Student Experience Notebook Sample

Experience Chemistry

SAVVAS

Experience Chemistry

Experience It!
IT'S THE SCIENCE OF DOING!

Welcome to "phenomenal" science! Check out this sample of the Student Experience Notebook. **It's not a textbook!** The **Student Experience Notebook** is a place for active doing, analyzing, reflecting, and documenting. It's designed to help students organize and synthesize their thinking and collect experimental evidence. *Experience Chemistry* helps you teach the science of doing.

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Savvas.com/ExperienceChemistry

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12 Storyline 2: Understanding Chemical Reactions

Investigation 7: Stoichiometry

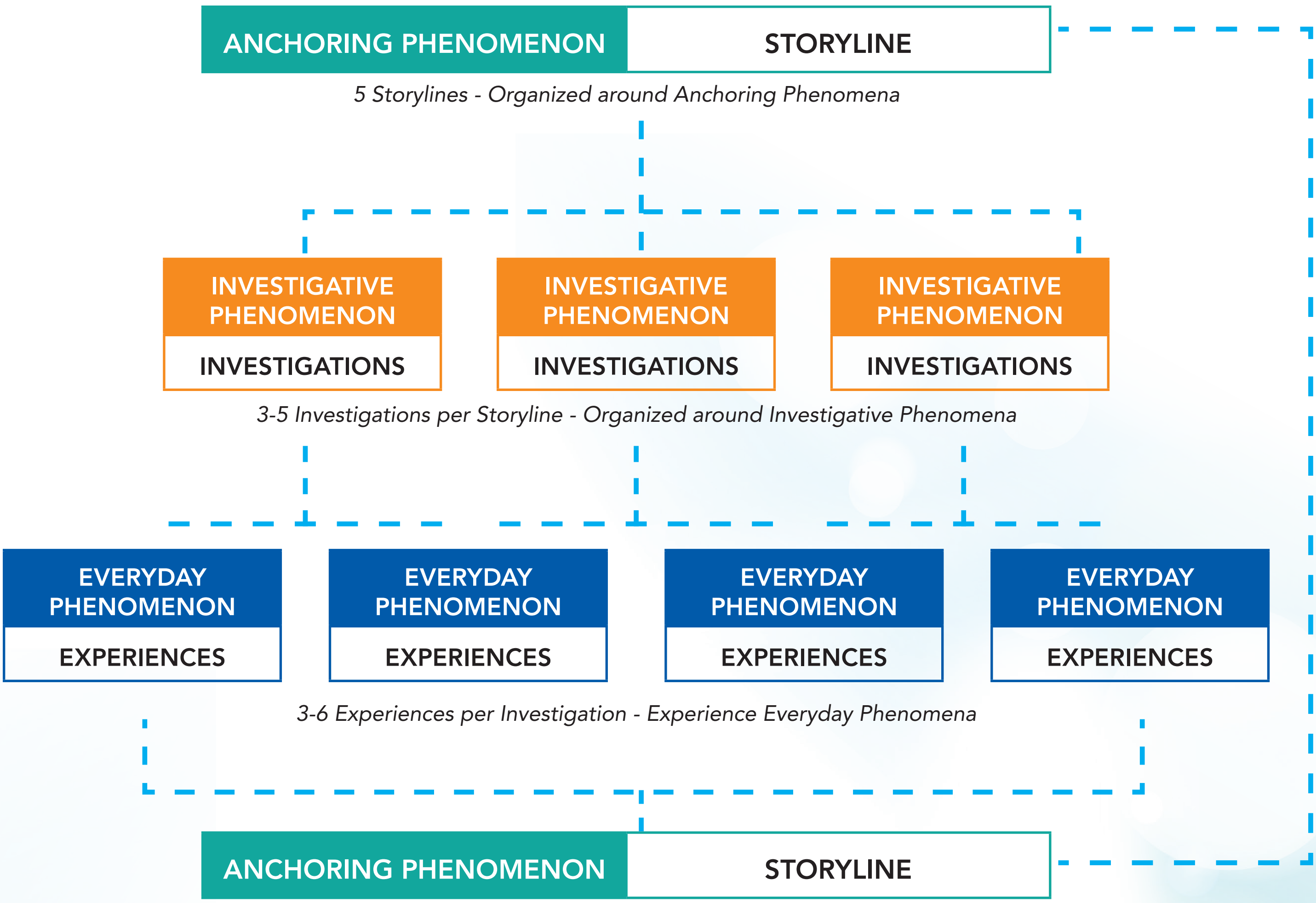
Experience 1: Quantifying Reactants and Products

Experience 2: Chemical Calculations

Experience 3: Limiting Reagent and Percent Yield

Look How It's Organized

Experience Chemistry is an exciting, innovative way to learn chemistry. Thought-provoking phenomena engage students in evidence-focused practices where learning is based on 'doing' science. The sequence of instruction drives learning through Anchoring, Investigative, and Everyday Phenomena.



Start Your Experience Here

1

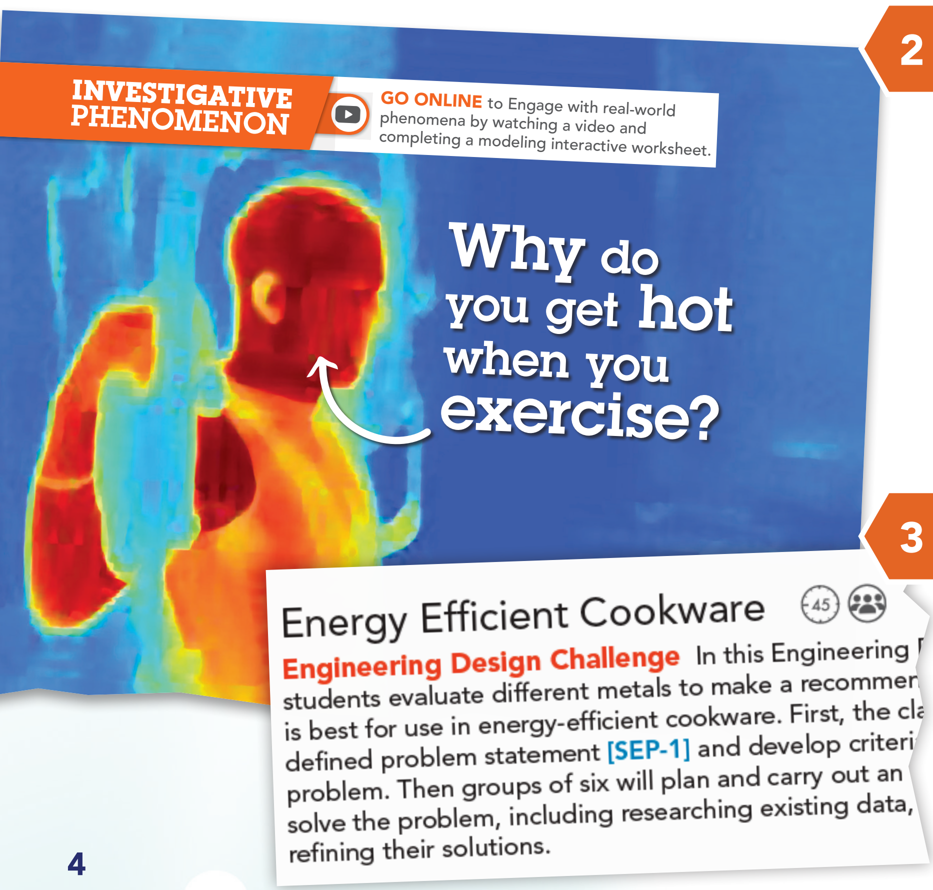
Anchoring Phenomenon

Launch each Storyline with an engaging **Anchoring Phenomenon Video**. Introduce and unify the upcoming chemistry concepts and give students an opportunity to ask questions.

2

Investigative Phenomenon

Introduce every Investigation with an **Investigative Phenomenon Video** that supports students as they make meaning of the Anchoring Phenomenon. This feature shows students how chemistry is applicable in their everyday lives.



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Everyday Phenomena

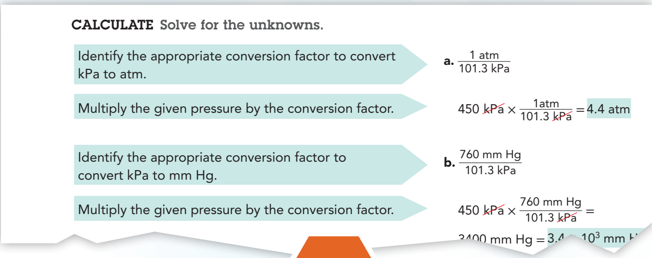
How do students make sense of the Anchoring and Investigative Phenomena? They interact with hands-on and digital **Everyday Phenomena**. From engineering design challenges to inquiry performance tasks, students experience the concepts of chemistry everyday.

FLINN SCIENTIFIC

4

Flinn Scientific Labs

Students engage with chemistry concepts through **inquiry labs**, engineering design challenges, performance-based assessments, virtual reality, and videos developed by Flinn Scientific.



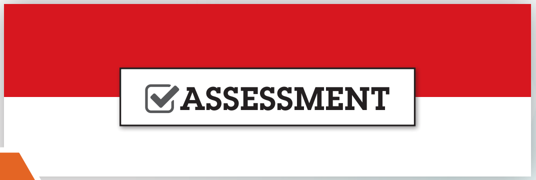
Math Support

5

Stepped-out examples break down **sample problems** for clarity and process guidance. **Problem Banks** give students additional opportunities to build mathematical fluency.

Revisit the Phenomenon

Students continue to work on their Claims-Evidence-Reasoning and Modeling Activities every time they **Revisit the Phenomena**.



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Performance-Based Assessments

Engineering and inquiry tasks give students opportunities to demonstrate their understanding of three-dimensional learning.

The Flinn Lab Experience

Experience Chemistry takes inquiry to a higher level. An exclusive partnership with Flinn Scientific, the leading classroom lab solutions provider, embeds engaging Flinn Scientific Labs into *Experience Chemistry* lessons. Experience *It!*

Hands-On Labs

Labs focus on real-world phenomena. Customize your lessons with four versions of every lab including **Open-Ended**, **Guided**, **Shortened**, and **Advanced**.

Lab Videos

Teachers and students experience everything in a clear and effortless way. Videos provide background, demos, and summaries of key concepts and practices.

