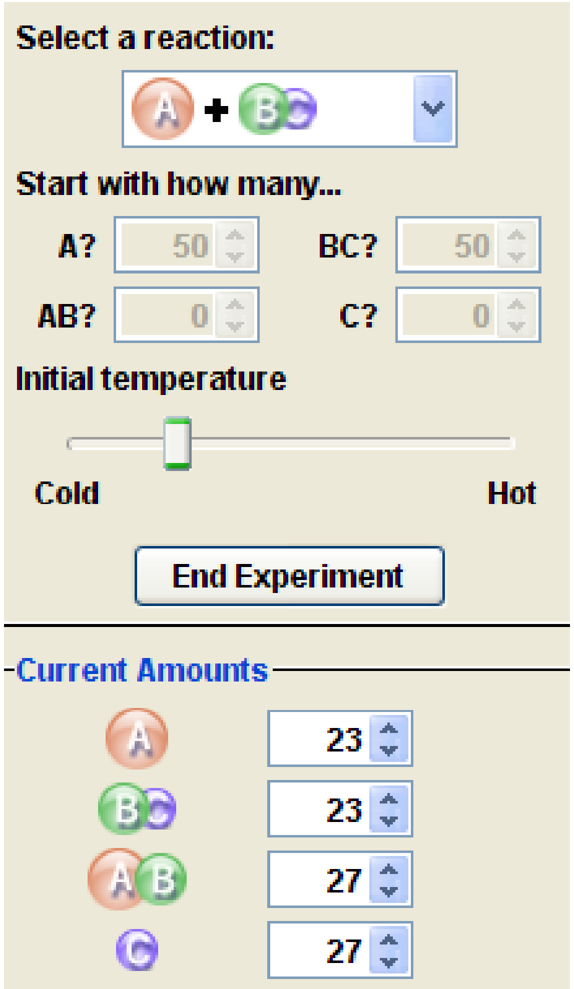


-Forward **-Reverse**

Which could show that equilibrium has been reached?



A

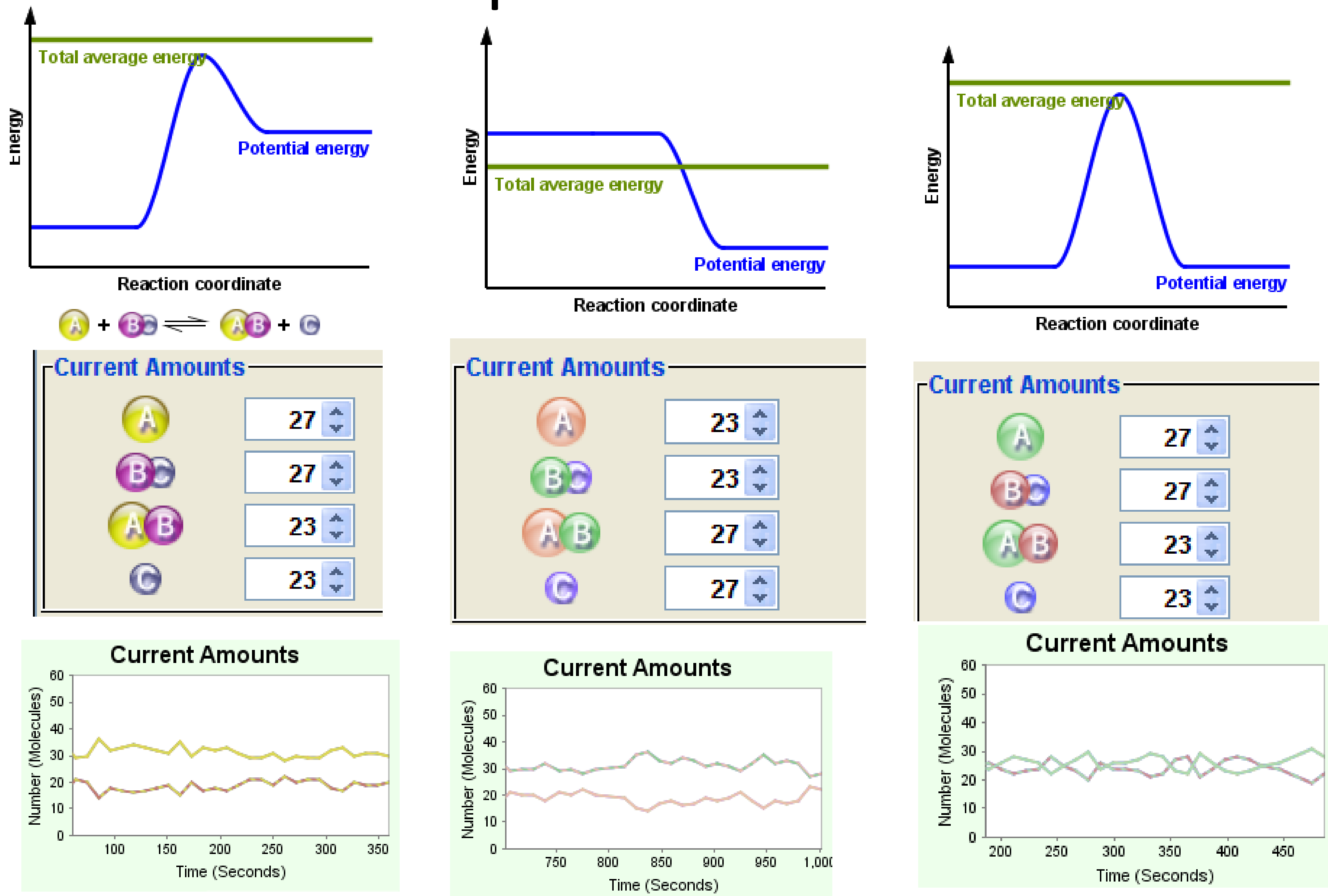


B

C neither

D either

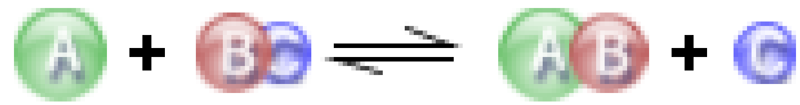
All are at equilibrium within limits

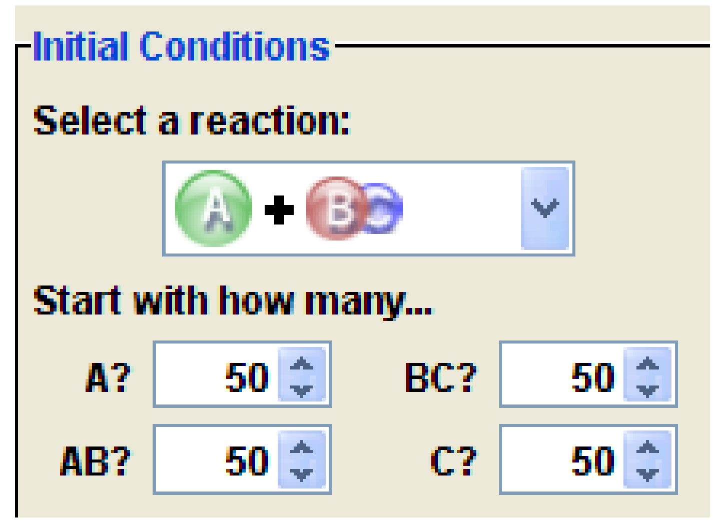


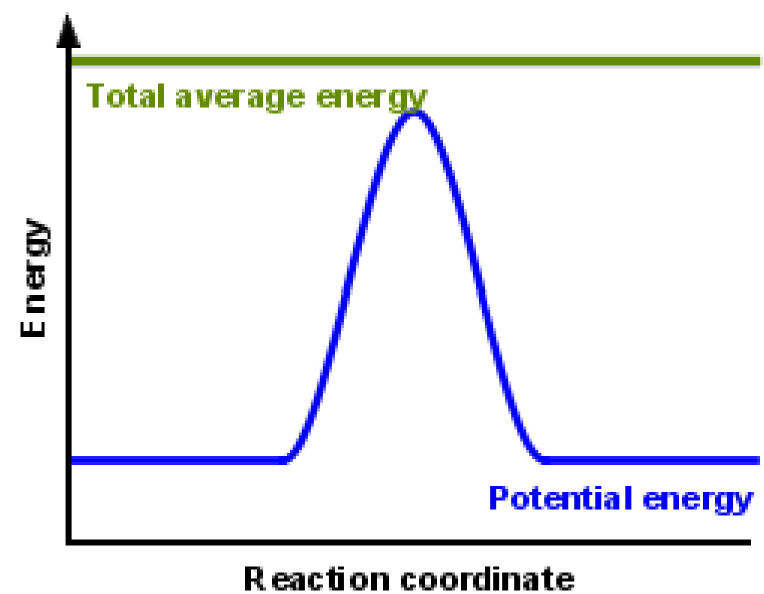
Which best shows that equilibrium has been reached?

