CollegeBoard Pre-AP®

Pre-AP® Chemistry

TEACHER RESOURCES

Units 3 and 4

ABOUT COLLEGE BOARD

College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success—including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

For further information, visit **www.collegeboard.org**.

PRE-AP EQUITY AND ACCESS POLICY

College Board believes that all students deserve engaging, relevant, and challenging grade-level coursework. Access to this type of coursework increases opportunities for all students, including groups that have been traditionally underrepresented in AP and college classrooms. Therefore, the Pre-AP program is dedicated to collaborating with educators across the country to ensure all students have the supports to succeed in appropriately challenging classroom experiences that allow students to learn and grow. It is only through a sustained commitment to equitable preparation, access, and support that true excellence can be achieved for all students, and the Pre-AP course designation requires this commitment.

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The sentence-writing strategies used in Pre-AP lessons are based upon The Writing Revolution, Inc., a national nonprofit organization that trains educators to implement The Hochman Method, an evidence-based approach to teaching writing. The strategies included in Pre-AP materials are meant to support students' writing, critical thinking, and content understanding, but they do not represent The Writing Revolution's full, comprehensive approach to teaching writing. More information can be found at **www.thewritingrevolution.org**.

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Acknowledgments

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Introduction to Pre-AP Chemistry

About Pre-AP

Introduction to Pre-AP

Every student deserves classroom opportunities to learn, grow, and succeed. College Board developed Pre-AP® to deliver on this simple premise. Pre-AP courses are designed to support all students across varying levels of readiness. They are not honors or advanced courses.

Participation in Pre-AP courses allows students to slow down and focus on the most essential and relevant concepts and skills. Students have frequent opportunities to engage deeply with texts, sources, and data as well as compelling higher-order questions and problems. Across Pre-AP courses, students experience shared instructional practices and routines that help them develop and strengthen the important critical thinking skills they will need to employ in high school, college, and life. Students and teachers can see progress and opportunities for growth through varied classroom assessments that provide clear and meaningful feedback at key checkpoints throughout each course.

DEVELOPING THE PRE-AP COURSES

Pre-AP courses are carefully developed in partnership with experienced educators, including middle school, high school, and college faculty. Pre-AP educator committees work closely with College Board to ensure that the course resources define, illustrate, and measure grade-level-appropriate learning in a clear, accessible, and engaging way. College Board also gathers feedback from a variety of stakeholders, including Pre-AP partner schools from across the nation who have participated in multiyear pilots of select courses. Data and feedback from partner schools, educator committees, and advisory panels are carefully considered to ensure that Pre-AP courses provide all students with grade-level-appropriate learning experiences that place them on a path to college and career readiness.

PRE-AP EDUCATOR NETWORK

Similar to the way in which teachers of Advanced Placement® (AP®) courses can become more deeply involved in the program by becoming AP Readers or workshop consultants, Pre-AP teachers also have opportunities to become active in their educator network. Each year, College Board expands and strengthens the Pre-AP National Faculty—the team of educators who facilitate Pre-AP Readiness Workshops and Pre-AP Summer Institutes. Pre-AP teachers can also become curriculum and assessment contributors by working with College Board to design, review, or pilot the course resources.

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HOW TO GET INVOLVED

Schools and districts interested in learning more about participating in Pre-AP should visit **preap.org/join** or contact us at **preap@collegeboard.org**.

Teachers interested in becoming members of Pre-AP National Faculty or participating in content development should visit **preap.org/national-faculty** or contact us at **preap@collegeboard.org**.

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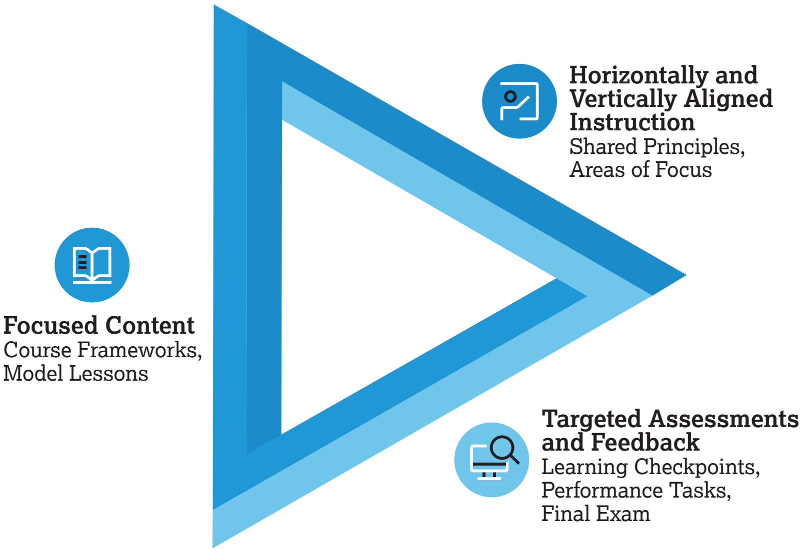
Pre-AP Approach to Teaching and Learning

Pre-AP courses invite all students to learn, grow, and succeed through focused content, horizontally and vertically aligned instruction, and targeted assessments for learning. The Pre-AP approach to teaching and learning, as described below, is not overly complex, yet the combined strength results in powerful and lasting benefits for both teachers and students. This is our theory of action.



FOCUSED CONTENT

Pre-AP courses focus deeply on a limited number of concepts and skills with the broadest relevance for high school coursework and college and career success. The course framework serves as the foundation of the course and defines these prioritized concepts and skills. Pre-AP model lessons and assessments are based directly on this focused framework. The course design provides students and teachers with intentional permission to slow down and focus.

HORIZONTALLY AND VERTICALLY ALIGNED INSTRUCTION

Shared principles cut across all Pre-AP courses and disciplines. Each course is also aligned to discipline-specific areas of focus that prioritize the critical reasoning skills and practices central to that discipline.

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SHARED PRINCIPLES

All Pre-AP courses share the following set of research-supported instructional principles. Classrooms that regularly focus on these cross-disciplinary principles allow students to effectively extend their content knowledge while strengthening their critical thinking skills. When students are enrolled in multiple Pre-AP courses, the horizontal alignment of the shared principles provides students and teachers across disciplines with a shared language for their learning and investigation, and multiple opportunities to practice and grow. The critical reasoning and problem-solving tools students develop through these shared principles are highly valued in college coursework and in the workplace.

Close Observation and Analysis

Students are provided time to carefully observe one data set, text, image, performance piece, or problem before being asked to explain, analyze, or evaluate. This creates a safe entry point to simply express what they notice and what they wonder. It also encourages students to slow down and capture relevant details with intentionality to support more meaningful analysis, rather than rushing to completion at the expense of understanding.

Higher-Order Questioning

Students engage with questions designed to encourage thinking that is elevated beyond simple memorization and recall. Higher-order questions require students to make predictions, synthesize, evaluate, and compare. As students grapple with these questions, they learn that being inquisitive promotes extended thinking and leads to deeper understanding.

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Evidence-Based Writing

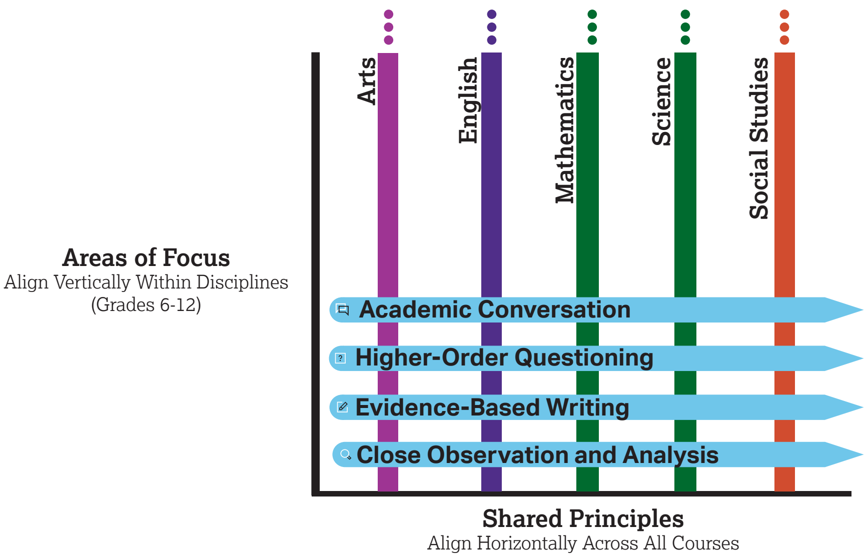
With strategic support, students frequently engage in writing coherent arguments from relevant and valid sources of evidence. Pre-AP courses embrace a purposeful and scaffolded approach to writing that begins with a focus on precise and effective sentences before progressing to longer forms of writing.