Lab Kits

Simplify lab set-up and solution preparation with time-saving lab kits aligned to the Performance-Based Assessments.

Engineering Design Challenges

Students design, test, and evaluate solutions. Focusing on defining and solving problems strengthens science and engineering skills.

Performance Tasks

Students demonstrate mastery of performance expectations by applying their understanding to a new situation in a Performance-Based Assessment at the end of every Investigation.

Virtual Reality

Immerse your students in 360° simulations that bring chemistry to life.

Meet the Authors

Christopher Moore, PhD, is an associate professor of physics education at the University of Nebraska Omaha. Dr. Moore has worked as a physical science teacher, a professional materials scientist, and a scholar and consultant on science education. His educational research focuses on the development of scientific reasoning and expert-like science practice abilities, with an emphasis on practices that cross disciplines. He is the author of *Creating Scientists: Teaching and Assessing Practices for NGSS* as well as *Teaching Science Thinking*.

Michael E. Wysession, PhD, is professor of Earth and Planetary Sciences, Washington University, St. Louis, Missouri. An author of more than 100 science publications, Dr. Wysession was awarded the prestigious National Science Foundation Presidential Faculty Fellowship and Packard Foundation Fellowship for his research in geophysics. He is an expert in geoscience literacy and serves as Chair of the Earth Science Literacy Initiative. Dr. Wysession is part of The Great Courses® video series and was a NGSS writing team leader.

Consulting Author

Bryn Lutes, PhD, received her doctorate in Chemistry from Washington University in St. Louis where she currently teaches General Chemistry, Advanced Inorganic Chemistry Laboratory, and Descriptive Inorganic Chemistry. She continuously works to incorporate in-class group activities and flipped-classroom instruction to facilitate student learning. She also has developed problems for, and coordinates the implementation of, a peer-led team learning (PLTL) program.

Program Contents

VOLUME 1

STORYLINE 1:

Atoms, Elements, and Molecules

1. Atomic Structure
2. The Periodic Table
3. Chemical Bonding

STORYLINE 2:

Understanding Chemical Reactions

4. Physical Properties of Materials
5. Chemical Quantities
6. Chemical Reactions
7. Stoichiometry
8. Thermochemistry

VOLUME 2

STORYLINE 3:

The Chemistry of Climate Change

9. The Behavior of Gases
10. Weather and Climate
11. Global Climate Change

STORYLINE 4:

The Dynamics of Chemical Reactions and Ocean Acidification

12. Reaction Rates and Equilibrium
13. Acids-Base Equilibria
14. Ocean Acidification

STORYLINE 5:

Industrial Applications

15. Oxidation-Reduction Reactions
16. Organic Chemistry
17. Nuclear Processes
18. Green Chemistry

Student Experiences

VOLUME 1

STORYLINE 1:
Atoms, Elements, and Molecules

Investigation 1:
Atomic Structure

EXPERIENCE

- 1.1 The Particle Nature of Matter
- 1.2 Modeling Atoms
- 1.3 Atomic Emission Spectra and the Bohr Model
- 1.4 Modern Atomic Theory
- 1.5 Electrons in Atoms

Investigation 2:
The Periodic Table

EXPERIENCE

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Chemical Bonding

EXPERIENCE

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STORYLINE 2:
Understanding Chemical Reactions

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Physical Properties of Materials

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- 4.4 Comparing Metals and Nonmetals
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- 4.6 Properties of Solutions

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Investigation 7:
Stoichiometry

EXPERIENCE

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- 7.3 Limiting Reagent and Percent Yield

Investigation 8:
Thermochemistry

EXPERIENCE

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- 8.3 Heat in Changes of State

VOLUME 2

STORYLINE 3:
The Chemistry of Climate Change

Investigation 9:
The Behavior of Gases

EXPERIENCE

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- 9.3 Ideal Gases
- 9.4 Gases in Earth's Atmosphere

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Weather and Climate

EXPERIENCE

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- 10.2 Water and Energy in the Atmosphere
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- 10.5 Short-Term Climate Factors

Investigation 11:
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STORYLINE 4:
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Investigation 12:
Reaction Rates and Equilibrium

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- 12.1 Rates of Reaction
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Investigation 13:
Acids-Base Equilibria

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- 13.2 Strong and Weak Acids and Bases
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Investigation 14:
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- 14.2 Earth's Ocean as a Carbon Sink
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STORYLINE 5:
Industrial Applications

Investigation 15:
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- 15.2 Modeling and Predicting Outcomes of Redox Reactions
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- 18.2 Principles of Green Chemistry
- 18.3 Designing Sustainable Processes

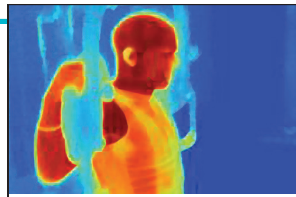
Understanding Chemical Reactions

Investigation 4
Physical Properties of Materials

Investigation 5
Chemical Quantities

Investigation 6
Chemical Reactions

Investigation 7
Stoichiometry



Investigation 8
Thermochemistry

ANCHORING PHENOMENON

Inquiry Launch Preparing and cooking foods involves a knowledge of food chemistry. Like chemists in a lab investigating a chemical reaction, chefs need to know lots of information before they begin their work. Look at the image of chefs preparing food in a restaurant kitchen. What types of information might they need in order to prepare a perfect meal?

Write a series of questions you think a chef would need and want answered to properly prepare a meal.

GO ONLINE to engage with real-world phenomena. Watch the anchoring phenomenon video and preview the optional **problem-based learning experience**.

INVESTIGATIVE PHENOMENON

GO ONLINE to Engage with real-world phenomena by watching a video and to complete a CER interactive worksheet.

What can make a recipe fail?

Stoichiometry

To avoid gluten, some amateur bakers often make the mistake of simply replacing the wheat flour with the same weight of a gluten-free flour, such as almond flour. The results can be disastrous. Once you have viewed the Investigative Phenomenon video and worked on a first draft of a Claim-Evidence-Reasoning exercise to explain "What can make a recipe fail?", answer these reflection questions.

1. **CCC Structure and Function** Yeast breads rise because yeast breaks down sucrose ($C_{12}H_{22}O_{11}$), or table sugar, during the process of cellular respiration and releases carbon dioxide. Steviol ($C_{20}H_{30}O_3$) is a zero-calorie sweetener. The chemical symbols are similar, with each being made up of carbon, hydrogen, and oxygen. Why can't you replace table sugar with an equal amount of steviol sweetener when baking bread?

2. **SEP Construct an Explanation** You baked whole wheat muffins using a recipe, but they were too sweet. For the second batch, you cut the amount of sugar in half. The second batch was dry, dense, and crumbly. Construct an explanation for why this happened.

Quantifying Reactants and Products

GO ONLINE to Explore and Explain how the amounts of reactants and products are related to each other.

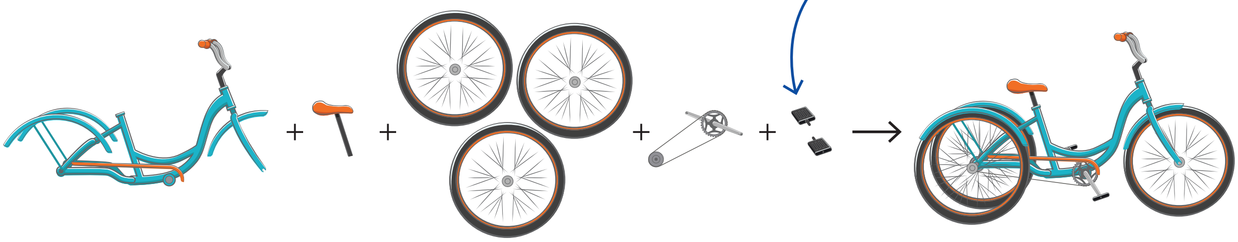
Equations as a Recipe

When making a product, how do you determine how much starting material you need? Whenever you make something, you need ingredients or parts, and you need them in the correct ratios to get the desired product.

Balanced equations are like recipes. They tell you the ingredients that you need and the proper ratios.

Equations Making tricycles is a job that requires quantitative information to create the final product.

To make 640 tricycles in a week, how many pedals need to be in the factory on Monday?



F	+	S	+	3W	+	G	+	2P	→	FSW_3GP_2
(frame)		(seat)		(wheels)		(gears)		(pedals)		

The ratio of reactant (P) to product (FSW_3GP_2) can be used as a conversion factor. → $\dfrac{2P}{FSW_3GP_2}$

Use the conversion factor to determine the number of pedals. → $640\ FSW_3GP_2 \times \dfrac{2P}{FSW_3GP_2} = 1280\ P$

3 **SEP Use Mathematics** If the supplier sends only 500 pedals one week, then how many tricycles would you be able to manufacture? Assume that none of the other parts will run out before using all the pedals.

SAMPLE PROBLEM

Using a Balanced Equation as a Recipe

In a five-day workweek, a tricycle manufacturing facility is scheduled to make 640 tricycles. How many wheels should be in the plant on Monday morning to make these tricycles?

ANALYZE List the knowns and unknown.

Knowns	Unknowns
number of tricycles = 640 FSW_3GP_2	Number of wheels = ? W
$F + S + 3W + G + 2P \rightarrow FSW_3GP_2$	

CALCULATE Solve for the unknown.

Write the two possible conversion factors relating wheels (W) to tricycles (FSW_3GP_2).

$$\frac{3\ W}{1\ FSW_3GP_2} \text{ and } \frac{1\ FSW_3GP_2}{3\ W}$$

Identify the conversion factor that gives the desired unit (W).

$$\frac{3\ W}{1\ FSW_3GP_2}$$

Multiply the number of tricycles by the conversion factor.

$$640\ \cancel{FSW_3GP_2} \times \frac{3\ W}{1\ \cancel{FSW_3GP_2}} = \boxed{1920\ W}$$

EVALUATE Does the result make sense?

If three wheels are required for each tricycle and more than 600 tricycles are being made, then a number of wheels in excess of 1,800 is a logical answer. The unit of the known (FSW_3GP_2) cancels, and the answer has the correct unit (W).

4 **SEP Apply Mathematical Concepts** **The tricycle manufacturing facility has decided to make 288 tricycles each day. How many tricycle seats, wheels, and pedals are needed for each day?**

GO ONLINE for more practice problems.

