Lab 17. Limiting Reactants: Why Does Mixing Reactants in Different Mole Ratios Affect the Amount of the Product and the Amount of Each Reactant That Is Left Over?

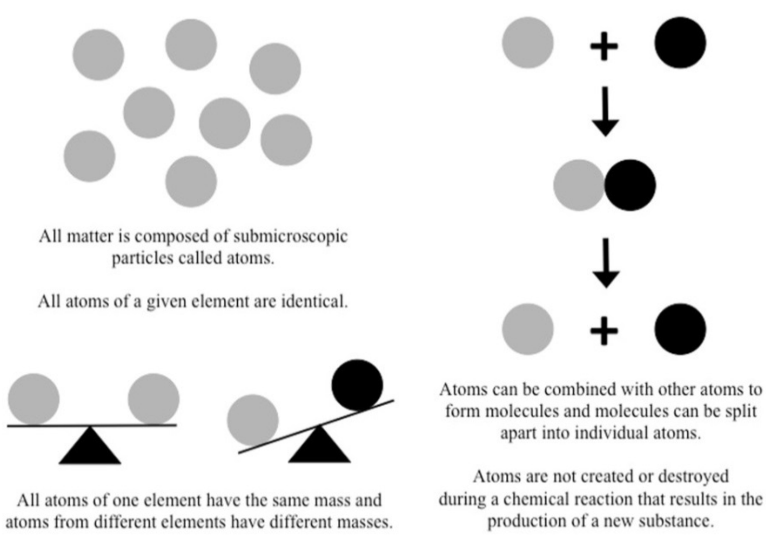
Introduction

Atomic theory is a model that has been developed over time to explain the properties and behavior of matter. This model consists of five important principles, as listed below (see also Figure L17.1):

1. All matter is composed of submicroscopic particles called atoms.
2. All atoms of a given element are identical.
3. All atoms of one element have the same mass, and atoms from different elements have different masses.
4. Atoms can be combined with other atoms to form molecules, and molecules can be split apart into individual atoms.
5. Atoms are not created or destroyed during a chemical reaction that results in the production of a new substance.

FIGURE L17.1

The basic principles of atomic theory



A chemical reaction, according to atomic theory, is simply the rearrangement of atoms. The substances (elements and/or compounds) that are changed into other substances during a chemical reaction are called *reactants*. The substances that are produced as a result of a chemical reaction are called *products*. Chemical equations show the reactants and products of a chemical reaction. A chemical equation includes the chemical formulas of the reactants and the products. The products and reactants are separated by an arrow symbol (→), and each individual substance's chemical formula is separated by a plus sign (+).

Atomic theory, as noted earlier, indicates that atoms are not created or destroyed during a chemical reaction. Thus, each side of the chemical equation must include the same number of each type of atom. When there is an equal number of each type of atom on each side of the equation, the equation is described as balanced. Chemists balance chemical equations by changing the number of each type of substance involved in the reaction; they do not change the number of atoms within each substance. The number of atoms found within a substance cannot be changed because it would change the nature of the substances involved in the reaction. For example, suppose a chemist needs to balance the following equation for the reaction of nitrogen and hydrogen gas:

$$N_2(g) + H_2(g) \rightarrow NH_3(g)$$

In this case, he or she cannot simply add another atom of nitrogen and take an atom of hydrogen away from the chemical formula for ammonia (NH_3) because this would change ammonia (NH_3) to diazene (N_2H_2). Chemists therefore use stoichiometric coefficients to indicate how much of each substance is involved in the reaction without changing the nature of those substances. The balanced chemical equation for the reaction of nitrogen and hydrogen gas, as a result, is denoted as follows:

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

The stoichiometric coefficients indicate the relative amount of each substance involved in the chemical reaction in terms of molecules or moles. This equation, as a result, can be read as, 1 molecule of nitrogen gas reacts with 3 molecules of hydrogen gas to yield 2 molecules of ammonia gas. The equation can also be read as, 1 mole of nitrogen gas reacts with 3 moles of hydrogen gas to yield 2 moles of ammonia gas.

The stoichiometric coefficients are also used to determine the *mole ratio*, which is the relationship between the amounts of any two compounds, in moles, that are involved in a chemical reaction. For example, the mole ratio of the reactants (N_2 and H_2) in the reaction listed above is 1:3 (1 mole of N_2 reacts with 3 moles of H_2) and the mole ratio between hydrogen gas and ammonia gas is 3:2 (3 moles of H_2 yields 2 moles of NH_3). Chemists use mole ratios as a conversion factor in many chemistry problems. Mole ratios are also useful when a chemist needs to create a specific amount of a product but must also minimize the amount of reactants that need to be purchased and limit the amount of waste that is left over.