Academic Conversation

Through peer-to-peer dialogue, students' ideas are explored, challenged, and refined. As students engage in academic conversation, they come to see the value in being open to new ideas and modifying their own ideas based on new information. Students grow as they frequently practice this type of respectful dialogue and critique and learn to recognize that all voices, including their own, deserve to be heard.

AREAS OF FOCUS

The areas of focus are discipline-specific reasoning skills that students develop and leverage as they engage with content. Whereas the shared principles promote horizontal alignment across disciplines, the areas of focus provide vertical alignment within a discipline, giving students the opportunity to strengthen and deepen their work with these skills in subsequent courses in the same discipline.



For information about the Pre-AP science areas of focus, see page 15.

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TARGETED ASSESSMENTS FOR LEARNING

Pre-AP courses include strategically designed classroom assessments that serve as tools for understanding progress and identifying areas that need more support. The assessments provide frequent and meaningful feedback for both teachers and students across each unit of the course and for the course as a whole. For more information about assessments in Pre-AP Chemistry, see page 46.

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Pre-AP Professional Learning

Pre-AP teachers are required to engage in two professional learning opportunities. The first requirement is designed to help prepare them to teach their specific course. There are two options to meet the first requirement: the Pre-AP Summer Institute (Pre-APSI) and the Online Foundational Module Series. Both options provide continuing education units to educators who complete the training.

- The Pre-AP Summer Institute is a four-day collaborative experience that empowers participants to prepare and plan for their Pre-AP course. While attending, teachers engage with Pre-AP course frameworks, shared principles, areas of focus, and sample model lessons. Participants are given supportive planning time where they work with peers to begin to build their Pre-AP course plan.
- The Online Foundational Module Series is available to all teachers of Pre-AP courses. This 12- to 20-hour course supports teachers in preparing for their Pre-AP course. Teachers explore course materials and experience model lessons from the student's point of view. They also begin to plan and build their own course so they are ready on day one of instruction.

The second professional learning requirement is to complete at least one of the Online Performance Task Scoring Modules, which offer guidance and practice applying Pre-AP scoring guidelines to student work.

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About the Course

Introduction to Pre-AP Chemistry

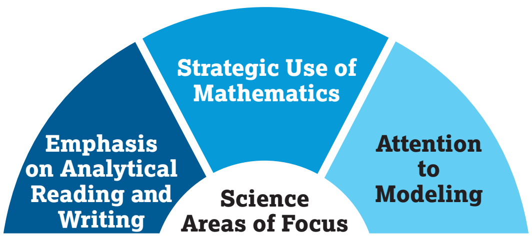
The Pre-AP Chemistry course emphasizes the integration of content with science practices—powerful reasoning tools that support students in analyzing the natural world around them. Having this ability is one of the hallmarks of scientific literacy and is critical for numerous college and career endeavors in science and the social sciences.

Rather than seeking to cover all topics traditionally included in a standard chemistry textbook, this course focuses on the foundational chemistry knowledge and skills that matter most for college and career readiness. The Pre-AP Chemistry Course Framework highlights how to guide students to connect core ideas within and across the units of the course, promoting the development of a coherent understanding of matter at the atomic scale.

The components of this course have been crafted to prepare not only the next generation of chemists, but also a broader base of chemistry-informed citizens who are well equipped to respond to the array of science-related issues that impact our lives at the personal, local, and global levels.

PRE-AP SCIENCE AREAS OF FOCUS

The Pre-AP science areas of focus, shown below, are science practices that students develop and leverage as they engage with content. They were identified through educator feedback and research about where students and teachers need the most curriculum support. These areas of focus are vertically aligned to the science practices embedded in other science courses in high school, including AP, and in college, giving students multiple opportunities to strengthen and deepen their work with these skills throughout their educational career. They also support and align to the NGSS and AP science practices of theory building and refinement.



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Emphasis on Analytical Reading and Writing

Students engage in analytical reading and writing to gain, retain, and apply scientific knowledge and to carry out scientific argumentation.

In prioritizing analytical reading, Pre-AP Chemistry classrooms ask students to extract, synthesize, and compare complex information, often by moving between texts, tables and graphs of experimental data, and representations of motions and interactions at the molecular level. Through analytical writing activities, Pre-AP Chemistry students must integrate and translate that information to generate scientific questions, design methods for answering questions, and develop scientific arguments. Moreover, the application of these skills to the understanding of informal science texts, such as articles found in newspapers, online sources, and magazines, prepares students to be discerning consumers of scientific information.

Strategic Use of Mathematics

Students integrate mathematics with conceptual understanding to model chemical phenomena.

Mathematics is an essential tool for the study of chemistry. However, introductory chemistry courses often focus on the use of mathematics without context-focused applications. This practice can result in students being able to solve mathematical problems in chemistry class, but without an understanding of the underlying chemical principles. As an alternative approach, Pre-AP Chemistry requires students to demonstrate their knowledge using multiple representations that integrate conceptual understanding with the use of mathematics. Students are also challenged to use data and observations to build mathematical models that reflect their conceptual understanding and can be used to make predictions.

Attention to Modeling

Students develop and refine models to connect macroscopic observations to structure, motion, and interactions occurring at the atomic scale.

In Pre-AP Chemistry, the development of models to explain their macroscopic observations is a primary means through which students develop an understanding of the molecular world. Engaging students in creating and revising models reinforces other scientific reasoning skills, such as data analysis and scientific argumentation. Modeling also helps illustrate for students how scientific knowledge is constructed and modified over time as new data and evidence emerge and models are revised based on this new information.

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PRE-AP CHEMISTRY AND CAREER READINESS

The Pre-AP Chemistry course resources are designed to expose students to a wide range of career opportunities that depend upon chemistry knowledge and skills. Chemistry lies at the interface of the physical and life sciences. As science, engineering, and healthcare move increasingly towards the molecular scale, chemistry provides ideal preparation for 21st century careers. Examples include not only careers within the physical sciences, such as forensic scientist or food chemist, but also other endeavors where chemistry knowledge is relevant such as the work of an engineer, policymaker, or healthcare worker.

Career clusters that involve chemistry, along with examples of careers in chemistry or related to chemistry, are provided below. Teachers should consider discussing these with students throughout the year to promote motivation and engagement.

Career Clusters Involving Chemistry	
agriculture, food, and natural resources healthcare and health science hospitality and tourism information technology	manufacturing STEM (science, technology, engineering, and math)
Examples of Chemistry Careers	**Examples of Chemistry Related Careers**
atmospheric chemist chemical engineer chemistry teacher/professor environmental chemist food chemist geochemist hazardous waste manager materials scientist medicinal chemist nanotechnologist synthetic chemist	environmental scientist forensic scientist medical assistant patent lawyer pharmacist pharmacologist physician physician assistant science writer technical sales toxicologist

Source for Career Clusters: "Advanced Placement and Career and Technical Education: Working Together." Advance CTE and the College Board. October 2018. **https://careertech.org/resource/ap-cte-working-together.**

For more information about careers that involve chemistry, teachers and students can visit and explore the College Board's Big Future resources: **https://bigfuture.collegeboard.org/majors/physical-sciences-chemistry-chemistry**.

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SUMMARY OF RESOURCES AND SUPPORTS

Teachers are strongly encouraged to take advantage of the full set of resources and supports for Pre-AP Chemistry, which is summarized below. Some of these resources must be used for a course to receive the Pre-AP Course Designation. To learn more about the requirements for course designation, see details below and on page 56.