Interpreting Chemical Equations

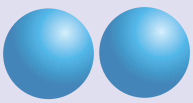
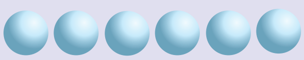
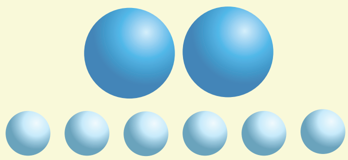
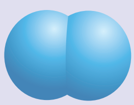
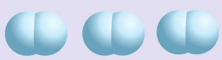
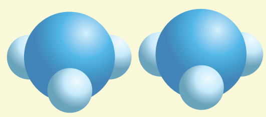
Ammonia is used to make many fertilizers. It is produced industrially by the reaction:

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

This balanced chemical equation gives the relative amounts of reactants and products in the reaction. You can quantify the reactants and products in terms of moles, mass, volume, and number of atoms or molecules. The calculation of quantities in chemical reactions is a subject called **stoichiometry.**

Quantifying Reactants and Products

In terms of what quantities can you interpret **balanced chemical equations?**

	Reactants				Products
Reaction	$N_2(g)$	+	$3H_2(g)$	→	$2NH_3(g)$
Atoms		+		→	
	2 atoms N	+	6 atoms H	→	2 atoms N and 6 atoms H
Molecules		+		→	
	1 molecule N_2	+	3 molecules H_2	→	2 molecules NH_3
Moles	1 mol N_2	+	3 mol H_2	→	2 mol NH_3
Mass	28.0 g N_2	+	3 × 2.0 g H_2	→	2 × 17.0 g NH_3
	34.0 g reactants			→	34.0 g product
Volume	Assume STP; 22.4 L	+	22.4 L; 22.4 L; 22.4 L	→	22.4 L; 22.4 L
	22.4 L N_2		67.2 L H_2	→	44.8 L NH_3

5 **CCC Patterns** Of the five ways to quantify reactants and products for ammonia, which have the same amount on the reactants side and the products side?

SAMPLE PROBLEM

Interpreting a Balanced Chemical Equation

Hydrogen sulfide, which smells like rotten eggs, is found in volcanic gases. The balanced equation for the burning of hydrogen sulfide is

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$

Interpret this equation in terms of

a. numbers of representative particles and moles.

b. masses of reactants and products.

ANALYZE **Identify the relevant concepts.**

The coefficients in the balanced equation give the relative number of representative particles and moles of reactants and products. A balanced chemical equation obeys the law of conservation of mass.

SOLVE **Apply the concepts to the situation.**

Use the coefficients in the balanced equation to identify the number of representative particles and moles.

a. 2 molecules H_2S + 3 molecules $O_2 \rightarrow$ 2 molecules SO_2 + 2 molecules H_2O, or
2 mol H_2S + 3 mol $O_2 \rightarrow$ 2 mol SO_2 + 2 mol H_2O

Use the periodic table to determine the molar mass of each substance.

b. 1 mol H_2S = 34.1 g H_2S, 1 mol O_2 = 32.0 g O_2,
1 mol SO_2 = 64.1 g SO_2, 1 mol H_2O = 18.0 g H_2O

Multiply the number of moles of each reactant and product by its molar mass.

2 mol H_2S + 3 mol $O_2 \rightarrow$ 2 mol SO_2 + 2 mol H_2O

$$\left(2\ \cancel{\text{mol}} \times 34.1\ \frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(3\ \cancel{\text{mol}} \times 32.0\ \frac{\text{g}}{\cancel{\text{mol}}}\right) \rightarrow \left(2\ \cancel{\text{mol}} \times 64.1\ \frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(2\ \cancel{\text{mol}} \times 18.0\ \frac{\text{g}}{\cancel{\text{mol}}}\right)$$

Add the masses on the reactants side and on the products side.

68.2 g H_2S + 96.0 g $O_2 \rightarrow$ 128.2 g SO_2 + 36.0 g H_2O

164.2 g = 164.2 g

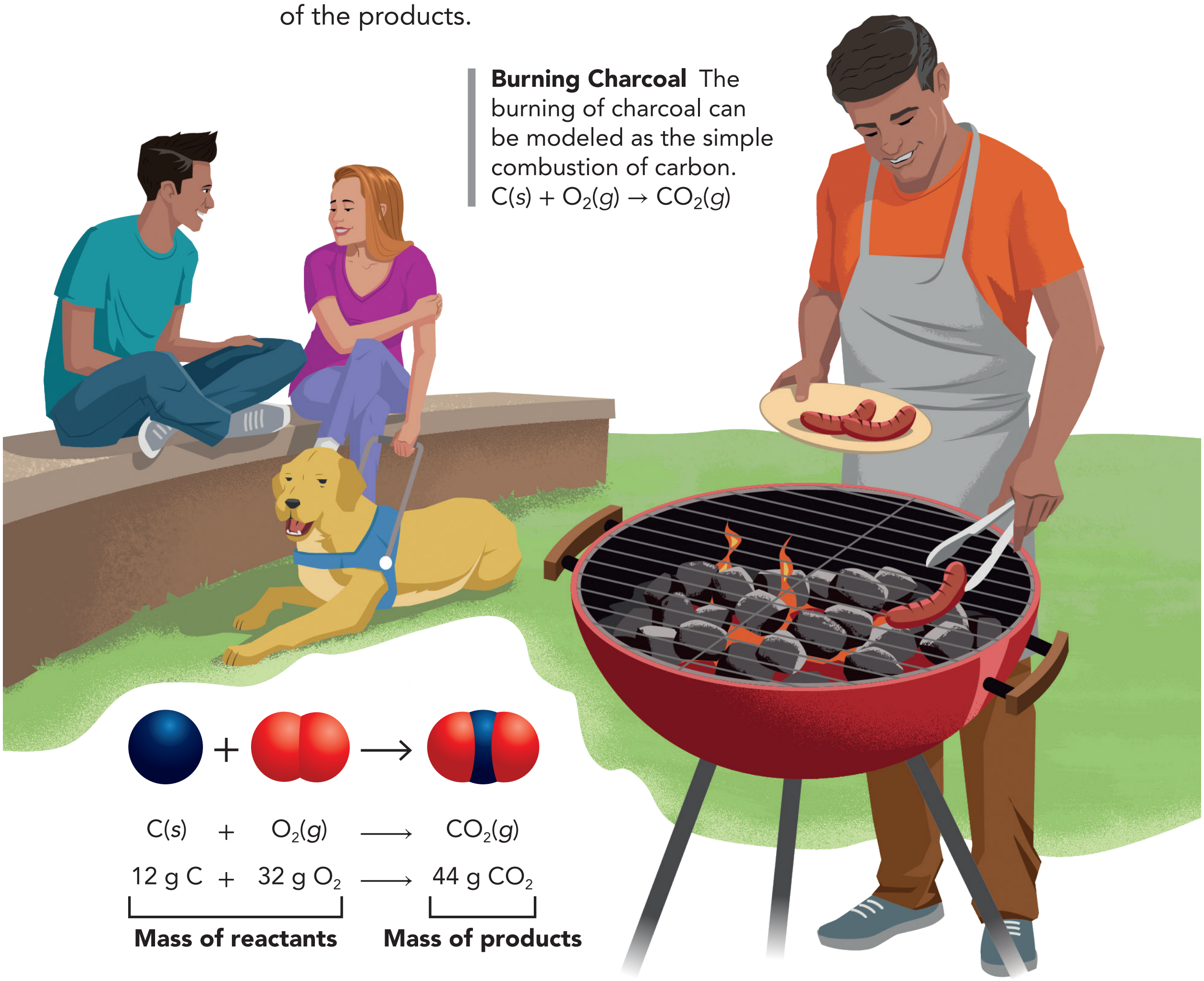
6 **CCC Energy and Matter** **Interpret the equation for the formation of water from its elements in terms of numbers of molecules, moles, and volumes of gases at STP.**

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

GO ONLINE for more practice problems.

What Is Conserved?

In 1789 Antoine Lavoisier discovered the **law of conservation of mass,** which states that atoms, and therefore mass, are neither created nor destroyed by chemical reactions. Atoms are rearranged to form new molecules, so the number of molecules and moles often change during a reaction. However, the number of atoms and the total mass of the reactants are always the same as the number of atoms and the total mass of the products.



Burning Charcoal The burning of charcoal can be modeled as the simple combustion of carbon. $C(s) + O_2(g) \rightarrow CO_2(g)$

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

$$\underbrace{12\text{ g C} + 32\text{ g } O_2}_{\textbf{Mass of reactants}} \longrightarrow \underbrace{44\text{ g } CO_2}_{\textbf{Mass of products}}$$

Conservation of Mass The molar masses of carbon and oxygen can be used to determine the total mass of the reactants. The molar mass of CO_2 can be used to determine the mass of the product. The mass of CO_2 equals the total mass of C and O_2.

7 **CCC Energy and Matter** The charcoal that was burned in a grill left only a fine, light ash. The ash weighs significantly less than the charcoal before being burned. What happened to the extra mass?

....

....

Proportionality of Reactants and Products

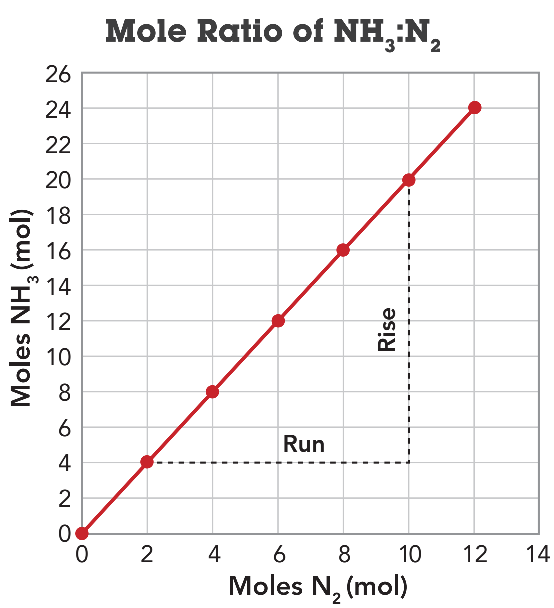
Balanced equations are like recipes. They tell you the ingredients that you need and their proper ratios. In a chemical equation, the chemical symbols provide the ingredients, and the coefficients provide the proper ratios. Stoichiometry tells you how to calculate the moles, mass, volume, or number of atoms or molecules of products or reactants using balanced chemical equations. This is possible because the reactants and products are proportional to each other.