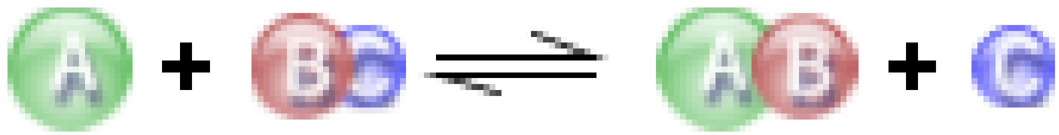
A. The number of reactants is greater than the products
B. The number of products is greater than the reactants
C. The number of products is equal to the reactants
D. The number of products varies little

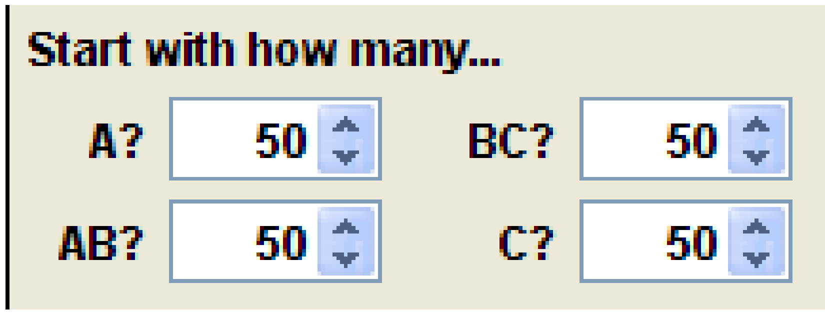
At equilibrium, what would you predict is in the container?