COURSE FRAMEWORK

The framework defines what students should know and be able to do by the end of the course. It serves as an anchor for model lessons and assessments, and it is the primary document teachers can use to align instruction to course content. **Use of the course framework is required**. *For more details see page 22.*

MODEL LESSONS

Teacher resources, available in print and online, include a robust set of model lessons that demonstrate how to translate the course framework, shared principles, and areas of focus into daily instruction. **Use of the model lessons is encouraged but not required**. *For more details see page 44.*

LEARNING CHECKPOINTS

Accessed through Pre-AP Classroom (the Pre-AP digital platform), these short formative assessments provide insight into student progress. They are automatically scored and include multiple-choice and technology-enhanced items with rationales that explain correct and incorrect answers. **Use of one learning checkpoint per unit is required**. *For more details see page 46.*

PERFORMANCE TASKS

Available in the printed teacher resources as well as on Pre-AP Classroom, performance tasks allow students to demonstrate their learning through extended problem-solving, writing, analysis, and/or reasoning tasks. Scoring guidelines are provided to inform teacher scoring, with additional practice and feedback suggestions available in online modules on Pre-AP Classroom. **Use of each unit's performance task is required**. *For more details see page 48.*

PRACTICE PERFORMANCE TASKS

Available in the student resources, with supporting materials in the teacher resources, these tasks provide an opportunity for students to practice applying skills and knowledge as they would in a performance task, but in a more scaffolded environment. **Use of the practice performance tasks is encouraged but not required**. *For more details see page 49.*

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FINAL EXAM

Accessed through Pre-AP Classroom, the final exam serves as a classroom-based, summative assessment designed to measure students' success in learning and applying the knowledge and skills articulated in the course framework. **Administration of the final exam is encouraged but not required**. *For more details see page 50.*

PROFESSIONAL LEARNING

Both the four-day Pre-AP Summer Institute (Pre-APSI) and the Online Foundational Module Series support teachers in preparing and planning to teach their Pre-AP course. **All Pre-AP teachers are required to either attend the Pre-AP Summer Institute or complete the module series. In addition, teachers are required to complete at least one Online Performance Task Scoring module**. *For more details see page 11.*

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Course Map

PLAN

The course map shows how components are positioned throughout the course. As the map indicates, the course is designed to be taught over 140 class periods (based on 45-minute class periods), for a total of 28 weeks.

Model lessons are included for approximately 50% of the total instructional time, with the percentage varying by unit. Each unit is divided into key concepts.

TEACH

The model lessons demonstrate how the Pre-AP shared principles and science areas of focus come to life in the classroom.

Shared Principles
Close observation and analysis
Higher-order questioning
Evidence-based writing
Academic conversation

Areas of Focus
Emphasis on analytical reading and writing
Strategic use of mathematics
Attention to modeling

ASSESS AND REFLECT

Each unit includes two learning checkpoints and a performance task. These formative assessments are designed to provide meaningful feedback for both teachers and students.

Note: The final exam, offered during a six-week window in the spring, is not represented in the map.

UNIT 1 **Structure and Properties of Matter**

~30 Class Periods

Pre-AP model lessons provided for approximately 50% of instructional time in this unit

KEY CONCEPT 1.1
Particle View of States of Matter

Learning Checkpoint 1

KEY CONCEPT 1.2
Phase Changes and Particle Interactions

KEY CONCEPT 1.3
Kinetic Molecular Theory

Learning Checkpoint 2

Performance Task for Unit 1

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UNIT 2 Chemical Bonding and Interactions

~40 Class Periods

Pre-AP model lessons provided for approximately 40% of instructional time in this unit

KEY CONCEPT 2.1
Classification and Interactions of Matter

KEY CONCEPT 2.2
Learning Objectives 2.2.A.1–2.2.C.1
Molecular Structure and Properties

Learning Checkpoint 1

KEY CONCEPT 2.2 (*continued*)
Learning Objectives 2.2.D.1–2.2.G.1
Molecular Structure and Properties

KEY CONCEPT 2.3
Covalent and Ionic Bonding

Learning Checkpoint 2

Performance Task for Unit 2

UNIT 3 Chemical Quantities

~30 Class Periods

Pre-AP model lessons provided for approximately 30% of instructional time in this unit

KEY CONCEPT 3.1
Counting Particles in Substances

Learning Checkpoint 1

KEY CONCEPT 3.2
Counting Particles in Chemical Reactions

Learning Checkpoint 2

Performance Task for Unit 3

UNIT 4 Chemical Transformations

~40 Class Periods

Pre-AP model lessons provided for approximately 30% of instructional time in this unit

KEY CONCEPT 4.1
Precipitation Chemistry

KEY CONCEPT 4.2
Oxidation–Reduction Chemistry

Learning Checkpoint 1

KEY CONCEPT 4.3
Acid–Base Chemistry

KEY CONCEPT 4.4
Thermochemistry

KEY CONCEPT 4.5
Reaction Rates

Learning Checkpoint 2

Performance Task for Unit 4

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Pre-AP Chemistry Course Framework

INTRODUCTION

Based on the Understanding by Design® (Wiggins and McTighe) model, the Pre-AP Chemistry Course Framework is back mapped from AP expectations and aligned to essential grade-level expectations. The course framework serves as a teacher's blueprint for the Pre-AP Chemistry instructional resources and assessments.

The course framework was designed to meet the following criteria:

- **Focused:** The framework provides a deep focus on a limited number of concepts and skills that have the broadest relevance for later high school, college, and career success.
- **Measurable:** The framework's learning objectives are observable and measurable statements about the knowledge and skills students should develop in the course.
- **Manageable:** The framework is manageable for a full year of instruction, fosters the ability to explore concepts in depth, and enables room for additional local or state standards to be addressed where appropriate.
- **Accessible:** The framework's learning objectives are designed to provide all students, across varying levels of readiness, with opportunities to learn, grow, and succeed.

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COURSE FRAMEWORK COMPONENTS

The Pre-AP Chemistry Course Framework includes the following components:

Big Ideas

The big ideas are recurring themes that allow students to create meaningful connections between course concepts. Revisiting the big ideas throughout the course and applying them in a variety of contexts allows students to develop deeper conceptual understandings.

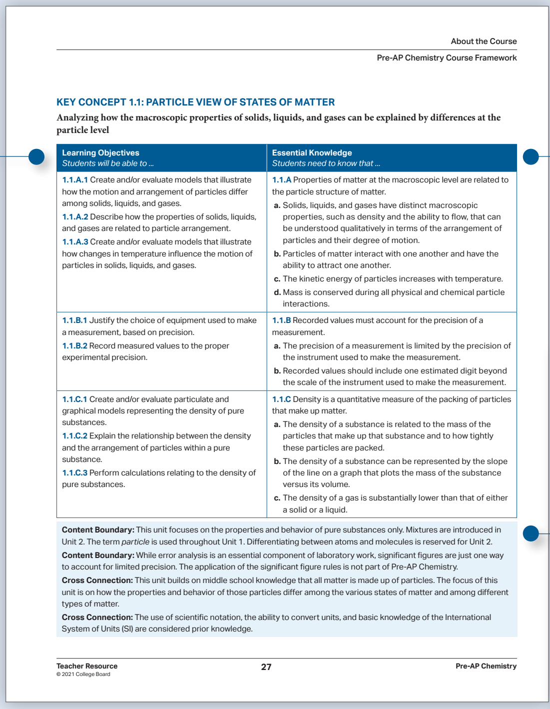
Enduring Understandings

Each unit focuses on a small set of enduring understandings. These are the long-term takeaways related to the big ideas that leave a lasting impression on students. Students build and earn these understandings over time by exploring and applying course content throughout the year.

Key Concepts

To support teacher planning and instruction, each unit is organized by key concepts. Each key concept includes relevant **learning objectives** and **essential knowledge statements** and may also include **content boundary and cross connection statements**. These are illustrated and defined below.

Learning Objectives: These objectives define what a student needs to be able to do with essential knowledge to progress toward the enduring understandings. The learning objectives serve as actionable targets for instruction and assessment.