For example, the number of moles of ammonia produced is proportional to the number of moles of nitrogen that reacted. The mass of ammonia produced in the reaction is also proportional to the mass of nitrogen. This information is provided by the chemical equation for the production of ammonia:

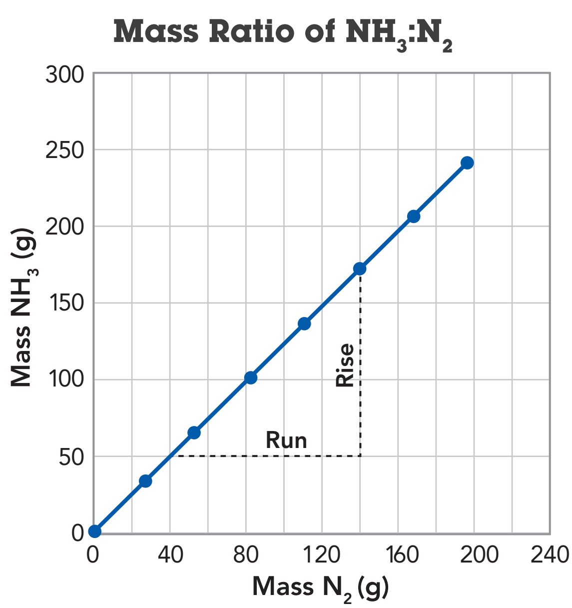
$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

The equation shows that two moles of ammonia are produced when one mole of nitrogen and three moles of hydrogen react.

Ammonia vs. Nitrogen (Moles) To make two moles of ammonia it takes one mole of nitrogen, a ratio of 2 NH_3:1 N_2. This mole ratio is given by the slope of this graph, which can be determined from the coefficients in the chemical equation.



Ammonia vs. Nitrogen (Mass) The slope of this graph gives the mass ratio. It is 1.21 NH_3:1 N_2, not 2 NH_3:1 N_2. Coefficients tell us the mole proportionality, not the mass proportionality.



8 **SEP Use Mathematics** Using the data from the graph, predict the mass of nitrogen needed to produce 300 g of ammonia.

Revisit

INVESTIGATIVE PHENOMENON

GO ONLINE to Elaborate on and Evaluate your knowledge of the proportionality of reactants and products by completing the peer review and writing activities.

In the CER worksheet you completed at the beginning of the investigation, you drafted an explanation for why a recipe can fail. With a partner, reevaluate your arguments.

9 **CCC Scale, Proportion, and Quantity** A simple bread recipe calls for 400 g of flour, 8 g of salt (NaCl), 1 g of yeast, and 0.3 L of water (H_2O). The recipe produces 1 loaf of bread. How much of each ingredient would you need to produce 3 loaves of bread?

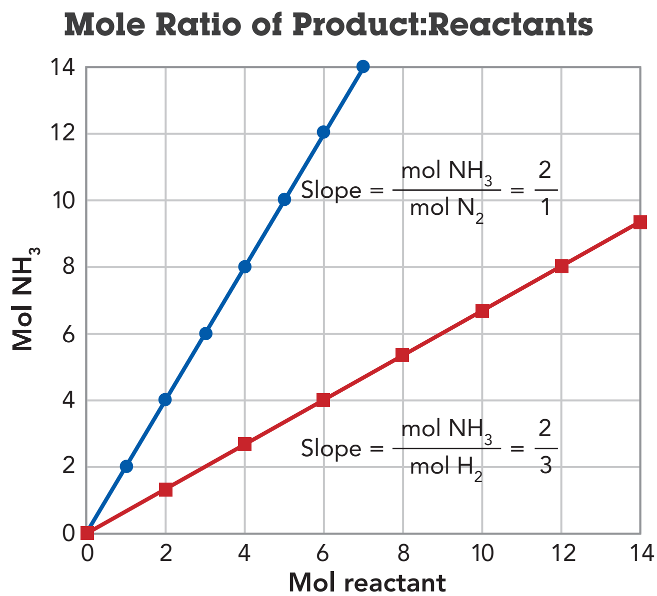
Chemical Calculations

GO ONLINE to Explore and Explain stoichiometric calculations.

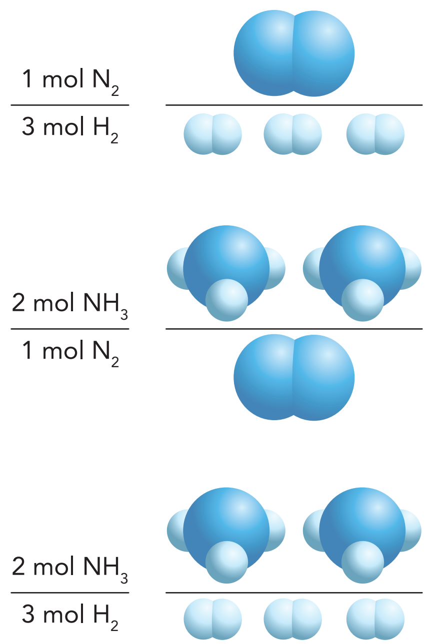
Mole Ratios

A **mole ratio** is a conversion factor derived from the coefficients of a balanced chemical equation interpreted in terms of moles. In chemical calculations, mole ratios are used to convert between a given number of moles of reactant or product to moles of a different reactant or product. For example, mole ratios can be determined from the balanced chemical equation for ammonia production: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$.

Mole-Mole Graph The number of moles of NH_3 is graphed as a function of the number of moles of N_2 (red line) and H_2 (blue line). The coefficients in the chemical equation provide the proportionality between individual reactants and/or products.



Mole Ratio The coefficients in the chemical equation can also be used to write the mole ratio between any of the reactants and/or products.



10 **SEP Develop a Model** What would the slopes of the lines be for a graph of the moles of product versus mole of each reactant for the reaction $2H_2 + O_2 \rightarrow 2H_2O$?

Mole-Mole Calculations

Mole ratios can be used in a mole-mole calculation, which is a conversion between a given number of moles of one reactant or product and moles of another reactant or product. If you're given the number of moles of one of the substances, *G*, then you can use the appropriate mole ratio to calculate the moles of the wanted substance, *W*. To choose the correct mole ratio, make sure the moles of the wanted substance are in the numerator.

Mole-Mole Flowchart Multiply the given number of moles by the appropriate mole ratio to calculate the moles of the wanted quantity.

$$aG \longrightarrow bW$$

Given quantity → Wanted quantity

$$G \times \boxed{\frac{b \text{ mol } W}{a \text{ mol } G}} \Rightarrow \text{mol } W$$

Given quantity | Mole ratio from balanced chemical equation | Wanted quantity

Applying the Mole-Mole Flowchart
How many moles of O_2 would you need to produce 25 mol H_2O from the reaction of H_2 and O_2?

Write the balanced equation. → $2H_2 + O_2 \rightarrow 2H_2O$

Develop a concept map for the calculation. → $a \text{ mol } H_2O \times \boxed{\text{Mole ratio}} \Rightarrow b \text{ mol } O_2$ (Given quantity; Wanted quantity)

Use the coefficients from the equation to write the mole ratios that include H_2O and O_2. → $\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}$ $\quad \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O}$

Choose the mole ratio that makes mol H_2O cancel out and calculate mol O_2. → $25 \cancel{\text{mol } H_2O} \times \frac{1 \text{ mol } O_2}{2 \cancel{\text{mol } H_2O}} = 12.5 \text{ mol } O_2$

11 **SEP Use Mathematics** How many moles of hydrogen gas would be required to produce 25 moles of H_2O?

SAMPLE PROBLEM

Calculating Moles of a Product

How many moles of NH_3 are produced when 0.60 mol of nitrogen react with hydrogen?

ANALYZE List the knowns and unknown.

Knowns	Unknown
moles of nitrogen = 0.60 mol N_2	moles of ammonia = ? mol NH_3

CALCULATE Solve for the unknown.

Write the balanced chemical equation for the formation of ammonia.

$N_2 + H_2 \rightarrow NH_3$ (unbalanced)

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

Write the mole ratio that will allow you to convert from moles N_2 to moles NH_3.

$$\frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2}$$

Remember that the mole ratio must have N_2 on the bottom so that the mol N_2 in the mole ratio will cancel with mol N_2 in the known.

Multiply the given quantity of N_2 by the mole ratio in order to find the moles of NH_3.

$$0.60 \cancel{\text{mol } N_2} \times \frac{2 \text{ mol } NH_3}{1 \cancel{\text{mol } N_2}} = \boxed{1.2 \text{ mol } NH_3}$$

EVALUATE Does the result make sense?

The ratio of 1.2 mol NH_3 to 0.60 mol N_2 is 2:1, as predicted by the balanced equation.

12 **SEP Apply Mathematical Concepts** **This equation shows the formation of aluminum oxide, which is found on the surface of aluminum objects exposed to the air.**

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

a. Write the six mole ratios that can be derived from this equation.

b. How many moles of aluminum are needed to form 3.7 mol Al_2O_3?

GO ONLINE for more practice problems.

Mass-Mass Calculations

Laboratory balances measure mass and cannot measure substances directly in moles. A mass-mass calculation is a conversion between a given mass of one reactant or product to the mass of another reactant or product.

$$\text{mass of } G \times \boxed{\frac{1 \text{ mol } G}{\text{mass } G}} \rightarrow \text{mol } G \times \boxed{\frac{b \text{ mol } W}{a \text{ mol } G}} \rightarrow \text{mol } W \times \boxed{\frac{\text{mass } W}{1 \text{ mol } W}} \rightarrow \text{mass of } W$$

Given quantity

Mole-mass relationship

Mole ratio from $aG \rightarrow bW$

Mole-mass relationship

Wanted quantity

Mass-to-Moles First, the mass of the given component *G* is converted to moles using the molar mass.

Mole Ratio Then, the mole ratio is used to determine the number of moles of the wanted component *W*.

Moles-to-Mass Finally, the moles of *W* are converted to mass using the molar mass of *W*.