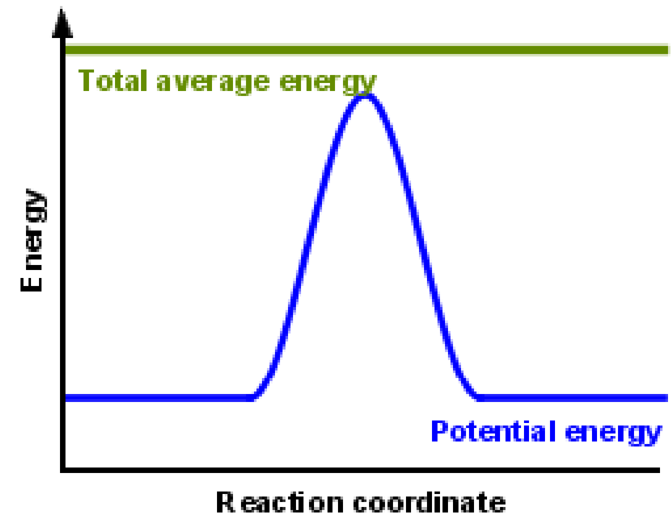




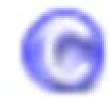






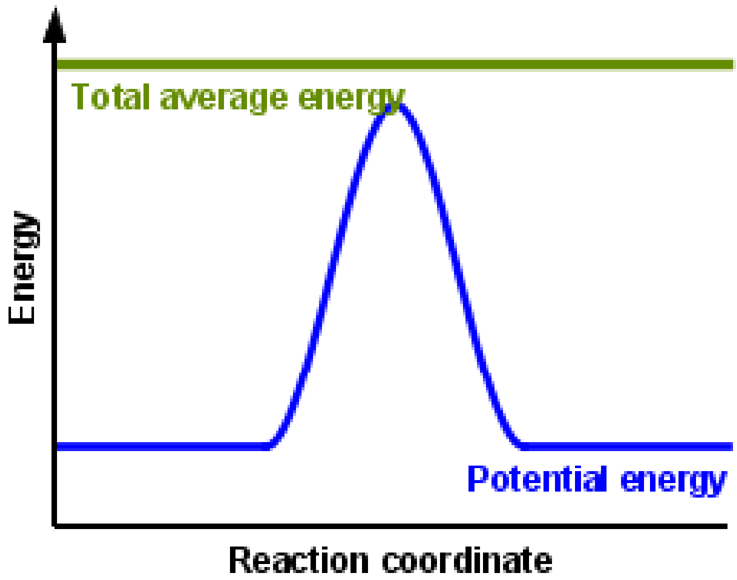


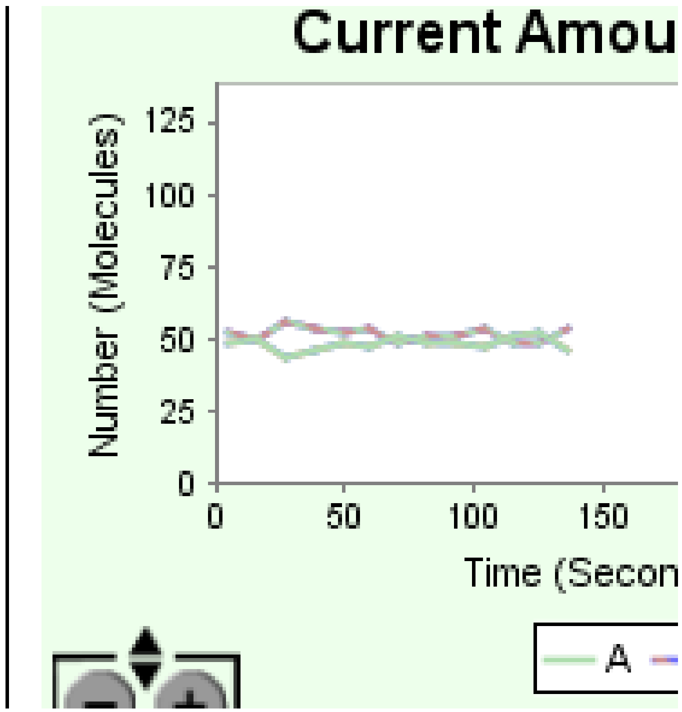
A. Container will have mostly  & 

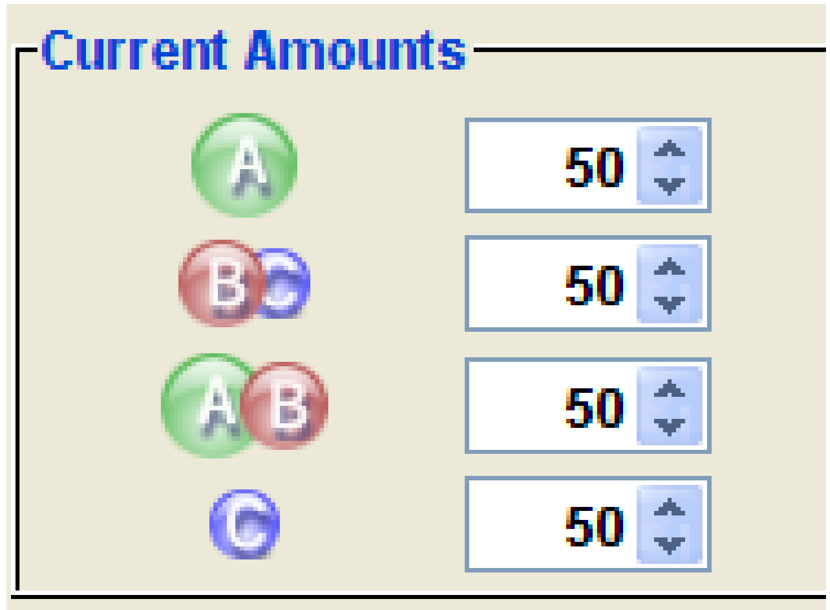
B. Container will have mostly  & 

C. Container will have a mixture of all four with nearly equal amounts

D. No reaction will occur since the products and reactants have the same energy

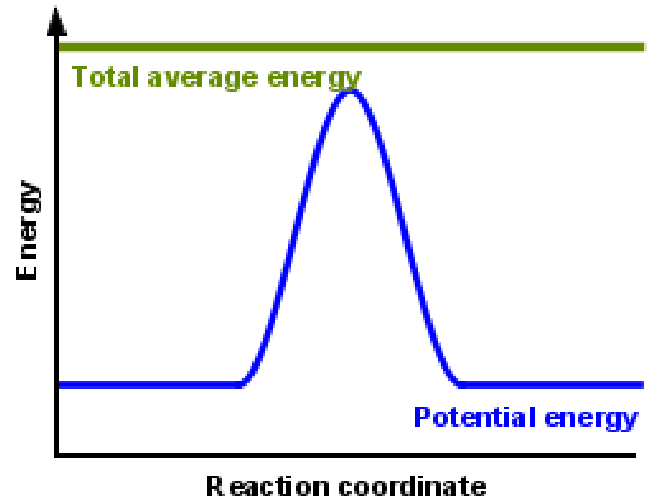

Total average energy
Energy
Potential energy
Reaction coordinate


Current Amou
Number (Molecules)
125
100
75
50
25
0
0
50
100
150
Time (Secon
A

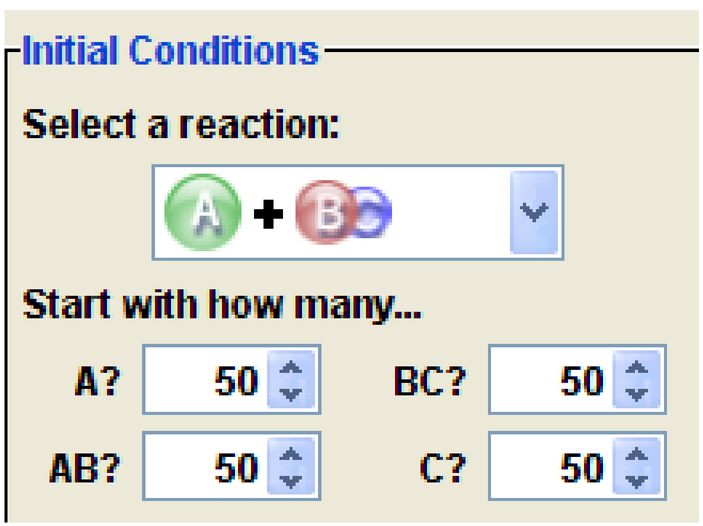

Current Amounts
A
50
B C
50
A B
50
C
50

data

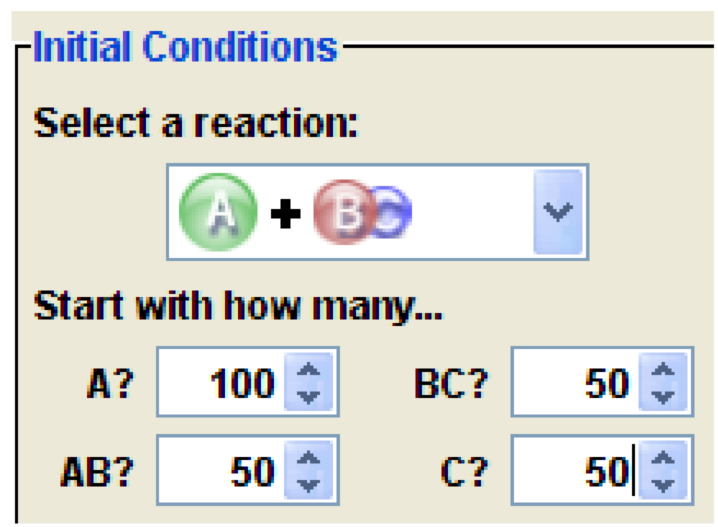
How will the equilibrium of second trial compare to the equilibrium of the first?

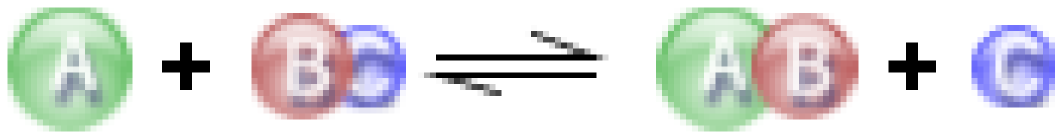


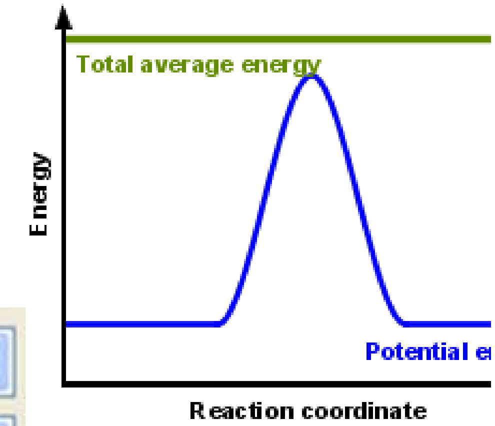
First experiment



Second experiment







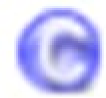
First trial

A?	50	BC?	50
AB?	50	C?	50

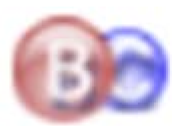
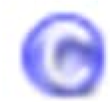
Second trial