About the Course
Pre-AP Chemistry Course Framework

KEY CONCEPT 1.1: PARTICLE VIEW OF STATES OF MATTER

Analyzing how the macroscopic properties of solids, liquids, and gases can be explained by differences at the particle level

Learning Objectives *Students will be able to ...*	Essential Knowledge *Students need to know that ...*
1.1.A.1 Create and/or evaluate models that illustrate how the motion and arrangement of particles differ among solids, liquids, and gases. 1.1.A.2 Describe how the properties of solids, liquids, and gases are related to particle arrangement. 1.1.A.3 Create and/or evaluate models that illustrate how changes in temperature influence the motion of particles in solids, liquids, and gases.	1.1.A Properties of matter at the macroscopic level are related to the particle structure of matter. **a.** Solids, liquids, and gases have distinct macroscopic properties, such as density and the ability to flow, that can be understood qualitatively in terms of the arrangement of particles and their degree of motion. **b.** Particles of matter interact with one another and have the ability to attract one another. **c.** The kinetic energy of particles increases with temperature. **d.** Mass is conserved during all physical and chemical particle interactions.
1.1.B.1 Justify the choice of equipment used to make a measurement, based on precision. 1.1.B.2 Record measured values to the proper experimental precision.	1.1.B Recorded values must account for the precision of a measurement. **a.** The precision of a measurement is limited by the precision of the instrument used to make the measurement. **b.** Recorded values should include one estimated digit beyond the scale of the instrument used to make the measurement.
1.1.C.1 Create and/or evaluate particulate and graphical models representing the density of pure substances. 1.1.C.2 Explain the relationship between the density and the arrangement of particles within a pure substance. 1.1.C.3 Perform calculations relating to the density of pure substances.	1.1.C Density is a quantitative measure of the packing of particles that make up matter. **a.** The density of a substance is related to the mass of the particles that make up that substance and to how tightly these particles are packed. **b.** The density of a substance can be represented by the slope of the line on a graph that plots the mass of the substance versus its volume. **c.** The density of a gas is substantially lower than that of either a solid or a liquid.

Content Boundary: This unit focuses on the properties and behavior of pure substances only. Mixtures are introduced in Unit 2. The term *particle* is used throughout Unit 1. Differentiating between atoms and molecules is reserved for Unit 2.

Content Boundary: While error analysis is an essential component of laboratory work, significant figures are just one way to account for limited precision. The application of the significant figure rules is not part of Pre-AP Chemistry.

Cross Connection: This unit builds on middle school knowledge that all matter is made up of particles. The focus of this unit is on how the properties and behavior of those particles differ among the various states of matter and among different types of matter.

Cross Connection: The use of scientific notation, the ability to convert units, and basic knowledge of the International System of Units (SI) are considered prior knowledge.

Teacher Resource 27 Pre-AP Chemistry
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Essential Knowledge Statements: The essential knowledge statements are linked to one or more learning objectives. These statements describe the knowledge required to perform the learning objective(s).

Content Boundary and Cross Connection Statements: When needed, content boundary statements provide additional clarity about the content and skills that lie within versus outside of the scope of this course.

Cross connection statements highlight important connections that should be made between key concepts within and across the units.

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BIG IDEAS IN PRE-AP CHEMISTRY

While the Pre-AP Chemistry framework is organized into four core units of study, the content is grounded in three big ideas, which are cross-cutting concepts that build conceptual understanding and spiral throughout the course. Since these ideas cut across units, they serve as the underlying foundation for the enduring understandings, key concepts, learning objectives, and essential knowledge statements that make up the focus of each unit.

The three big ideas that are central to deep and productive understanding in Pre-AP Chemistry are:

- **Structure and Properties:** All matter is composed of particles that are in constant motion and interact with one another. This movement and interaction is responsible for the observable properties of matter. Observed properties can be used to infer the number and type(s) of particle(s) in a sample of matter.
- **Energy:** Energy is transferred in all physical and chemical processes. During these processes, energy is either redistributed within the system or between systems.
- **Transformations**: At its heart, chemistry is about rearrangements of matter. These rearrangements, or transformations, involve the breaking and forming of intermolecular forces or chemical bonds. Macroscopic observations can be used to quantify and describe these rearrangements at the atomic scale.

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OVERVIEW OF PRE-AP CHEMISTRY UNITS AND ENDURING UNDERSTANDINGS

Unit 1: Structure and Properties of Matter	Unit 2: Chemical Bonding and Interactions
▪ Solids, liquids, and gases have different properties as a result of the motion of particles and the interactions among them. ▪ All measurements have uncertainty, and their level of precision must be accounted for in the design of an experiment and the recording of data. ▪ The amount of energy transferred during heating and cooling matter or changing its state is determined by the interactions among the particles that make up the matter. ▪ Observable properties of gases can be measured experimentally and explained using an understanding of particle motion.	▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles. ▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.
Unit 3: Chemical Quantities	**Unit 4: Chemical Transformations**
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction. ▪ In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.	▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions. ▪ All chemical reactions are accompanied by a transfer of energy. ▪ Chemical reactions occur at varying rates that are related to the frequency and success of collisions between reactants.

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Unit 1: Structure and Properties of Matter

Suggested Timing: Approximately 6 weeks

This course progresses from macroscopic to atomic explorations of properties of matter in order to help students develop a conceptual understanding of matter at the molecular level. The first unit is designed to spark students' interest in chemistry as they make meaningful connections between the familiar world of everyday, macroscopic variables and observations and the less familiar context of the motion and interactions of particles at the atomic level.

By the end of this unit, students develop a set of simple rules to describe the behavior of particles in pure substances through building and revising particulate models. They deepen their understanding throughout the unit as they support and verify predictions of these models using observations of real-world phenomena and calculations of various physical properties such as the density of solids and liquids, the basic parameters of gases such as pressure and volume, and the role energy plays in phase transitions. Students also consider how the attraction among particles influences properties; the factors that establish the strength of those forces will be explored in Unit 2.

ENDURING UNDERSTANDINGS

Students will understand that ...

- Solids, liquids, and gases have different properties as a result of the motion of particles and the interactions among them.
- All measurements have uncertainty, and their level of precision must be accounted for in the design of an experiment and the recording of data.
- The amount of energy transferred during heating and cooling matter or changing its state is determined by the interactions among the particles that make up the matter.
- Observable properties of gases can be measured experimentally and explained using an understanding of particle motion.

KEY CONCEPTS

- **1.1: Particle view of states of matter** – Analyzing how the macroscopic properties of solids, liquids, and gases can be explained by differences at the particle level
- **1.2: Phase changes and particle interactions** – Examining the role energy plays in phase transitions and how these transitions can be represented using phase diagrams and heating curves
- **1.3: Kinetic molecular theory** – Investigating gases and how their properties and behavior can be predicted from the kinetic molecular theory

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KEY CONCEPT 1.1: PARTICLE VIEW OF STATES OF MATTER

Analyzing how the macroscopic properties of solids, liquids, and gases can be explained by differences at the particle level

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
1.1.A.1 Create and/or evaluate models that illustrate how the motion and arrangement of particles differ among solids, liquids, and gases. **1.1.A.2** Describe how the properties of solids, liquids, and gases are related to particle arrangement. **1.1.A.3** Create and/or evaluate models that illustrate how changes in temperature influence the motion of particles in solids, liquids, and gases.	**1.1.A** Properties of matter at the macroscopic level are related to the particle structure of matter. **a.** Solids, liquids, and gases have distinct macroscopic properties, such as density and the ability to flow, that can be understood qualitatively in terms of the arrangement of particles and their degree of motion. **b.** Particles of matter interact with one another and have the ability to attract one another. **c.** The kinetic energy of particles increases with temperature. **d.** Mass is conserved during all physical and chemical particle interactions.
1.1.B.1 Justify the choice of equipment used to make a measurement, based on precision. **1.1.B.2** Record measured values to the proper experimental precision.	**1.1.B** Recorded values must account for the precision of a measurement. **a.** The precision of a measurement is limited by the precision of the instrument used to make the measurement. **b.** Recorded values should include one estimated digit beyond the scale of the instrument used to make the measurement.
1.1.C.1 Create and/or evaluate particulate and graphical models representing the density of pure substances. **1.1.C.2** Explain the relationship between the density and the arrangement of particles within a pure substance. **1.1.C.3** Perform calculations relating to the density of pure substances.	**1.1.C** Density is a quantitative measure of the packing of particles that make up matter. **a.** The density of a substance is related to the mass of the particles that make up that substance and to how tightly these particles are packed. **b.** The density of a substance can be represented by the slope of the line on a graph that plots the mass of the substance versus its volume. **c.** The density of a gas is substantially lower than that of either a solid or a liquid.