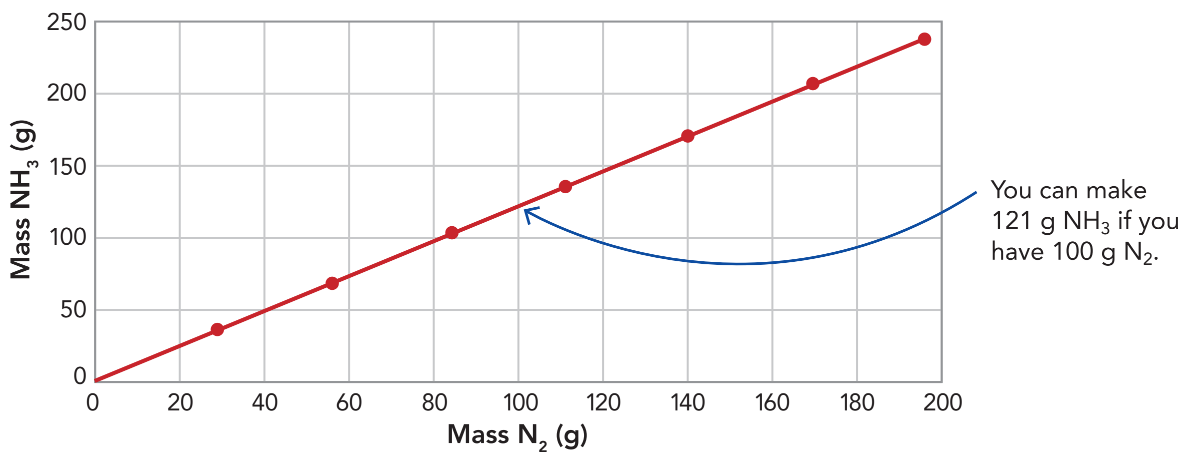
This method can be used to determine the mass of ammonia produced in the following reaction, if we start with 100 g of nitrogen.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

$$100 \text{ g } N_2 \times \boxed{\frac{1 \text{ mol } N_2}{28.0 \text{ } N_2}} \rightarrow 3.57 \text{ mol } N_2 \times \boxed{\frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2}} \rightarrow 7.14 \text{ mol } NH_3 \times \boxed{\frac{17.0 \text{ g } NH_3}{1 \text{ mol } NH_3}} \rightarrow = 121 \text{ g } NH_3$$

Mass Ratio of Ammonia Reaction Two moles of ammonia are made when one mole of nitrogen reacts. However, the mass ratio is about 1.21 NH_3:1 N_2 because the molar masses are 17 g/mol and 28 g/mol, respectively.

Mass Ratio of NH_3:N_2



13 **SEP Develop a Model** What are the mole ratio and the mass ratio for H_2O to O_2 in the reaction $2H_2 + O_2 \rightarrow 2H_2O$?

SAMPLE PROBLEM

Calculating the Mass of a Product

Calculate the number of grams of NH_3 produced when 5.40 g H_2 react with an excess of N_2. The balanced equation is $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$.

ANALYZE List the knowns and unknown.

Knowns	Unknown
mass of hydrogen = 5.40 g H_2	mass of ammonia = ? g NH_3
1 mol H_2 = 2.0 g H_2	
1 mol NH_3 = 17.0 g NH_3	

CALCULATE Solve for the unknown.

Identify the steps needed to determine the mass of ammonia.

$$\text{g } H_2 \rightarrow \text{mol } H_2 \rightarrow \text{mol } NH_3 \rightarrow \text{g } NH_3$$

Convert the given mass to moles.

$$5.40\ \cancel{\text{g } H_2} \times \frac{1\text{ mol } H_2}{2.0\ \cancel{\text{g } H_2}}$$

Convert from moles of the given reactant to moles of wanted product by using the correct mole ratio.

$$5.40\ \cancel{\text{g } H_2} \times \frac{1\ \cancel{\text{mol } H_2}}{2.0\ \cancel{\text{g } H_2}} \times \frac{2\text{ mol } NH_3}{3\ \cancel{\text{mol } H_2}}$$

Don't forget to cancel the units at each step.

Finish by converting moles to grams. Use the molar mass of NH_3.

$$\underbrace{5.40\ \cancel{\text{g } H_2}}_{\text{Given quantity}} \times \underbrace{\frac{1\ \cancel{\text{mol } H_2}}{2.0\ \cancel{\text{g } H_2}}}_{\text{Change given unit to moles}} \times \underbrace{\frac{2\ \cancel{\text{mol } NH_3}}{3\ \cancel{\text{mol } H_2}}}_{\text{Mole ratio}} \times \underbrace{\frac{17.0\text{ g } NH_3}{1\ \cancel{\text{mol } NH_3}}}_{\text{Change moles to grams}} = \boxed{31\text{ g } NH_3}$$

EVALUATE Does the result make sense?

Multiple conversion factors make it difficult to evaluate the result, but the molar mass of NH_3 is much greater than that of H_2, which means the answer was likely to have a larger value than the given mass.

14 **SEP Apply Mathematical Concepts** Acetylene gas (C_2H_2) is produced by adding water to calcium carbide (CaC_2).

$$CaC_2(s) + 2H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

How many grams of C_2H_2 are produced when water is added (in excess) to 5.00 g CaC_2?

GO ONLINE for more practice problems.

Volume-Volume Calculations

So far, you've learned how to use the molar mass to convert between moles and mass, and how to use the mole ratio to complete the stoichiometric calculation. The mole can also be related to other quantities, such as volume. A volume-volume calculation is a conversion between a given volume of one reactant or product and the volume of another reactant or product. Volume-volume calculations only apply to gases at STP because the molar volume is used as a conversion factor.

$$\text{Volume of } G \text{ (liters) at STP} \times \frac{1 \text{ mol } G}{22.4 \text{ L } G} \rightarrow \text{mol } G \times \frac{b \text{ mol } W}{a \text{ mol } G} \rightarrow \text{mol } W \times \frac{22.4 \text{ L } W}{1 \text{ mol } W} \rightarrow \text{Volume of } W \text{ (liters) at STP}$$

Given quantity

Mole-volume relationship

Mole ratio from $aG \rightarrow bW$

Mole-volume relationship

Wanted quantity

Volume-to-Moles First, the volume of the given component *G* is converted to moles using the molar volume.

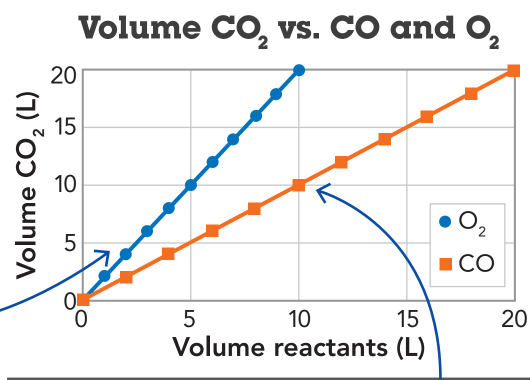
Mole Ratio Then, the mole ratio is used to determine the number of moles of the wanted component *W*.

Moles-to-Volume Finally, the moles of *W* are converted to volume using the molar volume of *W*.

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

$$1 \text{ L } O_2 \times \frac{1 \text{ mol } O_2}{22.4 \text{ L } O_2} \rightarrow \text{mol } O_2 \times \frac{2 \text{ mol } CO_2}{1 \text{ mol } O_2} \rightarrow \text{mol } CO_2 \times \frac{22.4 \text{ L } CO_2}{1 \text{ mol } CO_2} = 2 \text{ L } CO_2$$

Combustion of Carbon Monoxide To make 2 L of carbon dioxide, you need 1 L of oxygen. The volume ratio is 2 L CO_2:1 L O_2. Because of Avogadro's law, the mole ratio is also 2 mol CO_2:1 mol O_2.



The slope of the line for O_2 is 2 because the volume ratio is 2 L CO_2: 1 L O_2.

The slope of the line for CO is 1 because the volume ratio is 1 L CO_2: 1 L CO.

15 **SEP Develop a Model** What are the slopes of the lines on a graph of the volume of the product versus volume of the reactants for the reaction represented by $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$?

SAMPLE PROBLEM

Calculating the Volume of a Product

Nitrogen monoxide (NO) and oxygen gas combine to form the brown gas nitrogen dioxide (NO_2), which contributes to photochemical smog. How many liters of NO_2 are produced when 34 L O_2 react with an excess of NO at STP? The balanced equation is $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$.

ANALYZE List the knowns and unknown.

Knowns	Unknown
volume of oxygen = 34 L O_2	volume of nitrogen dioxide = ? L NO_2
1 mol O_2 = 22.4 L O_2 (at STP)	
1 mol NO_2 = 22.4 L NO_2 (at STP)	

CALCULATE Solve for the unknown.

Identify the steps needed to determine the unknown.

$$L\ O_2 \rightarrow mol\ O_2 \rightarrow mol\ NO_2 \rightarrow L\ NO_2$$

Convert the given volume to moles using the mole-volume ratio.

$$34\ \cancel{L\ O_2} \times \frac{1\ mol\ O_2}{22.4\ \cancel{L\ O_2}}$$

Then, convert from moles of given reactant to moles of wanted product by using the correct mole ratio.

$$34\ \cancel{L\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{22.4\ \cancel{L\ O_2}} \times \frac{2\ mol\ NO_2}{1\ \cancel{mol\ O_2}}$$

Finish by using the molar volume of NO_2 to convert from moles to liters.

$$\underbrace{34\ \cancel{L\ O_2}}_{\text{Given quantity}} \times \underbrace{\frac{1\ \cancel{mol\ O_2}}{22.4\ \cancel{L\ O_2}}}_{\text{Change to moles}} \times \underbrace{\frac{2\ \cancel{mol\ NO_2}}{1\ \cancel{mol\ O_2}}}_{\text{Mole ratio}} \times \underbrace{\frac{22.4\ L\ NO_2}{1\ \cancel{mol\ NO_2}}}_{\text{Change to liters}} = 68\ L\ NO_2$$

EVALUATE Does the result make sense?

Because 2 mol NO_2 are produced for each 1 mol O_2 that reacts, the volume of NO_2 should be twice the given volume of O_2. The answer should have two significant figures.

16 **SEP Apply Mathematical Concepts** How many liters of oxygen are required to burn 3.86 L of carbon monoxide?