A?	100	BC?	50
AB?	50	C?	50

A. There will be more  & 

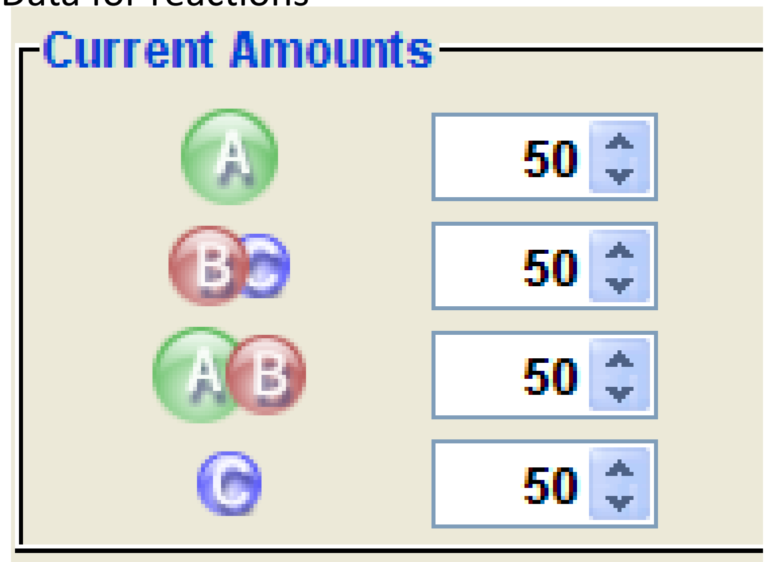
B. There will be more  & 

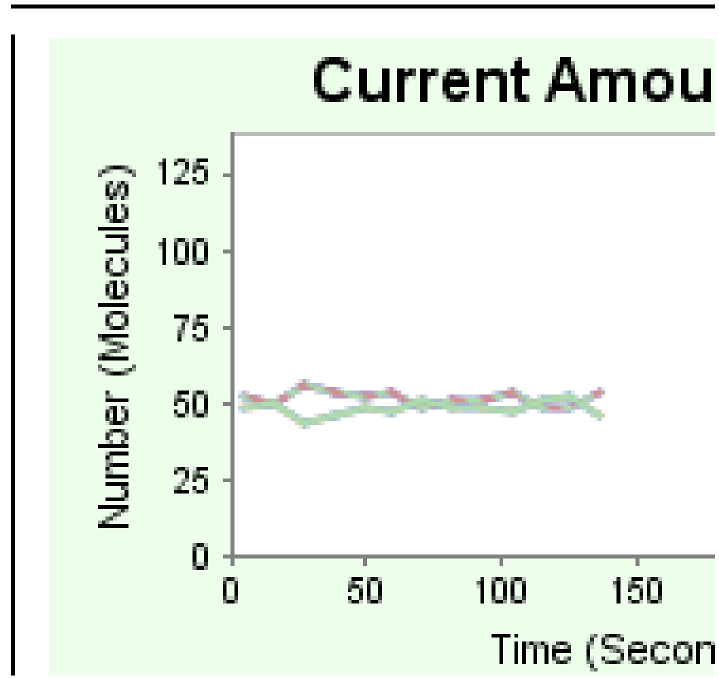
C. There will be more  &  & 

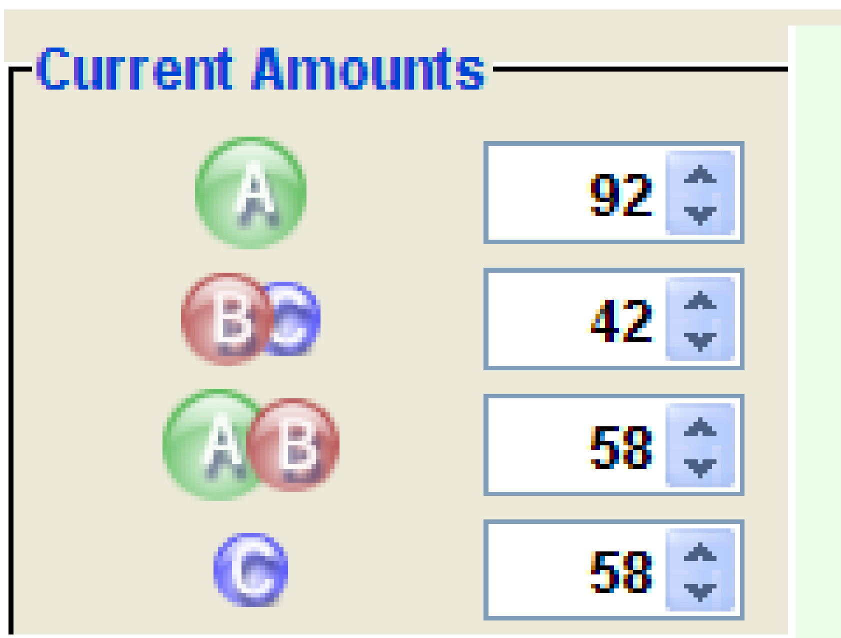
D. There will be more  &  & 

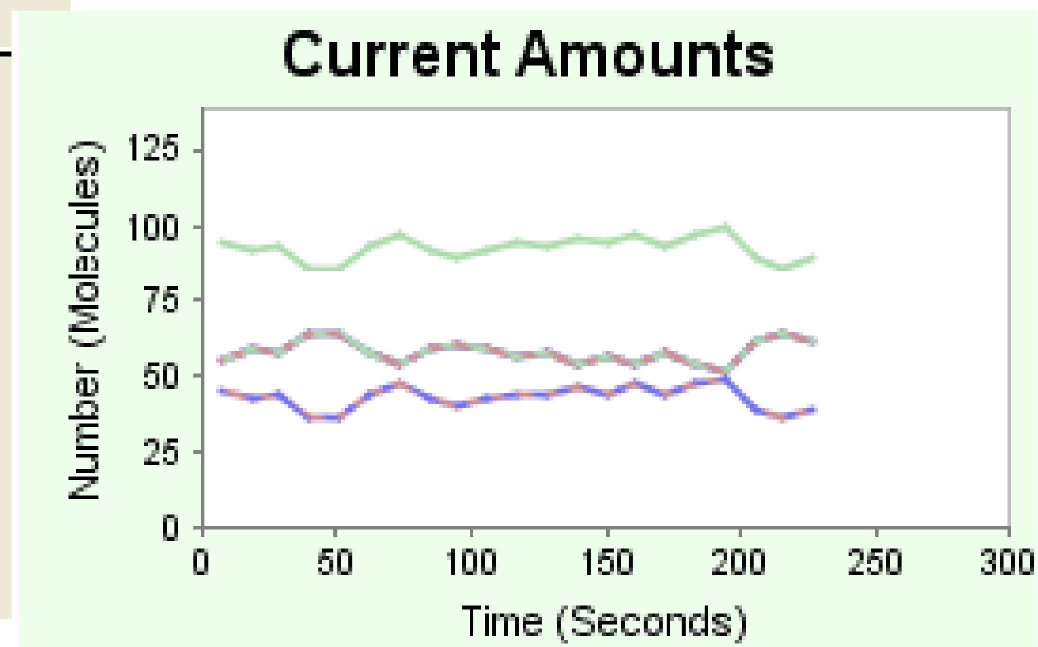
E. The ratios will still be about the same