Content Boundary: This unit focuses on the properties and behavior of pure substances only. Mixtures are introduced in Unit 2. The term *particle* is used throughout Unit 1. Differentiating between atoms and molecules is reserved for Unit 2.

Content Boundary: While error analysis is an essential component of laboratory work, significant figures are just one way to account for limited precision. The application of the significant figure rules is not part of Pre-AP Chemistry.

Cross Connection: This unit builds on middle school knowledge that all matter is made up of particles. The focus of this unit is on how the properties and behavior of those particles differ among the various states of matter and among different types of matter.

Cross Connection: The use of scientific notation, the ability to convert units, and basic knowledge of the International System of Units (SI) are considered prior knowledge.

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KEY CONCEPT 1.2: PHASE CHANGES AND PARTICLE INTERACTIONS

Examining the role energy plays in phase transitions and how these transitions can be represented using phase diagrams and heating curves

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
1.2.A.1 Create and/or evaluate a claim about the relationship between transfer of thermal energy and the temperature change in different samples. **1.2.A.2** Perform calculations using data gathered from a simple constant-pressure calorimetry experiment.	**1.2.A** The transfer of energy associated with a change in temperature of a sample of matter is heat. Specific heat capacity is a proportionality constant that relates the amount of energy absorbed by a substance to its mass and its change in temperature.
1.2.B.1 Use data to explain the direction of energy flow into or out of a system.	**1.2.B** Energy transfers are classified as endothermic or exothermic. **a.** In endothermic changes, energy flows from the surroundings to the system. **b.** In exothermic changes, energy flows from the system to the surroundings.
1.2.C.1 Explain the relationship between changes in states of matter and the attractions among particles. **1.2.C.2** Create and/or interpret models representing phase changes.	**1.2.C** Substances with stronger attractions among particles generally have higher melting and boiling points than substances with weaker attractions among particles.
1.2.D.1 Create and/or interpret heating and cooling curves and/or phase diagrams of pure substances. **1.2.D.2** Calculate the energy transferred when a substance changes state.	**1.2.D** The transitions between solid, liquid, and gas can be represented with heating and cooling curves and phase diagrams. **a.** Heating and cooling curves represent how a substance responds to the addition or removal of energy (as heat). **b.** The temperature of a substance is constant during a phase change. **c.** Energy changes associated with a phase change can be calculated using heat of vaporization or heat of fusion. **d.** Phase diagrams give information about a pure substance at a specific temperature and pressure, including phase transitions.

Content Boundary: The study of critical points and triple points is beyond the scope of the course. The focus of the study of phase diagrams should be on how the combination of temperature and pressure determine the state of matter of a given substance and identification of phase changes.

Cross Connection: The study of energy transfer in Unit 1 is limited to physical changes. Students will revisit thermochemistry in Unit 4, this time applied to chemical reactions.

Cross Connection: Forces of attraction between particles are identified as stronger or weaker in this unit as a way for students to begin to understand differences in macroscopic properties of substances. Students will revisit these attractive forces in Unit 2 as they learn about the types and relative strengths of intermolecular forces.

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KEY CONCEPT 1.3: KINETIC MOLECULAR THEORY

Investigating gases and how their properties and behavior can be predicted from the kinetic molecular theory

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
1.3.A.1 Create and/or evaluate models that illustrate how a gas exerts pressure. **1.3.A.2** Explain the relationship between pressure in a gas and collisions.	**1.3.A** The pressure of a gas is the force the gas applies to a unit area of the container it is in. **a.** Pressure arises from collisions of particles with the walls of the container. **b.** Pressure is measured using several different units that are proportional to each other.
1.3.B.1 Explain the relationships between the macroscopic properties of a sample of a gas using the kinetic molecular theory. **1.3.B.2** Create and/or evaluate models that illustrate how a sample of gas responds to changes in macroscopic properties.	**1.3.B** The kinetic molecular theory relates the macroscopic properties of a gas to the motion of the particles that comprise the gas. An ideal gas is a gas that conforms to the kinetic molecular theory.
1.3.C.1 Determine mathematically and/or graphically the quantitative relationship between macroscopic properties of gases. **1.3.C.2** Perform calculations relating to the macroscopic properties of gases.	**1.3.C** The relationships between macroscopic properties of a gas, including pressure, temperature, volume, and amount of gas, can be quantified.

Content Boundary: All gases studied in this unit are considered to be ideal. The derivation and discussion of the ideal gas law has been reserved for Unit 3, after students have been introduced to the mole.

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Unit 2: Chemical Bonding and Interactions

Suggested Timing: Approximately 8 weeks

This unit focuses on particle interactions and continues the unit progression from the macroscopic to the atomic level. Building on prior concepts taught in middle school about basic atomic structure, students build on and extend their understanding as they explore how the shape and structure of particles—including atoms, molecules, and ions—provide the explanatory framework for particle interactions. Students first consider intermolecular forces and connect them to both macroscopic observations and molecular structure. They then build on and deepen their preliminary understanding of bonding concepts from middle school and should begin to understand the electrostatic nature of many chemical interactions.

Throughout the unit, students revisit and revise the particulate models they developed in Unit 1 to account for the role of particle interactions. The patterns found in the periodic table are used to explain these phenomena.

ENDURING UNDERSTANDINGS

Students will understand that …

- The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.
- The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.

KEY CONCEPTS

- **2.1: Classification and interactions of matter** – Describing and classifying matter, with a focus on how intermolecular and intramolecular forces determine the properties of matter
- **2.2: Molecular structure and properties** – Relating the properties of molecular compounds to molecular structure
- **2.3: Covalent and ionic bonding** – Analyzing the differences between covalent and ionic bonding, with an emphasis on the electrostatic nature of ionic attractions

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KEY CONCEPT 2.1: CLASSIFICATION AND INTERACTIONS OF MATTER

Describing and classifying matter, with a focus on how intermolecular and intramolecular forces determine the properties of matter

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
2.1.A.1 Distinguish between atoms, molecules, and compounds at the particle level. **2.1.A.2** Create and/or evaluate models of pure substances.	**2.1.A** A pure substance always has the same composition. Pure substances include elements, molecules, and compounds. **a.** An element is composed of only one type of atom. **b.** A molecule is a particle composed of more than one atom. **c.** A compound is composed of two or more elements and has properties distinct from those of its component atoms.
2.1.B.1 Create and/or evaluate models of mixtures. **2.1.B.2** Interpret the results of an experiment involving the separation of a mixture.	**2.1.B** A mixture is composed of two or more different types of particles that are not bonded. **a.** Each component of a mixture retains its unique properties. **b.** Mixtures can be separated using physical processes such as filtration, evaporation, distillation, and chromatography.
2.1.C.1 Relate the total and partial pressure of a gas mixture to the number of particles and their proportions.	**2.1.C** In a mixture of gases, each gas contributes to the pressure of the gas. **a.** The total pressure of the mixture is the sum of the individual partial pressures of each gas that makes up the mixture. **b.** The partial pressures of each gas can be determined by comparing the fraction of particles of the gas in the mixture to the total number of gas particles.
2.1.D.1 Create and/or evaluate a claim about the types of forces that are overcome during the melting, boiling, and/or dissolving of substances.	**2.1.D** Attractions among particles of matter are the result of electrostatic interactions between particles. **a.** Intermolecular forces are responsible for many physical properties of substances including boiling point, melting point, surface tension, and volatility. **b.** Intramolecular forces hold atoms together in a molecule.

Cross Connection: Unit 1 treats particles as if they have no internal structure and are mostly identical. In this unit, students begin to distinguish between atoms and molecules and between mixtures and pure substances.

Cross Connection: The basics of atomic structure, including the shell model of the atom and the properties of the three basic subatomic particles, are considered prior knowledge from middle school.