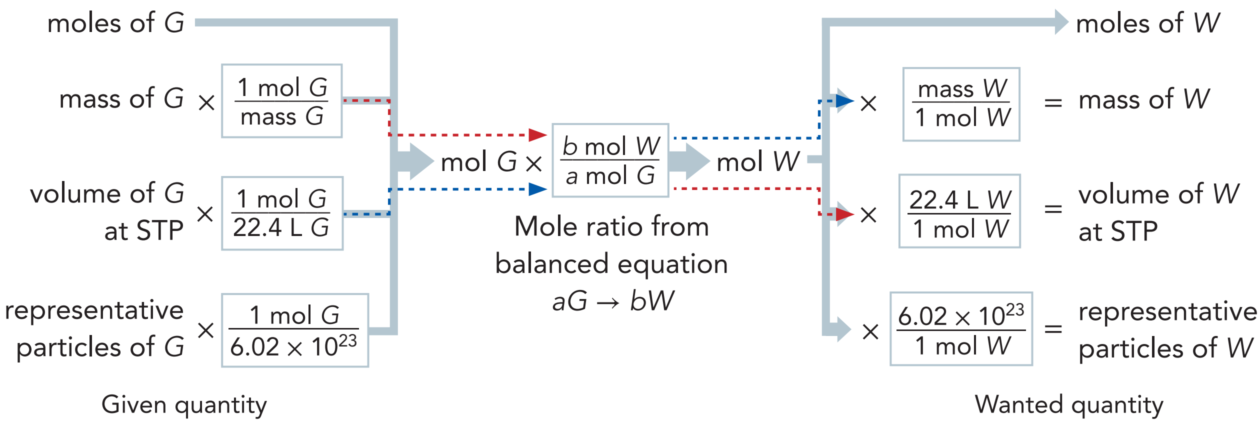
$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

GO ONLINE for more practice problems.

A Roadmap for Solving Stoichiometric Problems

Mass can be measured easily for solids and liquids, and volume can be measured easily for gases. What happens when a chemical reaction involves a combination of solids and gases? Combining the processes discussed so far provides a general framework that you can use to complete mass-volume, particle-mass, and volume-particle calculations.

Mass-Volume The red arrows show the process for calculating the volume of a gas needed in a reaction when given the mass of another substance.



Volume-Mass The blue arrows show the process for calculating the mass of a substance needed in a reaction when given the volume of a gas.

17 **SEP Computational Thinking** Sketch a flowchart for determining the number of representative particles of *W* needed if given the mass of *G*.

SAMPLE PROBLEM

Calculating Molecules of a Product

How many molecules of oxygen are produced when 29.2 g of water are decomposed by electrolysis according to this balanced equation?

$$2H_2O(l) \xrightarrow{\text{electricity}} 2H_2(g) + O_2(g)$$

ANALYZE List the knowns and unknown.

Knowns	Unknown
mass of water = 29.2 g H_2O	molecules of oxygen = ? molecules of O_2
1 mol H_2O = 18.0 g H_2O	
1 mol O_2 = 6.02×10^{23} molecules O_2	

CALCULATE Solve for the unknown.

Identify the steps needed to determine the unknown.

$$\text{g } H_2O \rightarrow \text{mol } H_2O \rightarrow \text{mol } O_2 \rightarrow \text{molecules } O_2$$

Convert the given mass to moles.

$$29.2\ \cancel{\text{g } H_2O} \times \frac{1 \text{ mol } H_2O}{18.0\ \cancel{\text{g } H_2O}}$$

Convert from moles of reactant to moles of wanted product.

$$29.2\ \cancel{\text{g } H_2O} \times \frac{1\ \cancel{\text{mol } H_2O}}{18.0\ \cancel{\text{g } H_2O}} \times \frac{1 \text{ mol } O_2}{2\ \cancel{\text{mol } H_2O}}$$

Finally, convert the wanted product from moles to molecules using Avogadro's number.

$$\underbrace{29.2\ \cancel{\text{g } H_2O}}_{\text{Given quantity}} \times \underbrace{\frac{1\ \cancel{\text{mol } H_2O}}{18.0\ \cancel{\text{g } H_2O}}}_{\text{Change to moles}} \times \underbrace{\frac{1\ \cancel{\text{mol } O_2}}{2\ \cancel{\text{mol } H_2O}}}_{\text{Mole ratio}} \times \underbrace{\frac{6.02 \times 10^{23} \text{ molecules } O_2}{1\ \cancel{\text{mol } O_2}}}_{\text{Change to molecules}}$$

$$= 4.88 \times 10^{23} \text{ molecules } O_2$$

EVALUATE Does the result make sense?

The given mass of water should produce a little less than 1 mole of oxygen, which is a little less than Avogadro's number of molecules. The answer has the right number of significant figures.

18 **SEP Apply Mathematical Concepts** How many molecules of oxygen are produced when 6.54 g of potassium chlorate ($KClO_3$) decompose?

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

GO ONLINE for more practice problems.

Revisit

INVESTIGATIVE PHENOMENON

GO ONLINE to Elaborate on and Evaluate your knowledge of stoichiometric calculations by completing the peer review and writing activities.

In the CER worksheet you completed at the beginning of the investigation, you drafted an explanation for why a recipe can fail. With a partner, reevaluate your arguments.

19 **SEP Use Mathematics** When dough bakes in the oven, baking soda, also known as sodium bicarbonate ($NaHCO_3$), decomposes into sodium carbonate (Na_2CO_3), water, and carbon dioxide. If your recipe calls for 2.0 grams of baking soda, what mass of carbon dioxide will be released during the reaction? Write a balanced chemical equation and use the molar masses in the table.

Molar Masses of Reactants and Products

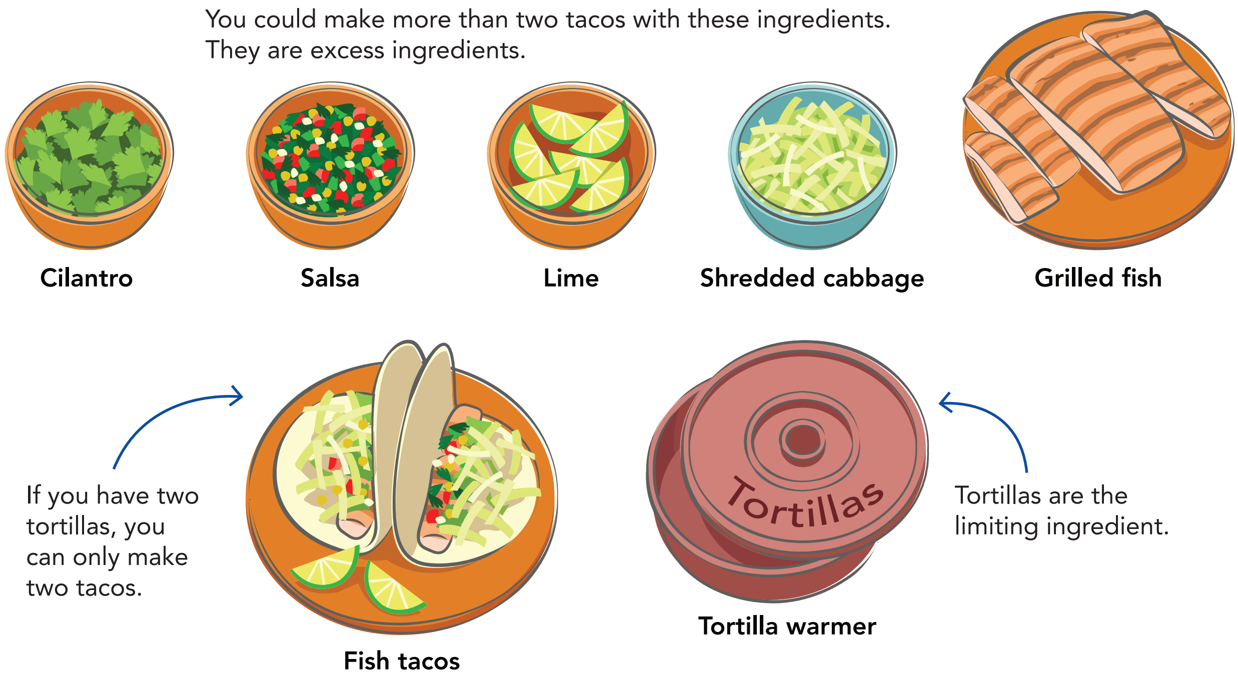
Substance	Molar mass (g/mol)
$NaHCO_3$	84
Na_2CO_3	106
H_2O	18
CO_2	44

Limiting Reagent and Percent Yield

GO ONLINE to Explore and Explain limiting reagents and reaction yields.

Limiting Ingredients

In any recipe, an insufficient amount of any of the ingredients will limit the amount of product you can make. The amount of product is determined by the amount of the limiting ingredient. No matter how much of the other ingredients you have, you can only make as much product as allowed by the limiting ingredient. For example, the limiting ingredient determines how many tacos you can make, even if you have more of every other ingredient.



Limiting and Excess Ingredients Combining a tortilla, fish, cabbage, cilantro, salsa, and a splash of lime produces a delicious taco. If you use up the tortillas before the other ingredients, they are the limiting ingredient.

20 **SEP Use a Model** Write a balanced equation for the production of sausage sandwiches. Assume that sausages only come in packs of five and buns in packs of eight. How many sandwiches can you make if you have one pack of each ingredient?

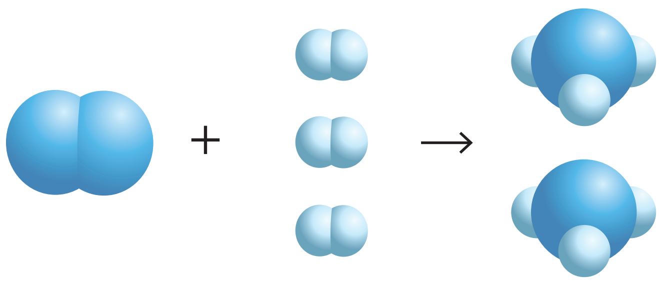
Limiting and Excess Reagents

In a chemical reaction, an insufficient amount of any of the reactants will limit the amount of product that forms. The reactant that determines the amount of product that can be formed is called the **limiting reagent.** The reaction stops after the limiting reagent is used up, even though some amount of the other reactant(s) remains. Any reactant that is not used up in a reaction is called the **excess reagent.**

Balanced Reactants The chemical equation for the production of ammonia is a precise "recipe" that calls for three molecules of hydrogen (H_2) for every one molecule of nitrogen (N_2). The product is two molecules of ammonia (NH_3), with no leftover reagents.