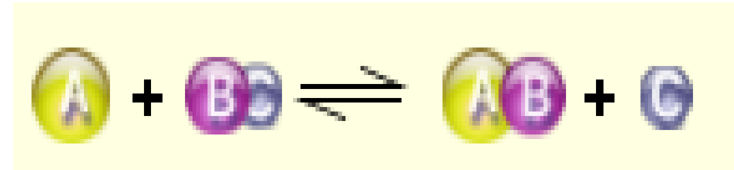
Data for reactions



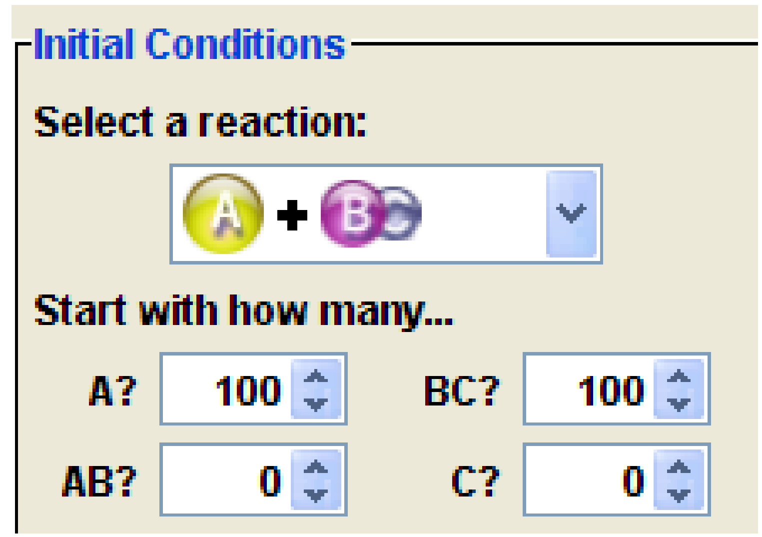


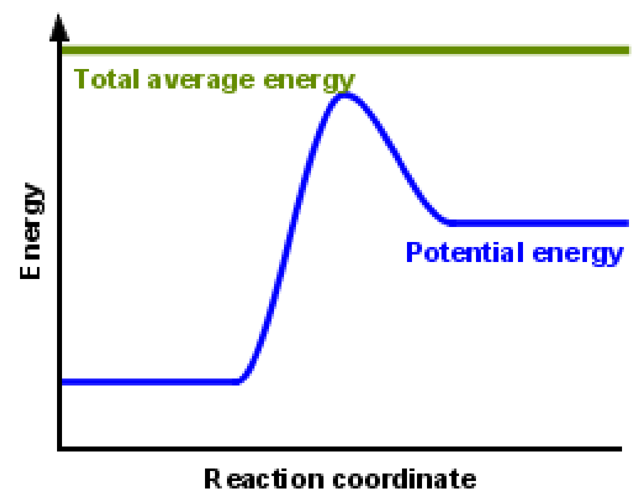


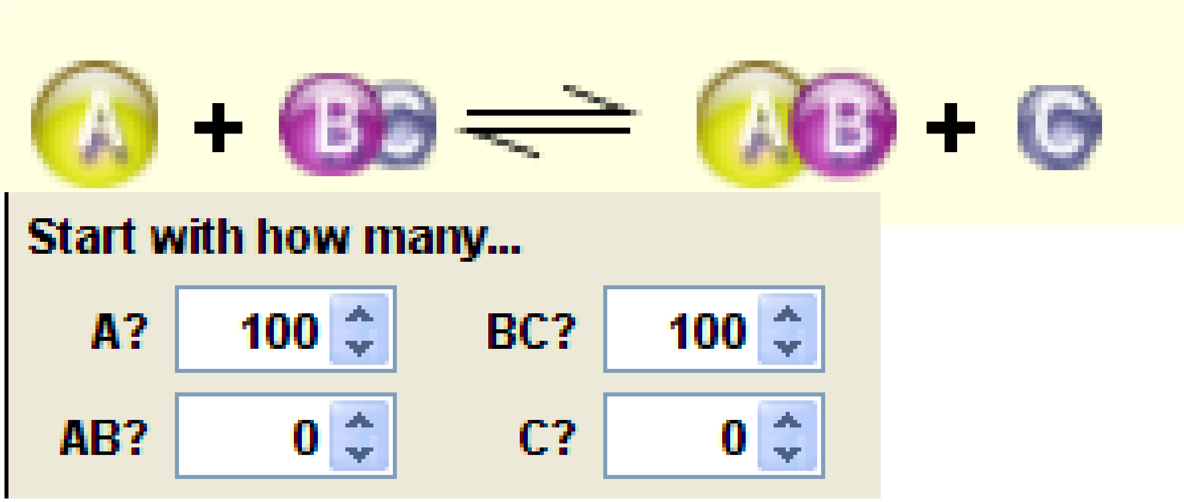


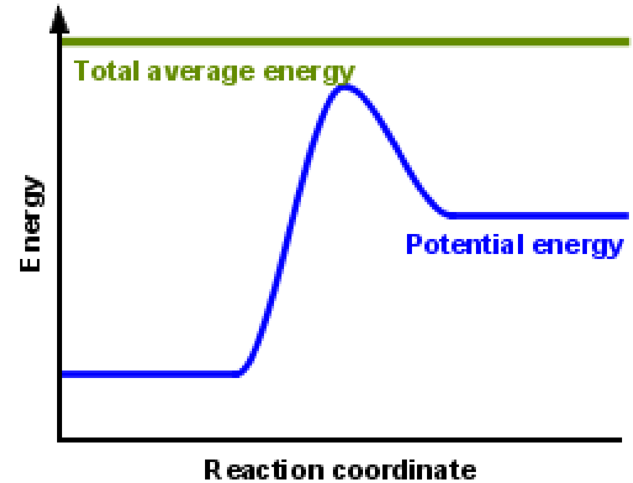


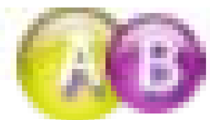
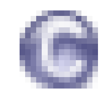
At equilibrium, what would you predict is in the container?

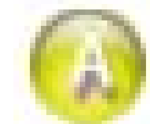


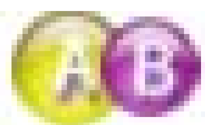
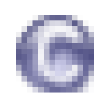


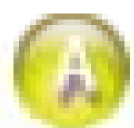




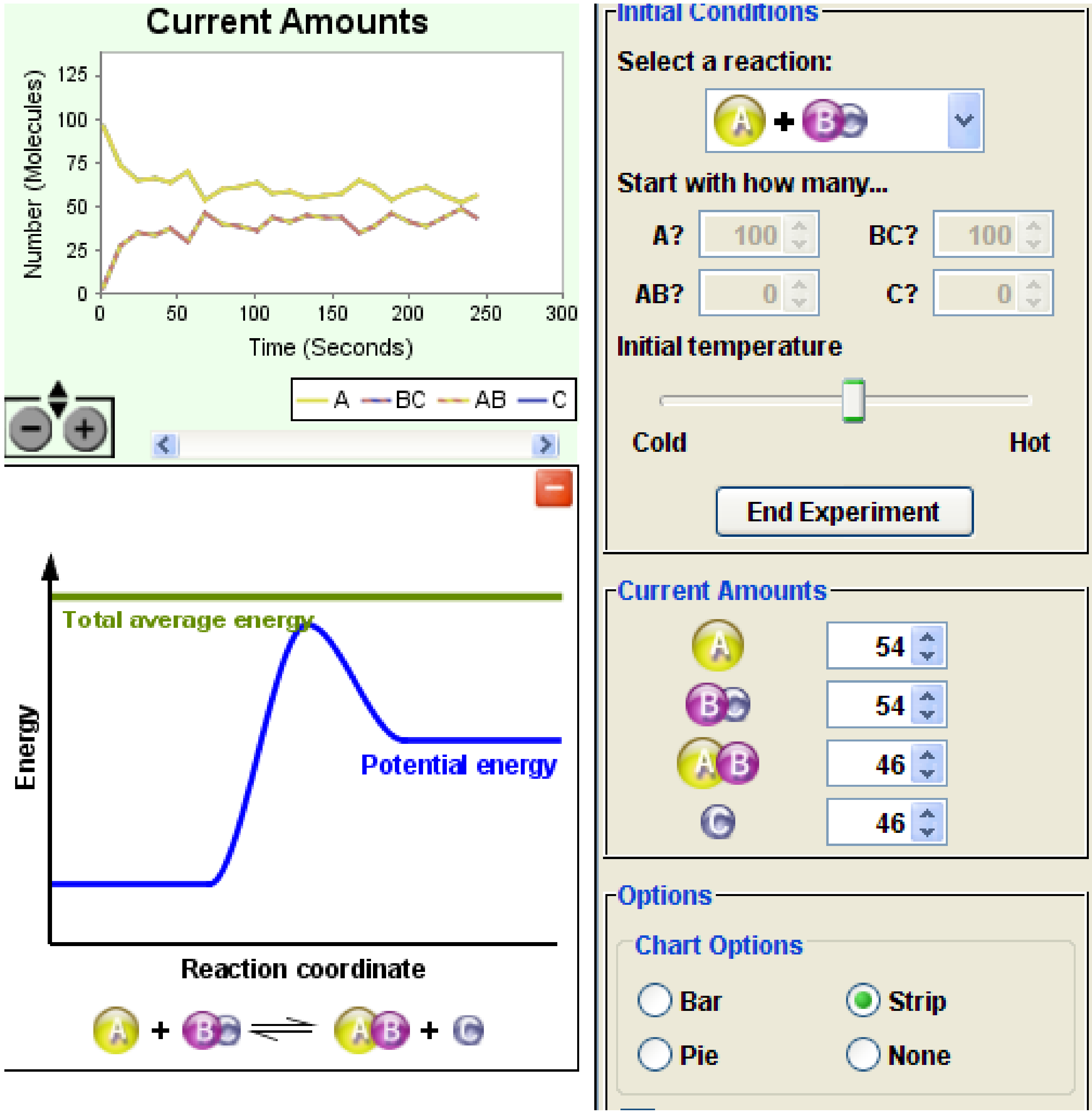
A. Container will have only  & 

B. Container will have only  & 

C. Container will have a mixture of all four with more  & 

D. Container will have a mixture of all four with more  & 

data



Current Amounts
Number (Molecules)
125
100
75
50
25
0
0
50
100
150
200
250
300
Time (Seconds)
A
BC
AB
C
Energy
Total average energy
Potential energy
Reaction coordinate
Initial Conditions
Select a reaction:
Start with how many...
A?
100
BC?
100
AB?
0
C?
0
Initial temperature
Cold
Hot
End Experiment
Current Amounts
54
54
46
46
Options
Chart Options
Bar
Strip
Pie
None

Reactions and Rates 4
Also uses ***Salts & Solubility*** and ***States of Matter***
Clicker Questions

LeChatlier's Principle

Trish Loeblein
PhET

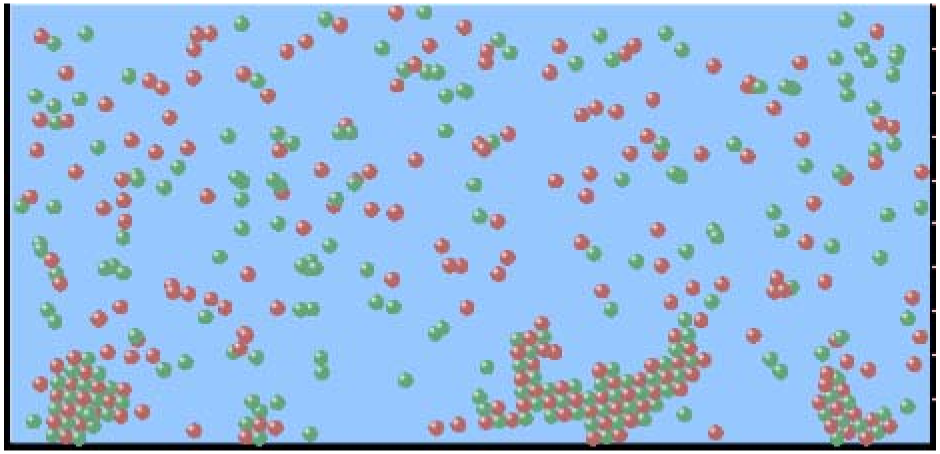
Learning Goals

Students will be able to:

- Explain how to make equilibrium systems change and predict what changes will happen.
- Compare and contrast salt-solution, phase, and chemical equilibriums.