To be able to use mole ratios to create a specific amount of a product, minimize costs, and limit waste, it is important to understand how varying the mole ratio of the reactants affects the amount of the product that is formed and the amount of the reactants that are left over at the end of a chemical reaction. You will therefore explore how mixing acetic acid and sodium bicarbonate in different mole ratios affects the amount of carbon dioxide (CO_2) gas that is produced and determine which reactant, if any, is left over at the end of the chemical reaction. You will then develop a conceptual model that you can use to explain your observations and predict the amount of CO_2 gas that will be produced in other conditions.

Your Task

Determine how varying the mole ratio of the reactants affects the amount of the product that is produced and the amount of the reactants that remain at the end of a chemical reaction. You will then develop a conceptual model that can be used to explain why mixing reactants in different mole ratios will affect the amount of product that is produced and the amount of each reactant left over. Once you have developed your conceptual model, you will need to test it to determine if it allows you to predict the dissolution rate of another solute under various conditions.

The guiding question for this investigation is, **Why does mixing reactants in different mole ratios affect the amount of the product and the amount of each reactant that is left over?**

Materials

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

Consumables	Equipment
• Solution of acetic acid, CH_3COOH • Sodium bicarbonate, $NaHCO_3$ • pH paper 1 M	• Side-arm Erlenmeyer flask with stopper (50 ml) • Pneumatic trough • Tubing (50 cm long) • Electronic or triple beam balance • Graduated cylinder (500 ml) • Graduated cylinder (250 ml) • Spatula or chemical scoop • Weighing paper or dishes

Safety Precautions

Follow all normal lab safety rules. 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.
- Handle all glassware 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 an experiment to determine how varying the mole ratio of the reactants affects the amount of the product that is formed and the amount of the reactants that remain at the end of a chemical reaction. To conduct this experiment, you will focus on the reaction of acetic acid and sodium bicarbonate. Acetic acid (CH_3COOH) reacts with sodium bicarbonate ($NaHCO_3$) according to the following equation:

$$CH_3COOH(aq) + NaHCO_3(s) \rightarrow NaCH_3CO_2(aq) + CO_2(g) + H_2O(l)$$

You will need to react sodium bicarbonate and acetic acid in different molar ratios while keeping everything else the same during your experiment. To do this, you will first need to decide which mole ratios (e.g., 2:1, 1:1, 1:3) and how many different mole ratios to test. You should, however, test at least five different mole ratios to have enough useful comparisons. Next, you will need to determine the amount of each reactant you need to use in each reaction. You should use the same amount of acetic acid (5 ml or 0.005 moles) in each reaction and vary the amount of sodium bicarbonate. You will therefore need to first determine the number of moles of sodium bicarbonate that you will need to use in each test. You can then calculate the mass of sodium bicarbonate that you will need to react with the 5 ml of acetic acid.

Once you have determined the amount of sodium bicarbonate you will need to use for each of the reactions, you will need to devise a way to determine how much product is produced during each reaction and if there are one or more reactants left over after the reaction is complete. You will therefore need to think about *what type of data you need to collect* during your experiment. To accomplish this task, think about the following questions:

- How will you know if there is any sodium bicarbonate left over at the end of the reaction?
- How will you know if there is any acetic acid left over at the end of the reaction?
- How will you measure the amount of product that is produced?

The easiest way to determine how much product is produced is to measure the amount of CO_2 that is formed after you combine the acetic acid and sodium bicarbonate. To accomplish this task, you will need to collect the CO_2 gas by water displacement. Figure L17.2 shows how to collect gas by water displacement.

Once you have collected your data, you will need to think about *how you will analyze the data*. The following questions may be helpful:

FIGURE L17.2

Gas collection using water displacement

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

Once you have carried out your experiments, your group will need to develop a conceptual model that can be used to explain why mixing reactants in different mole ratios will affect the amount of product that is produced and the amount of each reactant left over. The model also needs to be able to explain what is happening during the reaction at the submicroscopic level.

The last step in this investigation is to test your model. To accomplish this goal, you can use a different mole ratio to determine if your model leads to accurate predictions about the amount of product produced and which reactant or reactants will be left over under different conditions. If you are able to use your model to make accurate predictions under different conditions, then you will be able to generate the evidence you need to convince others that the conceptual model you developed is valid.

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

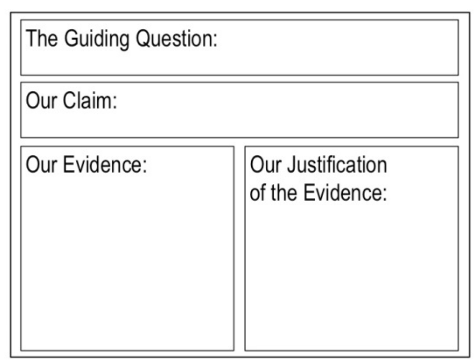
- why it is important to look for proportional relationships,
- how models are used to help understand natural phenomena,
- the difference between laws and theories in science, and
- the role of imagination and creativity in science.

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 L17.3.

FIGURE L17.3

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!