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KEY CONCEPT 2.2: MOLECULAR STRUCTURE AND PROPERTIES

Relating the properties of molecular compounds to molecular structure

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
2.2.A.1 Create and/or evaluate models that illustrate how molecular properties influence the type(s) of intermolecular force(s) present in a substance. **2.2.A.2** Create and/or evaluate a claim about the type(s), strength(s), and origin(s) of intermolecular forces present in a substance.	**2.2.A** Intermolecular forces occur between molecules and are the result of electrostatic interactions. **a.** London dispersion forces are attractions among temporary dipoles created by the random movement of electrons; these attractions occur between all types of molecules. Molecules with more electrons tend to have stronger London dispersion forces. **b.** Dipole–dipole forces are attractions among permanent dipoles on interacting molecules. **c.** Hydrogen bonding forces exist when hydrogen atoms covalently bonded to highly electronegative atoms (N, O, or F) are attracted to the negative ends of dipoles formed by highly electronegative atoms (N, O, or F) in other molecules.
2.2.B.1 Create and/or evaluate a claim that uses relative strength of intermolecular forces to explain trends in the physical properties of substances.	**2.2.B** Intermolecular forces can be used to explain trends in physical properties of substances including boiling point, melting point, surface tension, volatility, and solubility.
2.2.C.1 Describe trends in properties of elements based on their position in the periodic table and the shell model of the atom.	**2.2.C** The periodic table is an organizational tool for elements based on their properties. **a.** Patterns of behavior of elements are based on the number of electrons in the outermost shell (valence electrons). **b.** Important periodic trends include electronegativity and atomic radius.
2.2.D.1 Create and/or evaluate Lewis diagrams for molecular compounds and/or polyatomic ions. **2.2.D.2** Determine if given molecules are structural isomers.	**2.2.D** A Lewis diagram is a simplified representation of a molecule. **a.** Lewis diagrams show the bonding patterns between atoms in a molecule. **b.** Molecules with the same number and type of atoms but different bonding patterns are structural isomers, which have different properties from one another.
2.2.E.1 Determine molecular geometry from a Lewis diagram using valence shell electron pair repulsion theory.	**2.2.E** Valence shell electron pair repulsion (VSEPR) theory predicts molecular geometry from a Lewis diagram. Molecular geometries include linear, bent, trigonal planar, trigonal pyramidal, and tetrahedral arrangements of atoms.
2.2.F.1 Determine the polarity of a molecule from its molecular geometry and electron distribution.	**2.2.F** Molecules with asymmetric distributions of electrons are polar.
2.2.G.1 Create and/or evaluate a claim about the strength and type(s) of intermolecular forces present in a sample based on molecular polarity.	**2.2.G** Molecular geometry determines if a molecule has a permanent dipole and therefore the type(s) of intermolecular forces present in that molecule.

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Content Boundary: The study of expanded octets, resonance structures, and formal charge is beyond the scope of this course. Rather than focusing on exceptions to the octet rule, the focus is on helping students develop a deep understanding of the rationale for molecular structure. If students go on to take AP Chemistry, this introduction will provide the foundation for more advanced study.

Content Boundary: The quantum mechanical model of the atom and the writing of electron configurations are beyond the scope of this course. If students go on to take AP Chemistry, they will study the details of the electron structure of atoms, including electron configurations.

Content Boundary: The study of isomers is limited to structural isomers and is included so students can begin to develop an understanding that in addition to the number and type of atoms in a molecule, the arrangement of the atoms and bonds is also important in determining properties.

Cross Connection: Students should connect their study of phase changes and properties of matter from Unit 1 to intermolecular forces. This key concept leads with the study of intermolecular forces rather than building up to it. This approach enables students to immediately begin connecting macroscopic observations to atomic-level understandings even while they are learning about Lewis structures and molecular geometry. If students go on to take AP Chemistry, they will continue to build on their understanding of intermolecular forces.

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KEY CONCEPT 2.3: COVALENT AND IONIC BONDING

Analyzing the differences between covalent and ionic bonding, with an emphasis on the electrostatic nature of ionic attractions

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
2.3.A.1 Create and/or evaluate a claim about the type of bonding in a compound based on its component elements and its macroscopic properties.	**2.3.A** Bonding between elements can be nonpolar covalent, polar covalent, or ionic.
2.3.B.1 Interpret the results of an experiment to determine the type of bonding present in a substance.	**2.3.B** Ionic and covalent compounds have different properties based on their bonding. **a.** Properties of ionic compounds result from electrostatic attractions of constituent ions. **b.** Properties of covalent compounds result from bonds created by the sharing of electrons and intermolecular forces.
2.3.C.1 Explain the relationship between the relative strength of attractions between cations and anions in an ionic solid in terms of the charges of the ions and the distance between them.	**2.3.C** Ionic solids are made of cations and anions. **a.** The relative number of cations and anions retain overall electrical neutrality. **b.** As the charge on each ion increases the relative strength of the interaction will also increase. **c.** As the distance between ions increases the relative strength of the interaction will decrease.
2.3.D.1 Create and/or evaluate representations of ionic and covalent compounds.	**2.3.D** Ionic and covalent compounds can be represented by particulate models, structural formulas, chemical formulas, and chemical nomenclature.

Content Boundary: The study of ionic compounds should include those compounds containing the polyatomic ions listed on the Pre-AP Chemistry equation sheet. The naming of acids and organic compounds is beyond the scope of this course. Nomenclature should be consistent with recommendations of the International Union of Pure and Applied Chemistry (IUPAC).

Content Boundary: While students should have a conceptual understanding of the role electrostatic interactions play in ionic compounds, quantitative applications of Coulomb's law are beyond the scope of this course. If students go on to take AP Chemistry or AP Physics, they will study Coulomb's law in more detail.

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Unit 3: Chemical Quantities

Suggested Timing: Approximately 6 weeks

This unit explores chemical transformations of matter by building on the physical transformations studied in Units 1 and 2. Leveraging what has been learned about particles in Units 1 and 2, this unit introduces students to the importance of the mole concept for collecting data about particles and chemical reactions. Since chemistry deals with large numbers of particles, students are introduced to the idea of counting by weighing. To reinforce the particle nature of matter studied in Units 1 and 2, students use particulate representations of reactions to connect the amount of reactant consumed and the amount of product formed to the rearrangement of particles on the molecular level. Students will also use balanced chemical equations and mathematics to reason about amounts of reactants and products in chemical reactions.

ENDURING UNDERSTANDINGS

Students will understand that …

- The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.
- In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.

KEY CONCEPTS

- **3.1: Counting particles in substances** – Using the mole concept to count by weighing
- **3.2: Counting particles in chemical reactions** – Reasoning about amounts of reactants and products in chemical reactions using balanced chemical equations

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KEY CONCEPT 3.1: COUNTING PARTICLES IN SUBSTANCES

Using the mole concept to count by weighing

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
3.1.A.1 Explain the relationship between the mass of a substance, the number of particles of that substance, and the number of moles of that substance. **3.1.A.2** Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **a.** A mole of a substance contains Avogadro's number (6.02×10^{23}) of particles. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.
3.1.B.1 Explain the relationships between macroscopic properties of gas samples. **3.1.B.2** Perform calculations using the ideal gas law. **3.1.B.3** Create and/or evaluate models based on the ideal gas law.	**3.1.B** The ideal gas law describes the mathematical relationship between pressure, volume, number of gas particles, and temperature. **a.** Two samples of gas with the same pressure, volume, and temperature have the same number of particles. **b.** The mass of the particles can be computed from atomic masses. **c.** Because macroscopic samples of a gas contain many particles, moles are useful units for counting particles.

Content Boundary: The determination of empirical and molecular formulas is beyond the scope of this course.

Cross Connection: The focus on gases in this key concept about the mole allows students to draw connections between this unit and what they learned about gases in Units 1 and 2. Gases are a useful context for learning about the mole because a large quantity of gas is needed to measure properties of the gas.