If you add water to this salt solution, what will happen?

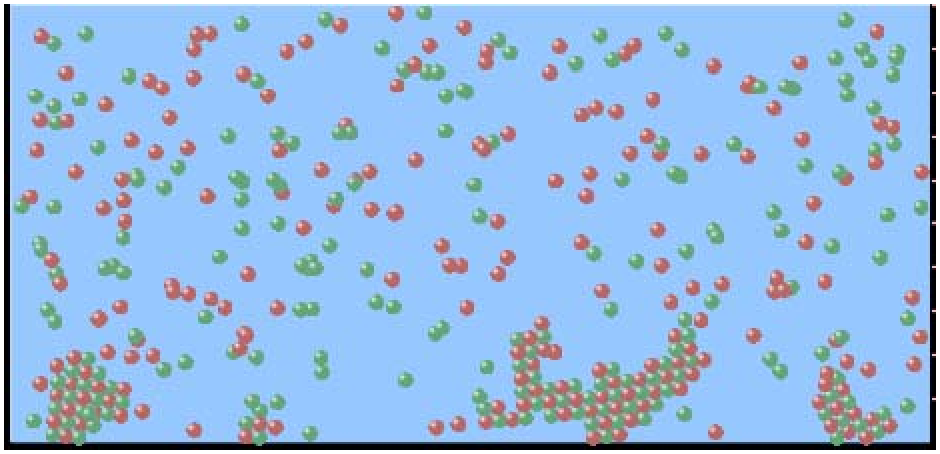
$$NaCl(s) \rightleftharpoons Na^+{}_{(aq)} + Cl^-{}_{(aq)}$$



A. The system will shift to the right
B. The system will shift to the left
C. LeChatlier's principle doesn't apply to physical systems

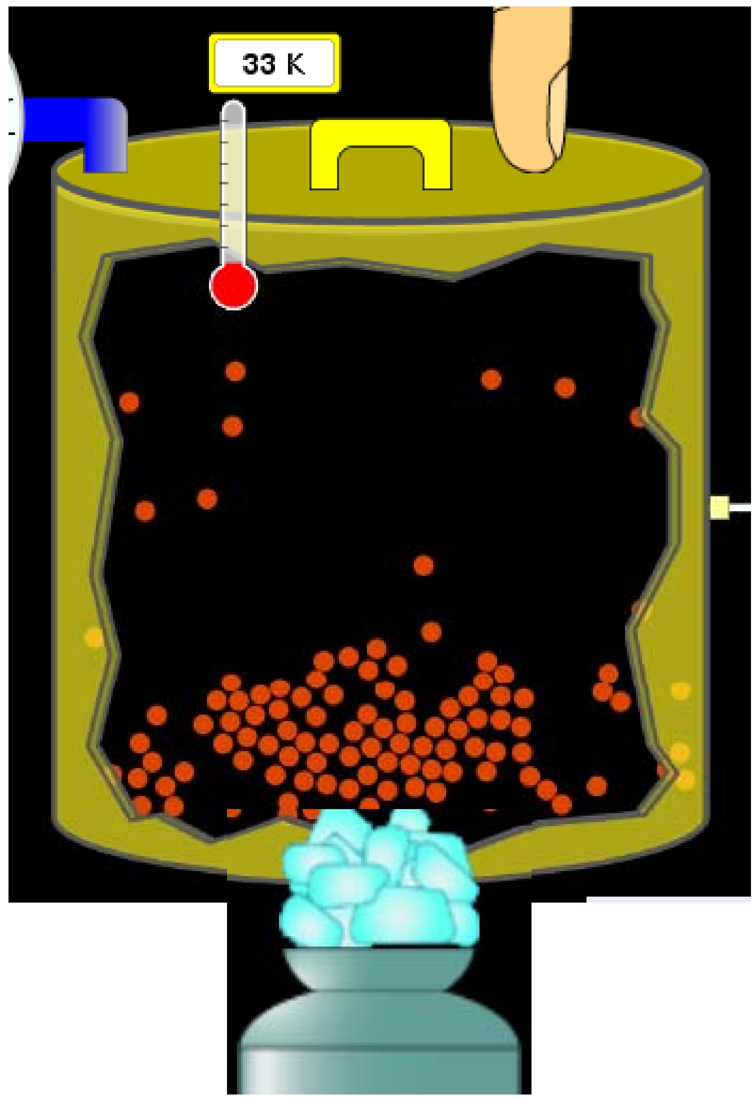
If you increased the air pressure above this salt solution, what will happen?

$$NaCl(s) \rightleftharpoons Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$



A. The system will shift to the right
B. The system will shift to the left
C. This system would not be effected by pressure changes.

If you cooled the container, what will happen? $Ne_{(l)} \rightleftharpoons Ne_{(g)}$

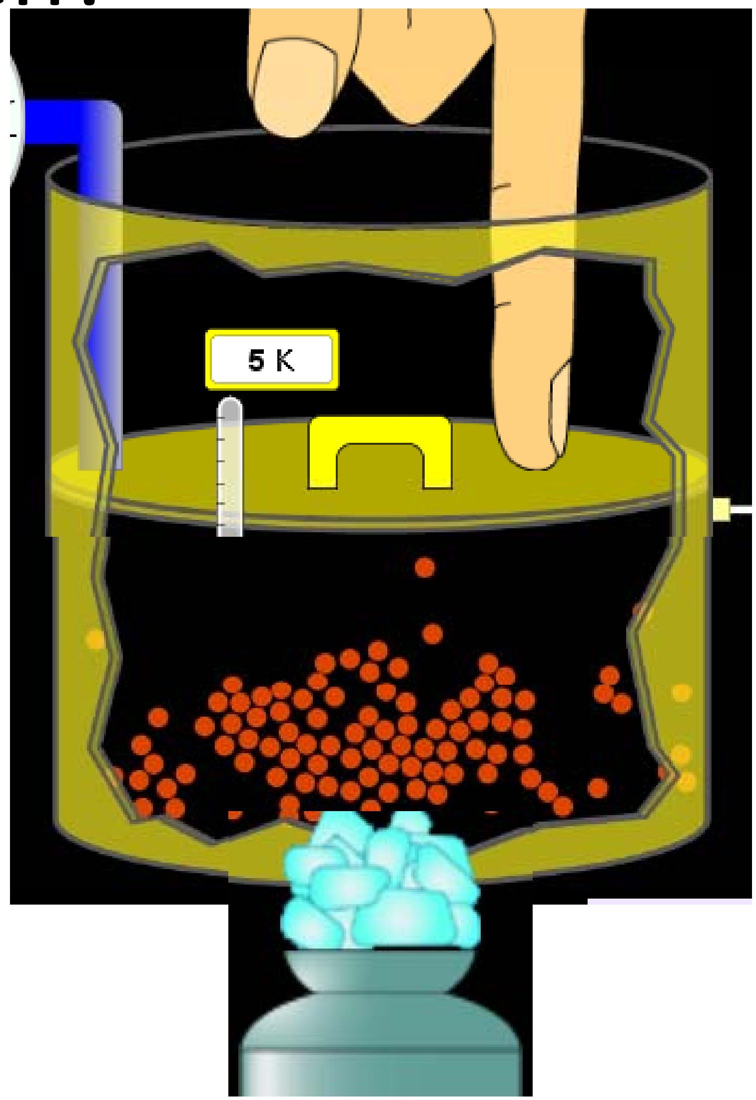


A. The system will shift to the right
B. The system will shift to the left
C. This system is not effected by temperature

If you made the container smaller, while keeping the temperature constant, what will happen?

