Lab 22. Chemical Equilibrium: Why Do Changes in Temperature, Reactant Concentration, and Product Concentration Affect the Equilibrium Point of a Reaction?

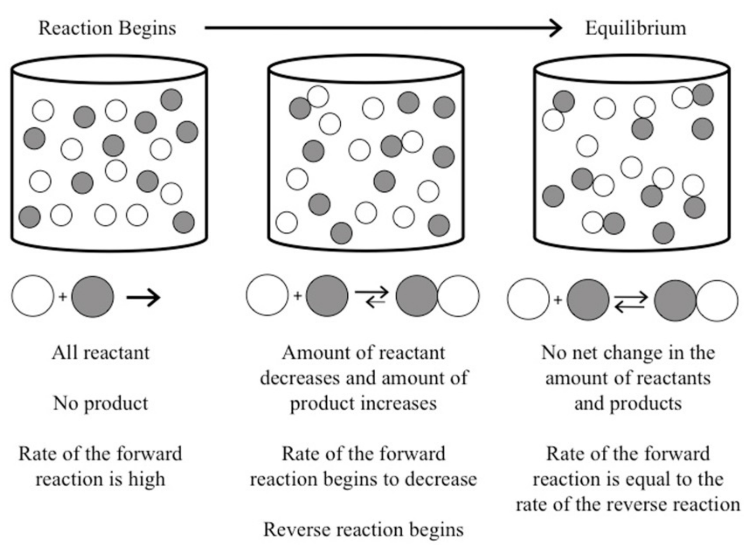
Introduction

It is often useful to think of a reaction as a process that consists of two components acting in opposite directions. From this view, a reaction begins with all reactants and no products. The reactants then begin to interact with each other and transform into products. The rate at which the reactants transform into products will begin to decrease over time as the concentration of the reactant decreases. At this point, some of the products will begin to revert back into reactants. The rate at which the products revert back into reactants will increase as the concentration of the product increases. There is a point, as a result, where the forward and reverse components of a reaction are happening at equal rates. This point is called *chemical equilibrium*. At equilibrium, the rates of the forward and reverse components of the reaction are equal but the concentrations of reactants and products are not. Figure L22.1 illustrates this process.

Chemical equilibrium, therefore, can be defined as the point in a reaction where the rate at which reactants transform into products is equal to the rate at which products revert back into reactants. The *equilibrium point* of a chemical reaction occurs when the amount or concentration of the products and reactants in a closed system is stable. Chemists use a specific property, such as color, concentration, or density, to determine when a reaction is in equilibrium. It is important to note, however, that chemists view the state of chemical equilibrium as dynamic because reactants continue to transform into products and products continue to revert back into reactants even though the amount of reactants and products in the closed system is stable.

FIGURE L22.1

The forward and reverse reactions associated with chemical equilibrium



The equilibrium point of a reaction can change because chemical equilibrium is not static. There are a number of different factors that can change the equilibrium point of a reaction by changing the rate at which reactants transform into products or by changing the rate at which products revert back into the reactants. These factors include a change in temperature, pressure, reactant concentration, and product concentration. When any of these factors are changed, the equilibrium point of the reaction will move and the concentration of products and reactants in the system at the new equilibrium point will be different.

To control the amount of product or reactant present at the equilibrium point of a reaction in a closed system, chemists need to understand how various factors affect chemical equilibrium and why these various factors change the equilibrium point of a reaction. You will therefore explore how three specific factors affect the equilibrium point of chemical reaction. You will then develop a conceptual model that you can use to explain your observations and predict how the equilibrium point of a different reaction will change when the equilibrium point is disturbed by changing these same three factors.

Your Task

Determine *how* changes in temperature and the addition of extra reactant and product affect the equilibrium point of the reaction between iron(III) nitrate and potassium thiocyanate. Then develop a conceptual model that you can use to explain *why* these factors influence the equilibrium point of a reaction. Once you have developed your conceptual model, you will need to test it to determine if it allows you to predict how the equilibrium point of a different reaction will change under similar conditions.

The guiding question of this investigation is, **Why do changes in temperature, reactant concentration, and product concentration affect the equilibrium point of a reaction?**

Materials

You may use any of the following materials during your investigation:

Consumables	Equipment
• M iron(III) nitrate, $Fe(NO_3)_3$ • M potassium thiocyanate, KSCN • 1.5 M copper(II) chloride, $CuCl_2$ • 4 M sodium chloride, NaCl • 0.05 M silver nitrate, $AgNO_3$ • Distilled water • Ice	• 9 test tubes • Test tube rack • Graduated cylinder (10 ml) • 6 disposable graduated Beral pipettes • Beaker (50 ml) • 2 beakers (each 250 ml), for hot- and cold-water baths • Thermometer • Hot plate