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KEY CONCEPT 3.2: COUNTING PARTICLES IN CHEMICAL REACTIONS

Reasoning about amounts of reactants and products in chemical reactions using balanced chemical equations

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
3.2.A.1 Create and/or evaluate models of chemical transformations.	**3.2.A** All chemical transformations involve the rearrangement of atoms to form new combinations. **a.** Since the atoms are not created or destroyed, the total numbers of each atom must remain constant. **b.** Chemical transformations can be modeled by balanced chemical equations and particulate representations.
3.2.B.1 Explain the relationship between the quantity of reactants consumed and the quantity of products formed in a chemical transformation. **3.2.B.2** Perform stoichiometric calculations involving the quantity of reactants and products in a chemical system.	**3.2.B** A balanced chemical reaction equation, combined with the mole concept, can be used to quantify the amounts of reactants consumed and products formed during a chemical transformation.
3.2.C.1 Create and/or evaluate models of a reaction mixture before and/or after a reaction has occurred, including situations with a limiting reactant.	**3.2.C** The limiting reactant is the reactant that is completely consumed during a chemical reaction. The limiting reactant determines the amount of product formed.
3.2.D.1 Calculate the theoretical yield and/or percent yield of a chemical reaction.	**3.2.D** A balanced chemical reaction equation, combined with the mole concept, can be used to calculate the theoretical and percent yield of a reaction.

Content Boundary: Stoichiometric calculations involving limiting reactants are limited to whole numbers of moles (for both the initial and final quantities), such as what could be represented in particle diagrams to focus on conceptual understanding instead of algorithmic calculations.

Cross Connection: Stoichiometric calculations will be used in Unit 4 to investigate specific types of reactions.

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Unit 4: Chemical Transformations

Suggested Timing: Approximately 8 weeks

In this unit, students explore the primary driving forces in chemical reactions through symbolic, particulate, and mathematical representations. The study of precipitation reactions, oxidation–reduction reactions, and acid–base reactions allows students to apply what they have learned about bonding in Unit 2 and stoichiometric relationships in Unit 3 as they explore specific reaction types and predict products of reactions. An emphasis on net ionic equations allows students to focus on the substances that are directly involved in chemical reactions. Students will also revisit and extend the concepts of energy from Unit 1 as they apply them to energy changes involved in chemical transformations, building to the fundamental understanding that breaking chemical bonds requires energy and that bond formation releases energy. Students will also study the rates of chemical reactions and factors that influence the rates, using a particulate perspective.

ENDURING UNDERSTANDINGS

Students will understand that …

- Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.
- All chemical reactions are accompanied by a transfer of energy.
- Chemical reactions occur at varying rates that are related to the frequency and success of collisions between reactants.

KEY CONCEPTS

- **4.1: Precipitation chemistry** – Investigating how solubility is related to precipitation and can drive chemical reactions
- **4.2: Oxidation–reduction chemistry** – Analyzing how electron transfer can drive chemical reactions
- **4.3: Acid–base chemistry** – Examining properties of acids and bases and how proton transfer can drive chemical reactions
- **4.4: Thermochemistry** – Extending the study of energy by analyzing energy transformations that occur during chemical reactions
- **4.5: Reaction rates** – Investigating the factors that influence reaction rates

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KEY CONCEPT 4.1: PRECIPITATION CHEMISTRY

Investigating how solubility is related to precipitation and can drive chemical reactions

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
4.1.A.1 Predict the products of a precipitation reaction.	**4.1.A** Precipitation reactions may occur when two aqueous solutions are mixed, because some ionic compounds are insoluble in water and therefore precipitate out of solution.
4.1.B.1 Create and/or evaluate models of precipitation reactions.	**4.1.B** Precipitation reactions can be modeled by molecular equations, net ionic equations, and particulate representations.
4.1.C.1 Create and/or evaluate models that represent the concentration of a solution. **4.1.C.2** Perform calculations relating to the molarity of solutions.	**4.1.C** Molarity is one way to quantify the concentration of a solution. It describes the number of dissolved particles in a unit volume of that solution.
4.1.D.1 Predict the amount of solid produced in a precipitation reaction using gravimetric analysis based on the concentrations of the starting solutions. **4.1.D.2** Evaluate the results of a gravimetric analysis.	**4.1.D** Gravimetric analysis is a quantitative method for determining the amount of a substance by selectively precipitating the substance from an aqueous solution.

Content Boundary: The focus of predicting products of precipitation reactions is not to have students memorize solubility rules or use a table of solubilities. Instead, students should focus on understanding that all sodium, potassium, ammonium, and nitrate salts are soluble in water.

Cross Connection: Students continue to use principles of stoichiometry learned in Unit 3, now applied to precipitation reactions.

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KEY CONCEPT 4.2: OXIDATION–REDUCTION CHEMISTRY

Analyzing how electron transfer can drive chemical reactions

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
4.2.A.1 Identify a reaction as an oxidation–reduction reaction based on the change in oxidation numbers of reacting substances. **4.2.A.2** Create and/or evaluate a claim about which reacting species is oxidized or reduced in an oxidation–reduction reaction.	**4.2.A** Electrons are transferred between reactants in oxidation–reduction (redox) reactions. **a.** Substances lose electrons in the process of oxidation and gain electrons in the process of reduction. **b.** Oxidation numbers are useful for determining if electrons are transferred in a chemical reaction. **c.** Electrons are conserved in redox reactions.
4.2.B.1 Predict whether a redox reaction will occur between two reactants using an activity series. **4.2.B.2** Create and/or evaluate an activity series from experimental measurements.	**4.2.B** An activity series lists elements in order of decreasing ease of oxidation and can be used to determine whether a redox reaction will occur between two species.
4.2.C.1 Create and/or evaluate models of redox reactions.	**4.2.C** Redox reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

Content Boundary: Oxidation–reduction is a broad classification of reactions, including synthesis, decomposition, and combustion reactions. However, predicting products for oxidation–reduction reactions is limited to single-replacement reactions.

Cross Connection: Students continue to use principles of stoichiometry learned in Unit 3, now applied to oxidation–reduction reactions.

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KEY CONCEPT 4.3: ACID–BASE CHEMISTRY

Examining properties of acids and bases and how proton transfer can drive chemical reactions

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
4.3.A.1 Create and/or evaluate models of strong and weak acids and bases. **4.3.A.2** Distinguish between strong and weak acids in terms of degree of dissociation in aqueous solution. **4.3.A.3** Evaluate a claim about whether a compound is a strong or weak acid or base.	**4.3.A** Acids and bases are described as either strong or weak based on the degree to which they dissociate in aqueous solution.
4.3.B.1 Explain the relationship between the hydrogen ion concentration and the pH of a solution. **4.3.B.2** Calculate the pH of a solution.	**4.3.B** The pH of a solution is a measure of the molarity of H_3O^+ (or H^+) in the solution.
4.3.C.1 Predict the products of a reaction between a strong acid and a strong base.	**4.3.C** Acid–base reactions involve the transfer of a hydrogen ion from the acid to the base. Strong acid–base reactions produce water and an aqueous ionic compound.
4.3.D.1 Create and/or evaluate models of a reaction between a strong acid and a strong base.	**4.3.D** Acid–base reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

Content Boundary: The study of acids and bases is limited to the Arrhenius and Brønsted-Lowry definitions. According to these definitions, strong acids include HCl, HBr, HI, H_2SO_4, $HClO_4$, and HNO_3, and strong bases include group 1 and group 2 metal hydroxides (e.g., NaOH and KOH).

Cross Connection: Students continue to use principles of stoichiometry learned in Unit 3, now applied to acid–base reactions.

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KEY CONCEPT 4.4: THERMOCHEMISTRY

Extending the study of energy by analyzing energy transformations that occur during chemical reactions

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
4.4.A.1 Create and/or evaluate a claim about whether a reaction is endothermic or exothermic from experimental observations. **4.4.A.2** Explain the relationship between the measured change in temperature of a solution and the energy transferred by a chemical reaction. **4.4.A.3** Calculate energy changes in chemical reactions from calorimetry data.	**4.4.A** A temperature change during a reaction is the result of energy transfer during the process of breaking and forming bonds. **a.** Bond breaking is always an endothermic process and bond formation is always an exothermic process. **b.** Calorimetry can be used to quantify energy changes in a reaction.
4.4.B.1 Create and/or evaluate a claim about the energy transferred as a result of a chemical reaction based on bond energies.	**4.4.B** The relative strength of bonds in reactants and products determines the energy change in a reaction. Bond energy tables and Lewis diagrams provide a way to estimate these changes quantitatively for a wide variety of chemical reactions.