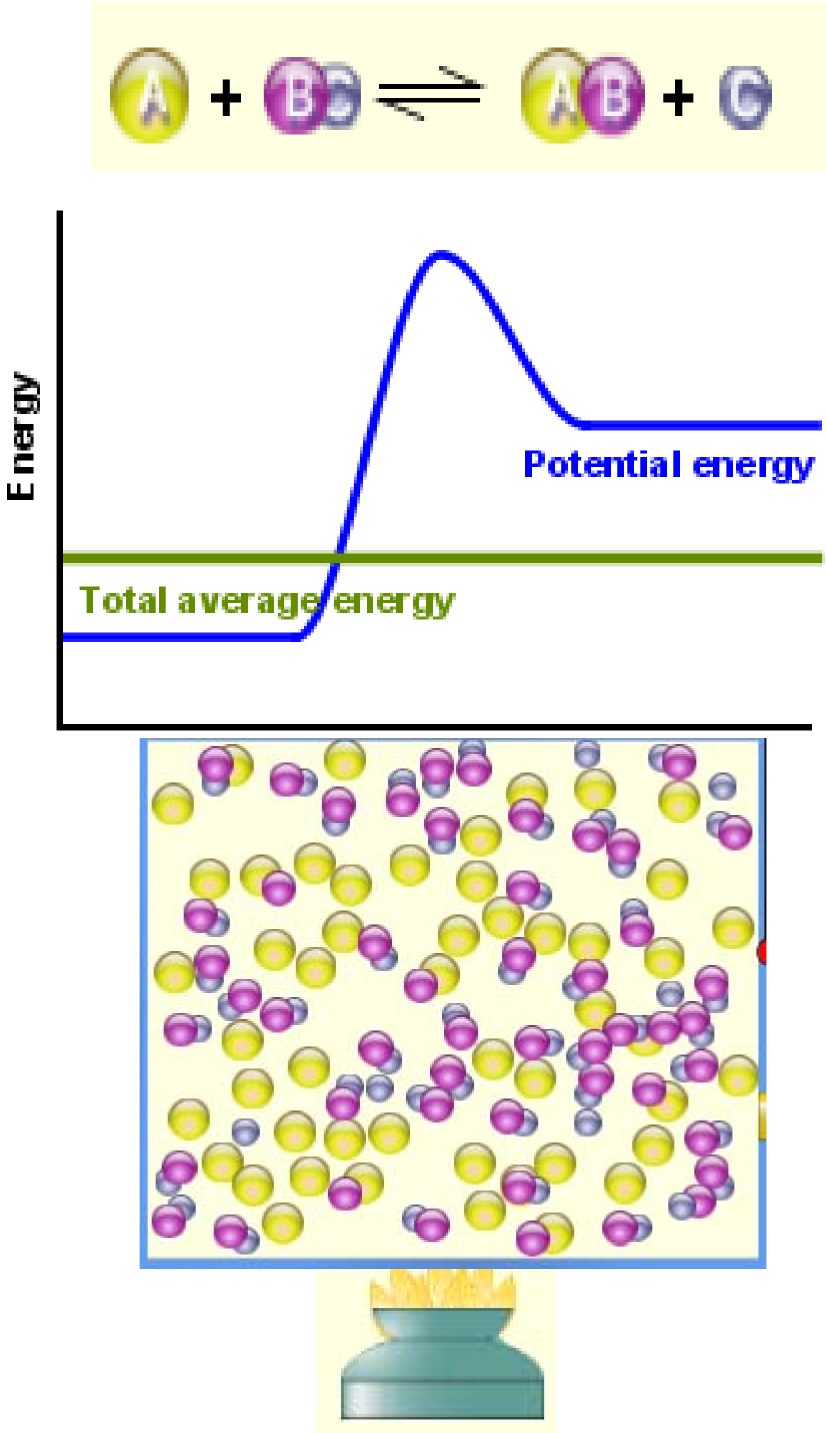
$$Ne_{(l)} \rightleftharpoons Ne_{(g)}$$

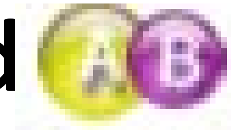
A. The system will shift to the right
B. The system will shift to the left
C. This system would not effected

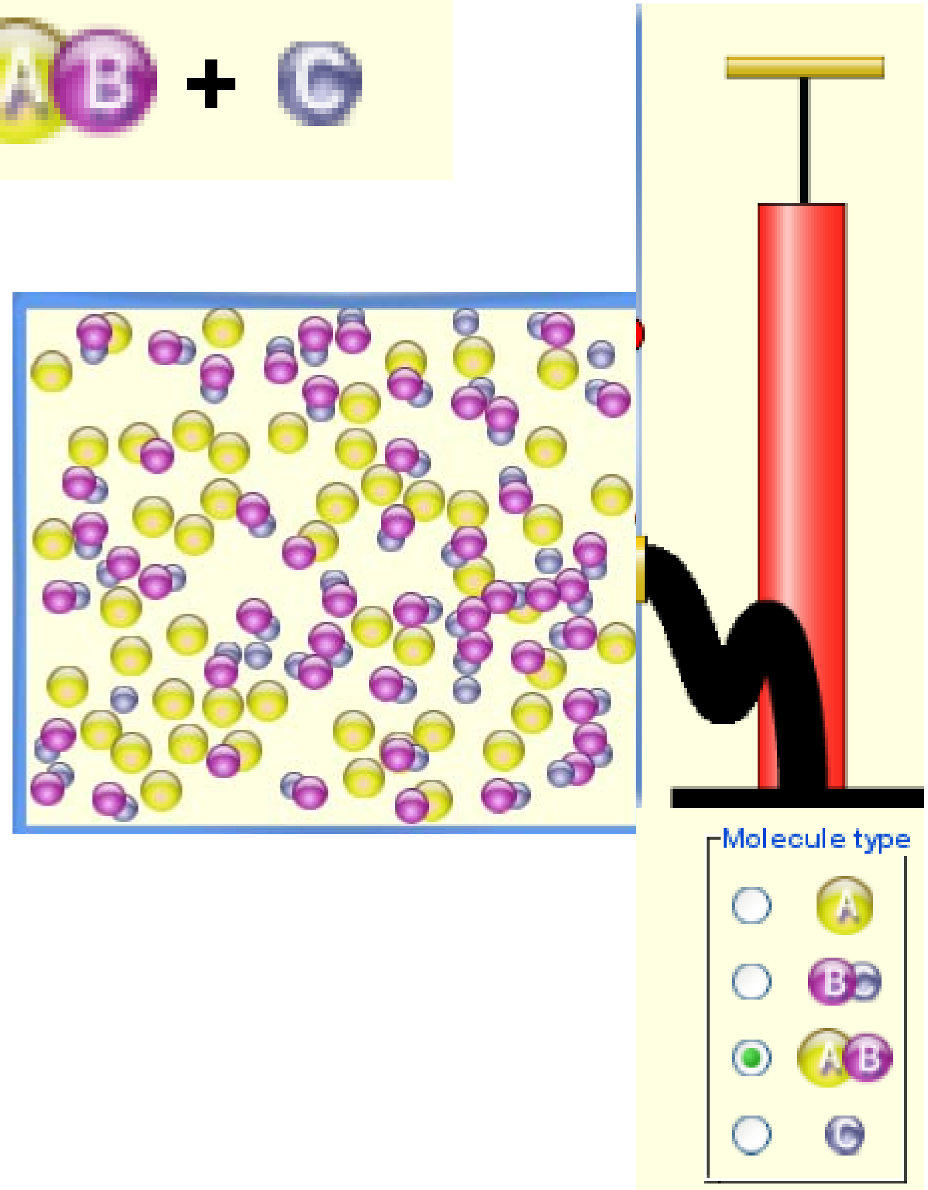


What would happen if you added energy using the heater ?