Reactants | **Products**

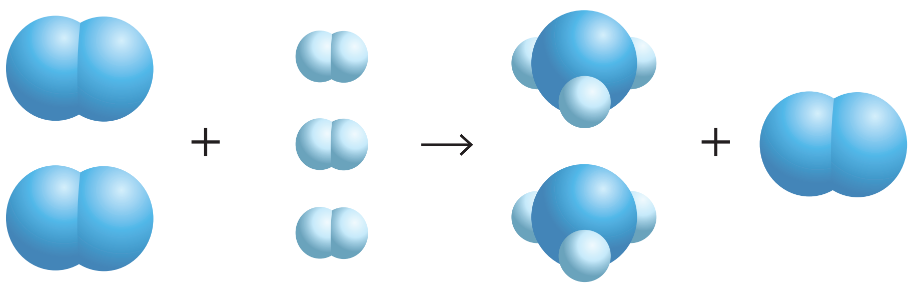
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$



1 molecule N_2 + 3 molecules $H_2 \longrightarrow$ 2 molecules NH_3

Unbalanced Reactants In this particular experiment, H_2 is the limiting reagent and N_2 is the excess reagent. After all of the H_2 is used up to make NH_3, there is still some N_2 left over.

Before Reaction | **After Reaction**



2 molecules N_2 + 3 molecules $H_2 \longrightarrow$ 2 molecules NH_3 + 1 molecule N_2

21 **SEP Interpret Data** **Varying masses of sodium metal react with a fixed mass of chlorine. The graph shows the masses of sodium used and sodium chloride produced. Explain the general shape of the graph and identify the limiting and excess reagents.**

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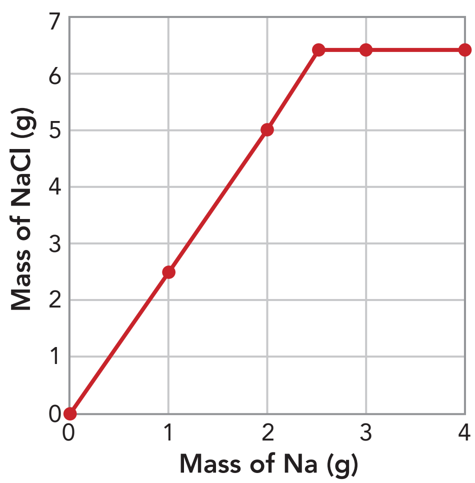
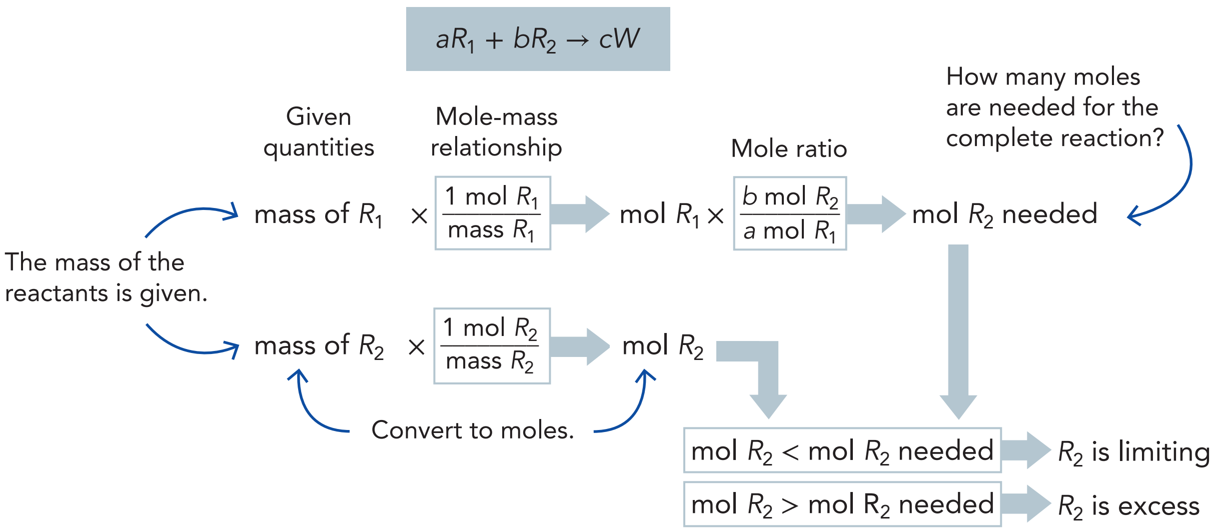


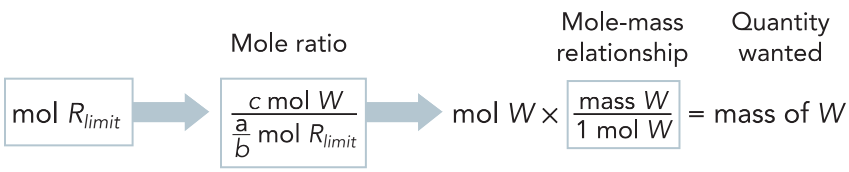
Mass of Products and Reactants

Often in stoichiometric problems, the given quantities of reactants are expressed in units other than moles, such as mass. The amount of each reactant first has to be converted from mass to moles before the mole ratio is applied to determine the limiting reagent. Then, the limiting reagent can be used to determine the mass of the products.

Determining the Limiting Reagent The mole ratio is used to determine the number of moles of one of the reactants needed to complete the reaction. If you do not have enough, then this is the limiting reagent.



Determining Mass from the Limiting Reagent The limiting reagent limits the reaction. It is used in a mole-mass calculation with the mole ratio to determine the mass of the product.



22 **SEP Analyze Data** **The table shows the masses of sodium used and sodium chloride produced when varying masses of sodium react with a fixed mass of chlorine. From the data, estimate the total mass of chlorine that was available for each trial.**

$Na(g) + Cl_2(g)$ Reaction Data

Mass Na (g)	Mass NaCl (g)
1	2.5
2	5
2.5	6.5
4	6.5

SAMPLE PROBLEM

Determining the Limiting Reagent

Copper reacts with sulfur to form copper(I) sulfide according to the following balanced equation: $2Cu(s) + S(s) \rightarrow Cu_2S(s)$. What is the limiting reagent when 80.0 g Cu reacts with 25.0 g S?

ANALYZE **List the knowns and unknown.**

Knowns	Unknown
mass of copper = 80.0 g Cu	limiting reagent = ?
mass of sulfur = 25.0 g S	

CALCULATE **Solve for the unknown.**

Choose one of the reactants and convert from mass to moles.

$$80.0\ \cancel{\text{g Cu}} \times \frac{1\ \text{mol Cu}}{63.5\ \cancel{\text{g Cu}}} = 1.26\ \text{mol Cu}$$

Convert the other reactant from mass to moles.

$$25.0\ \cancel{\text{g S}} \times \frac{1\ \text{mol S}}{32.1\ \cancel{\text{g S}}} = 0.779\ \text{mol S}$$

Convert moles of Cu to moles of S needed to react with 1.26 moles of Cu. Use the mole ratio from the balanced equation.

$$\underbrace{1.26\ \cancel{\text{mol Cu}}}_{\text{Given quantity}} \times \underbrace{\frac{1\ \text{mol S}}{2\ \cancel{\text{mol Cu}}}}_{\text{Mole ratio}} = \underbrace{0.630\ \text{mol S}}_{\text{Needed amount}}$$

Compare the amount of sulfur needed with the given amount of sulfur.

0.630 mol S (amount needed) $<$ 0.779 mol S (given amount). Sulfur is in excess. Therefore, copper is the limiting reagent.

If you used the actual number of moles of S to find the amount of copper needed, then you would still identify copper as the limiting reagent.

EVALUATE **Does the result make sense?**

Since the ratio of the given moles of Cu to moles of S was less than the ratio (2:1) from the balanced equation, copper should be the limiting reagent.

23 **SEP Apply Mathematical Concepts** **The equation for the combustion of ethene (C_2H_4) is $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$. If 2.70 mol C_2H_4 reacts with 6.30 mol O_2, identify the limiting reagent.**

GO ONLINE for more practice problems.

SAMPLE PROBLEM

Using the Limiting Reagent to Find the Quantity of a Product

What is the maximum number of grams of Cu_2S that can be formed when 80.0 g Cu react with 25.0 g S?

$$2Cu(s) + S(s) \rightarrow Cu_2S(s)$$

ANALYZE List the knowns and unknown.

Knowns	Unknown
limiting reagent = 1.26 mol Cu	yield = ? g Cu_2S
1 mol Cu_2S = 159.1 g Cu_2S	

CALCULATE Solve for the unknown.

Identify the steps needed to determine the mass of product.

mol Cu → mol Cu_2S → g Cu_2S

Convert moles of limiting reagent to moles of product.

$$1.26\ \cancel{\text{mol Cu}} \times \frac{1\ \text{mol Cu}_2\text{S}}{2\ \cancel{\text{mol Cu}}}$$

Use the mole ratio from the balanced equation.

Finish by converting from moles to mass of product.

$$1.26\ \cancel{\text{mol Cu}} \times \frac{1\ \cancel{\text{mol Cu}_2\text{S}}}{2\ \cancel{\text{mol Cu}}} \times \frac{159.1\ \text{g Cu}_2\text{S}}{1\ \cancel{\text{mol Cu}_2\text{S}}} = 1.00 \times 10^2\ \text{g Cu}_2\text{S}$$

EVALUATE Does the result make sense?

Copper is the limiting reagent. The maximum number of grams of Cu_2S produced should be more than the amount of Cu that reacted because Cu and S combine. However, the mass of Cu_2S produced should be less than the total mass of the reactants (105.0 g) because S was in excess.

24 **SEP Apply Mathematical Concepts** **The incomplete combustion of ethene is given by the equation $C_2H_4(g) + 2O_2(g) \rightarrow 2CO(g) + 2H_2O(g)$.**

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2,

a. identify the limiting reagent.

b. calculate the moles of water produced.

c.