Safety Precautions

Follow all normal lab safety rules. Iron(III) nitrate is a body tissue irritant; it will also stain clothes and skin. Potassium thiocyanate and copper(II) chloride are toxic by ingestion. Silver nitrate is toxic by ingestion, is corrosive to body tissues, and stains clothes and skin. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Use caution when working with hot plates because they can burn skin. Hot plates also need to be kept away from water and other liquids.
- Handle all glassware (including thermometers) with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in developing your model is to design and carry out three experiments. The goal of the first experiment will be to determine how a change in reactant concentration affects the equilibrium point of a reaction. The goal of the second experiment will be to determine how a change in product concentration affects the equilibrium point of a reaction. The goal of the third experiment will be to determine how temperature affects the equilibrium point of a reaction. For these three experiments, you will focus on the reaction of iron(III) nitrate and potassium thiocyanate. Iron(III) ions react with thiocyanate ions to form $FeSCN^{2+}$ complex ions according to the following reaction:

$$Fe^{3+}(aq) \quad + \quad SCN^{-}(aq) \quad \leftrightarrows \quad FeSCN^{2+}(aq)$$

Yellow   Colorless   Orange-Red

You can prepare a stock solution of $FeSCN^{2+}$ by mixing 40 ml of distilled water with 1 ml of 0.1 M $Fe(NO_3)_3$ and 2 ml of 0.1 M KSCN. You can then add 2 ml of this stock solution to several different test tubes to create a control condition and several treatment conditions for each experiment. You can then change the temperature, reactant concentration, or product concentration in the treatment conditions as needed and leave the control condition alone for comparison purposes. You must, however, determine what type of data you need to collect, how you will collect the data, and how you will analyze the data for each experiment.

To determine *what type of data you need to collect*, think about the following questions:

- What type of measurements or observations will you need to record during each experiment?
- When will you need to make these measurements or observations?

To determine *how you will collect the data*, think about the following questions:

- What will serve as your independent variable in each experiment?
- How will you change the independent variable in each experiment?
- What types of comparisons will you need to make?
- What will you do to reduce measurement error?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze the data*, think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Once you have carried out your three experiments, your group will need to develop a conceptual model. This conceptual model will need to be able to provide an underlying reason for your findings about the effect of temperature, changes in reactant concentration, and changes in product concentration on the equilibrium point of a reaction. Your model should also include an explanation of what is happening at the submicroscopic level between and within molecules during a reaction. The collision theory of reaction rates and the concept of chemical equilibrium should serve as the theoretical foundation for your model.

The last step in this investigation is to test your model. To accomplish this goal, you can use a different reaction to determine if your model leads to accurate predictions about how the equilibrium point changes in response to different factors. If you can use your model to make accurate predictions about how the equilibrium point of a different reversible reaction changes, then you will be able to generate the evidence you need to convince others that the conceptual model you developed is valid.

You can use the reversible formation of copper(II) complexes to test your model. When copper(II) chloride ($CuCl_2$) is dissolved in water, two different solutes are present in the solution. These solutes include Cu^{2+} ions and Cl^- ions. These solutes interact with water molecules to form two different complex ions. One complex ion is $Cu(H_2O)_6^{2+}$ and the other is $CuCl_4^{2-}$. The reversible equation for the formation of the two complex ions is

$$\underset{\text{Blue}}{Cu(H_2O)_6^{2+}(aq)} + 4Cl^-(aq) \leftrightarrows \underset{\text{Green}}{CuCl_4^{2-}(aq)} + 6H_2O$$

You can change the equilibrium point by adding NaCl, or $AgNO_3$ or by changing the temperature of the solution. To change the concentration of the reactants or the products, simply add 2 ml of the copper(II) chloride solution to a test tube and then add up to eight drops of NaCl or $AgNO_3$. The addition of NaCl will increase the number of Cl^- ions in the system. The addition of $AgNO_3$, in contrast, will decrease the number of Cl^- ions in the system (because the Ag^+ ions react with Cl^- ions to form AgCl). To change the temperature of the system, use a hot-water bath or an ice bath.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

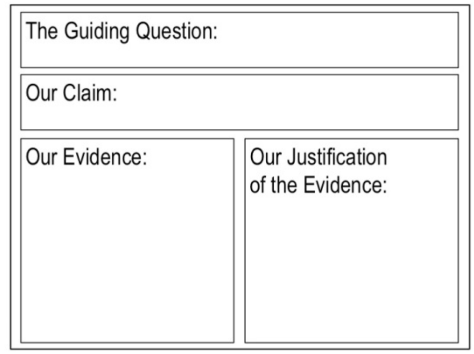
- how models are used to help understand natural phenomena,
- why it is important to understand what makes a system stable or unstable and what controls rates of change in a system,
- the importance of imagination and creativity in science, and
- the role of experiments in science.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L22.2.

FIGURE L22.2

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

- How did your group collect the data? Why did you use that method?
- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!