A. The system will shift to the right
B. The system will shift to the left
C. Both reactants and products would have more energy, but the amounts would not change much

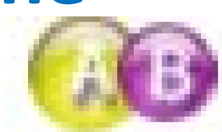


What would happen if you added  ?



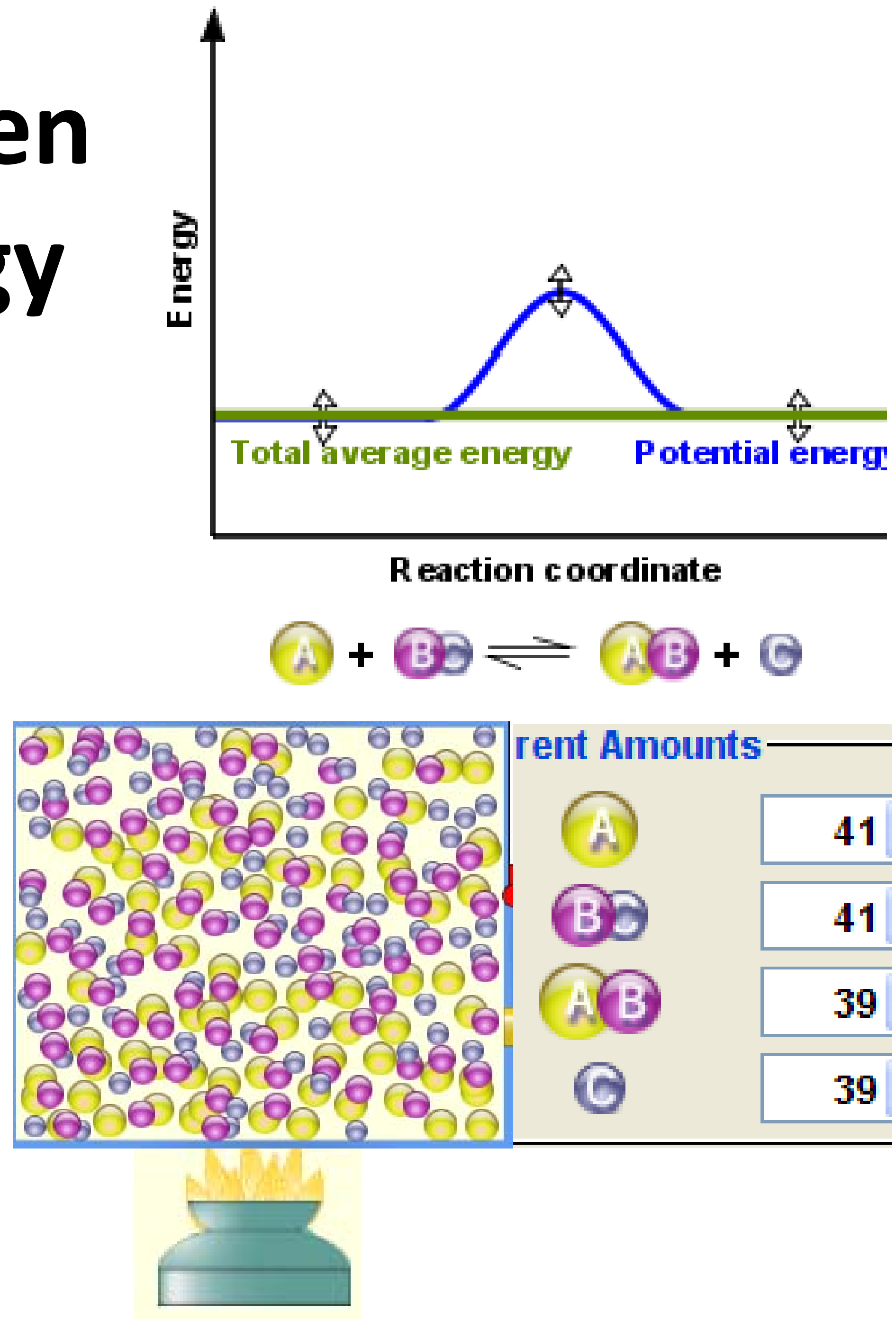
A. The system will shift to the right

B. The system will shift to the left

C. The only change would be the amount of 

What would happen if you added energy using the heater ?

A. The system will shift to the right
B. The system will shift to the left
C. Both reactants and products would have more energy, but the amounts would not change much



Plans for using PhET simulation activities in Loeblein's High School Chemistry

This is a list of lessons that can be found in the Teaching Ideas section of the PhET website

IC In Class Activity; **CQ** clicker questions; **HW** homework ; **Demo**: teacher centered group discussion

Introduction to Atoms, Molecules and Ions:

- Build an Atom: IC/CQ
- Salts & Solubility 1: IC/CQ
- Isotopes: IC/CQ
- States of Matter: demo/IC/CQ
- Models of Hydrogen Atom: IC/Demo includes Neon lights and Discharge Lamps

Formulas, Composition, Measuring chemicals, Chemical Reactions, Stoichiometry

- Reactions and Rates 1: Demo/IC/CQ
- Balancing Chemical Reactions: IC/CQ
- Reactants, Products, and Leftovers: 2 activities HW/CQ

Solutions

- Salts & Solubility 2: IC/HW
- Sugar and Salts: IC/HW/CQ
- Molarity: IC/CQ
- Concentration (activity still in draft)
- Beer's Law (activity still in draft)

Gases

- Gas Properties & Balloons and Buoyancy: Demo/IC/HW/CQ
- Gas Properties – Gas Laws IC/HW/CQ

Thermochemistry Introduction

- Reactions and Rates 2**:** IC/CQ

Atomic structure, Periodicity and General Bonding

- Build an Atom: IC/CQ
- Build a Molecule: IC or HW/CQ
- Molecule Polarity: IC or HW /CQ
- Molecular Shapes: IC or HW /CQ
- Molecules and Light: IC
- Greenhouse Gases: IC

Liquids and Solids

- Density:IC/CQ
- States of Matter and States of Matter Basics: IC/CQ
- Atomic Interactions: Demo or HW (activity still in draft)

Chemical Kinetics and Equilibrium

- Reaction and Rates 3: IC/CQ
- Reaction and Rates 4 (also uses Salts & Solubility, States of Matter): IC/CQ

Acids, Bases and Electrolytes

- pH Scale: IC/CQ
- Acid Base Solutions: IC/CQ
- Salts &Solubility 3: IC/CQ
- Sugar and Salt Solutions Demo

Nuclear sims:

- Beta Decay IC
- Alpha Decay IC/CQ
- Radioactive Dating Game IC/HW
- Nuclear Fission IC (authored with Chasteen)
- Rutherford: (activity still in draft)

Feb 2013 The pdf of all my lessons are available at **https://phet.colorado.edu/en/contributions/view/3459**

Reactions and Rates Activity: College version for Rate Experiments tab

Learning Goals: Students will be able to

1. Describe how initial concentration and temperature effect reaction rates
2. Determine mathematical rate expressions.

I. Rate and initial concentration

1. Work with a partner to write an experimental design using the **Rate Experiment** tab of *Reactions and Rates* to answer this question: How does the rate of the reaction between A and BC depend on the concentration of A and BC?

2. Compare your design with another group's and agree on a common procedure

3. Divide up the types of reactions, run the experiment that you designed, record data on different reactions.

4. Share your results and discuss the reliability of your procedure. If need be, make corrections, retest and collect new data.

5. Based on your data, write mathematical expressions for the rate of reactions based on both the change of the concentration of the reactant A and another for B. The equations start like this, and then you would calculate the values from your data.

Rate = d [A] / d t =

Rate = d [BC] / d t =

6. Explain why you think the rate expressions might be the same or different.

7. Test your ideas on one Design Your Own reaction and see if your explanation makes sense. Explain what changes you may have to make to your ideas.

I. Rate and temperature

8. Work with your group to design an experiment using the **Rate Experiment** tab of *Reactions and Rates* to answer this question: How does the rate of the reaction between A and BC depend on the temperature of the molecules?
Procedure:

9. Divide up the types of reactions and collect data on different reactions, then share your results. Data:

10. Write a few sentences describing the relationships you observed between temperature and rate.

11. Explain why you think temperature changes effect reactions differently depending on the energy- reaction coordinate.