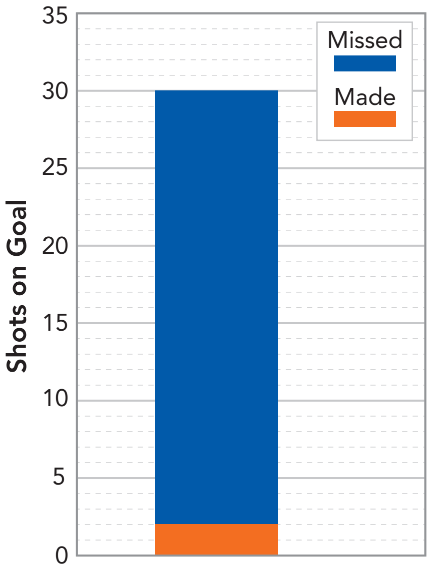
GO ONLINE for more practice problems.

Percent Yield

Success Stats In the average professional hockey game, a team will make thirty shots at the goal. Theoretically, every shot could result in a score. However, this outcome does not occur. The average professional team scores fewer than two goals per game. The success percentage is the ratio of the actual score to the theoretical score expressed as a percent:

$$\text{Percent Success} = \frac{\text{actual score}}{\text{theoretical score}} \times 100\%$$

Percent Success A hockey team may score on less than 7% of the shots that they make on the goal.



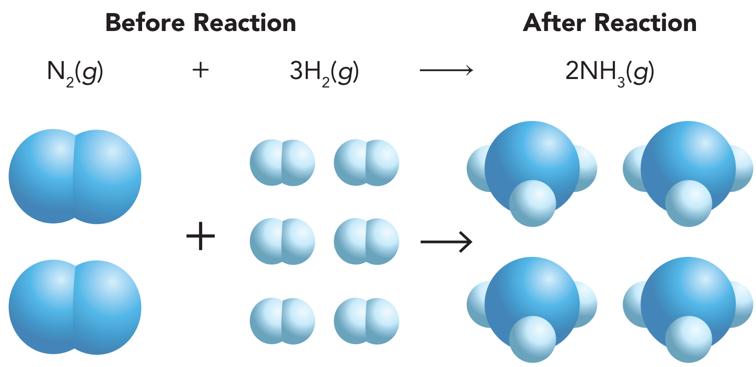
Improving the Score To improve, the team could either try to make more shots on the goal during a game or increase their percent success by making more of the shots they attempt.

25 **SEP Define a Problem** Grades on tests can also be thought of as a success statistic. How would you define the actual score and theoretical score on an exam, and how would you calculate the percent success?

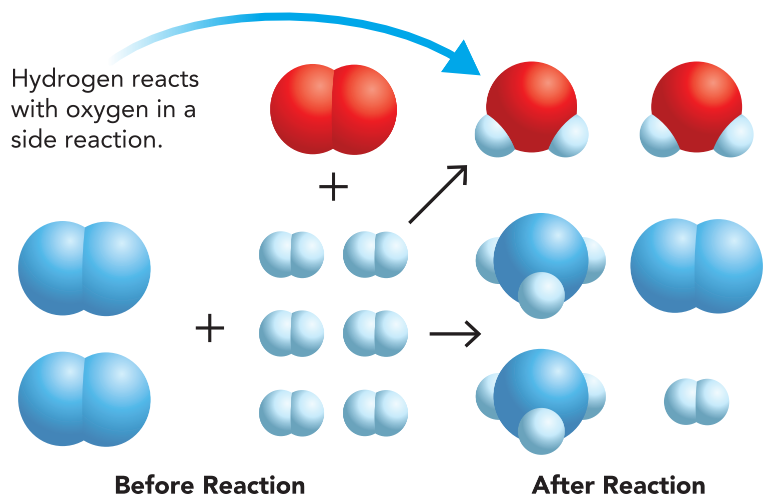
Percent Yield in Reactions When a balanced chemical equation is used to calculate the amount of product of a reaction, the calculated value represents the **theoretical yield**. It is the maximum amount of product that can be formed. The actual amount of product made during a real reaction is called the **actual yield**. You can measure the mass of the product of a laboratory experiment to find the actual yield. The **percent yield** is the ratio of the actual to the theoretical yield expressed as a percent, and represents the efficiency of a reaction:

$$\text{Percent Yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

Theoretical Yield The balanced chemical equation for the formation of ammonia can be used to determine the theoretical yield. Theoretical yield assumes that all of the reactants are used to make the product.



Side Reactions and Actual Yield Often, side reactions reduce the yield of a reaction. In this case, only 50% of the possible ammonia was produced because oxygen caused a side reaction. The oxygen may have been introduced from an impure gas source.



26 **SEP Construct an Explanation** Imagine you are a chemical engineer at a chemical plant. One day the air conditioning in the plant stops working, resulting in high humidity. The percent yield for a chemical you produce drops significantly. Construct an explanation for the decrease in yield.

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SAMPLE PROBLEM

Calculating the Theoretical Yield

Calcium carbonate, which is found in seashells, is decomposed by heating. The balanced equation for this reaction is

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

What is the theoretical yield of CaO if 24.8 g $CaCO_3$ is heated?

ANALYZE **List the knowns and unknown.**

Knowns	Unknown
mass of calcium carbonate = 24.8 g $CaCO_3$	theoretical yield = ? g CaO
1 mol CaO = 56.1 g CaO	

CALCULATE **Solve for the unknown.**

Identify the steps to determine the theoretical yield.

Theoretical yield is a mass-mass calculation.

$$\text{g } CaCO_3 \rightarrow \text{mol } CaCO_3 \rightarrow \text{mol } CaO \rightarrow \text{g } CaO$$

Convert the given mass of the reactant to moles of the reactant.

$$24.8\ \cancel{\text{g } CaCO_3} \times \frac{1\ \text{mol } CaCO_3}{100.1\ \cancel{\text{g } CaCO_3}}$$

Then, convert the moles of the reactant to moles of the wanted product using the mole ratio.

$$24.8\ \cancel{\text{g } CaCO_3} \times \frac{1\ \cancel{\text{mol } CaCO_3}}{100.1\ \cancel{\text{g } CaCO_3}} \times \frac{1\ \text{mol } CaO}{1\ \cancel{\text{mol } CaCO_3}}$$

Finish by converting from moles to mass of the wanted product. Use the molar mass of CaO.

$$24.8\ \cancel{\text{g } CaCO_3} \times \frac{1\ \cancel{\text{mol } CaCO_3}}{100.1\ \cancel{\text{g } CaCO_3}} \times \frac{1\ \cancel{\text{mol } CaO}}{1\ \cancel{\text{mol } CaCO_3}} \times \frac{56.1\ \text{g } CaO}{1\ \cancel{\text{mol } CaO}}$$

$$= 13.9\ \text{g } CaO$$

EVALUATE **Does the result make sense?**

The mole ratio of CaO to $CaCO_3$ is 1:1. The ratio of their masses in the reaction should be the same as the ratio of their molar masses, which is slightly greater than 1:2. The result of the calculations shows that the mass of CaO is slightly greater than half the mass of $CaCO_3$.

27 **SEP Apply Mathematical Concepts** **When 84.8 g of iron(III) oxide react with an excess of carbon monoxide, iron is produced. What is the theoretical yield of iron?**

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$$

GO ONLINE for more practice problems.

SAMPLE PROBLEM

Calculating the Percent Yield

What is the percent yield if 13.1 g CaO are actually produced when 24.8 g $CaCO_3$ are heated?

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

ANALYZE **List the knowns and unknown.**

Knowns	Unknown
actual yield = 13.1 g CaO	percent yield = ? %
theoretical yield = 13.9 g CaO	

CALCULATE **Solve for the unknown.**

Substitute the values for actual yield and theoretical yield into the equation for percent yield.

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

$$\text{percent yield} = \frac{13.1\ \cancel{\text{g CaO}}}{13.9\ \cancel{\text{g CaO}}} \times 100\% = 94.2\%$$

EVALUATE **Does the result make sense?**

In this example, the actual yield is slightly less than the theoretical yield. Therefore, the percent yield should be slightly less than 100 percent.

28 **SEP Apply Mathematical Concepts** **If 50.0 g of silicon dioxide are heated with an excess of carbon, 27.9 g of silicon carbide are produced.**

$$SiO_2(s) + 3C(s) \xrightarrow{\Delta} SiC(s) + 2CO(g)$$

What is the percent yield of this reaction?

29 **SEP Apply Mathematical Concepts** **If 15.0 g of nitrogen react with 15.0 g of hydrogen, 10.5 g of ammonia are produced. What is the theoretical yield and percent yield of this reaction?**

GO ONLINE for more practice problems.

Revisit

INVESTIGATIVE PHENOMENON

GO ONLINE to Elaborate on and Evaluate your knowledge of percent yield, actual yield, and theoretical yield by completing the discussion and engineering design activities.

In the CER worksheet you completed at the beginning of the investigation, you drafted an explanation for why a recipe can fail. With a partner, reevaluate your arguments.

30 **SEP Analyze and Interpret Data** A simple bread recipe calls for 400 g of flour, 8 g of salt, 1 g of yeast, and 0.3 L of water. The recipe produces 1 loaf of bread. The data table shows the amounts of each ingredient you have. Identify the limiting reagent. What is the theoretical yield, assuming you could make partial loaves? How many whole loaves of bread can you actually make? What is the percent yield? How much of each ingredient do you have left over?

Available Ingredients

Ingredients	Amount (g)
Flour	1,350
Salt	450
Yeast	7
Water	unlimited

GO ONLINE to Evaluate what you learned about the consistent proportions of reactants and products in chemical reactions by using the available assessment resources.

In the Performance-Based Assessment, you used different amounts of reagents to collect, analyze, and interpret data in order to understand limiting and excess reagents. Wrap up your analysis by answering the following questions.

31 **SEP Use Mathematics** During a demonstration, 2.0 L of 1.5 *M* acetic acid (CH_3COOH) is mixed with a 454 g box of baking soda ($NaHCO_3$). What is the limiting reactant?

32 **CCC Consistency in Natural Systems** When an asteroid enters Jupiter's atmosphere at great speed, it becomes extremely hot. Jupiter's atmosphere is rich in flammable gases, such as hydrogen and methane, but falling asteroids never start planet-wide fires on Jupiter. Use what you know about combustion and limiting reagents to provide a possible explanation.

33 **Revisit the Anchoring Phenomenon** How does what you learned in this investigation help you explain why chefs measure the amount of ingredients they need before preparing foods?

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