Content Boundary: The focus of the study of bond energy should be on the fundamental understanding that bond breaking requires energy and bond formation releases energy rather than on algorithmic calculations.

Cross Connection: Students apply their knowledge of molecular structure from Unit 2 in the study of bond energy.

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KEY CONCEPT 4.5: REACTION RATES

Investigating the factors that influence reaction rates

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
4.5.A.1 Construct and/or evaluate particulate representations that illustrate how changes in concentration, temperature, or surface area of reactants alter the rate of a chemical reaction. **4.5.A.2** Explain how experimental changes in the rate of a reaction are related to changes in the concentration, temperature, or surface area of the reactants.	**4.5.A** The rate of a chemical reaction can be measured by determining how quickly reactants are transformed into products. **a.** The reaction rate is related to the frequency of collisions between reactant species and the proportion of effective collisions. **b.** The frequency of collisions increases with the concentration of gases or dissolved species and with the surface area of a solid. **c.** The proportion of effective collisions increases directly as temperature increases.

Content Boundary: The study of rate laws and mechanisms is beyond the scope of the course. If students go on to take AP Chemistry, they will study kinetics in much more depth.

Cross Connection: The study of reaction rates relies on an understanding of the particle nature of matter that has been developed in Units 1 through 3.

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Pre-AP Chemistry Model Lessons

Model lessons in Pre-AP Chemistry are developed in collaboration with chemistry educators across the country and are rooted in the course framework, shared principles, and areas of focus. Model lessons are carefully designed to illustrate on-grade-level instruction. Pre-AP strongly encourages teachers to internalize the lessons and then offer the supports, extensions, and adaptations necessary to help all students achieve the lesson goals.

The purpose of these model lessons is twofold:

- **Robust instructional support for teachers:** Pre-AP Chemistry model lessons are comprehensive lesson plans that, along with accompanying student resources, embody the Pre-AP approach to teaching and learning. Model lessons provide clear and substantial instructional guidance to support teachers as they engage students in the shared principles and areas of focus.
- **Key instructional strategies:** Commentary and analysis embedded in each lesson highlights not just what students and teachers do in the lesson, but also how and why they do it. This educative approach provides a way for teachers to gain unique insight into key instructional moves that are powerfully aligned with the Pre-AP approach to teaching and learning. In this way, each model lesson works to support teachers in the moment of use with students in their classroom.

Teachers have the option to use any or all model lessons alongside their own locally developed instructional resources. Model lessons target content areas that tend to be challenging for teachers and students. While the lessons are distributed throughout all four units, they are concentrated more heavily in the beginning of the course to support teachers and students in establishing a strong foundation in the Pre-AP approach to teaching and learning.

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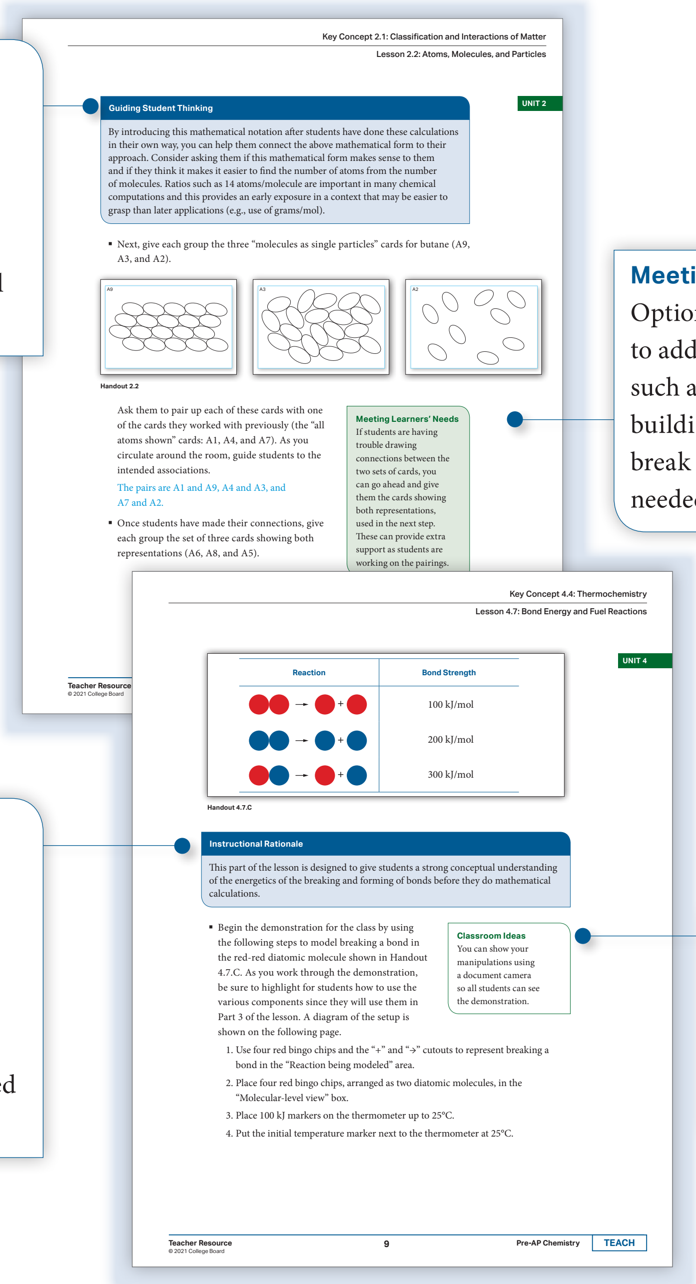
SUPPORT FEATURES IN MODEL LESSONS

The following support features recur throughout the Pre-AP Chemistry lessons, to promote teacher understanding of the lesson design and provide direct-to-teacher strategies for adapting lessons to meet their students' needs:

- Instructional Rationale
- Guiding Student Thinking
- Meeting Learners' Needs
- Classroom Ideas

Guiding Student Thinking:
Ways to facilitate productive student thinking and prevent or address student misconceptions in critical areas of the lesson.

Meeting Learners' Needs:
Optional differentiation strategies to address diverse learning needs, such as ideas for just-in-time skill building during a lesson or ways to break a task into smaller tasks, if needed, to make it more accessible.



Key Concept 2.1: Classification and Interactions of Matter
Lesson 2.2: Atoms, Molecules, and Particles

UNIT 2

Guiding Student Thinking

By introducing this mathematical notation after students have done these calculations in their own way, you can help them connect the above mathematical form to their approach. Consider asking them if this mathematical form makes sense to them and if they think it makes it easier to find the number of atoms from the number of molecules. Ratios such as 14 atoms/molecule are important in many chemical computations and this provides an early exposure in a context that may be easier to grasp than later applications (e.g., use of grams/mol).

- Next, give each group the three "molecules as single particles" cards for butane (A9, A3, and A2).

Handout 2.2

Ask them to pair up each of these cards with one of the cards they worked with previously (the "all atoms shown" cards: A1, A4, and A7). As you circulate around the room, guide students to the intended associations.

The pairs are A1 and A9, A4 and A3, and A7 and A2.

- Once students have made their connections, give each group the set of three cards showing both representations (A6, A8, and A5).

Meeting Learners' Needs
If students are having trouble drawing connections between the two sets of cards, you can go ahead and give them the cards showing both representations, used in the next step. These can provide extra support as students are working on the pairings.

Teacher Resource
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Key Concept 4.4: Thermochemistry
Lesson 4.7: Bond Energy and Fuel Reactions

UNIT 4

Reaction	Bond Strength
	100 kJ/mol
	200 kJ/mol
	300 kJ/mol

Handout 4.7.C

Instructional Rationale

This part of the lesson is designed to give students a strong conceptual understanding of the energetics of the breaking and forming of bonds before they do mathematical calculations.

- Begin the demonstration for the class by using the following steps to model breaking a bond in the red-red diatomic molecule shown in Handout 4.7.C. As you work through the demonstration, be sure to highlight for students how to use the various components since they will use them in Part 3 of the lesson. A diagram of the setup is shown on the following page.
    1. Use four red bingo chips and the "+" and "→" cutouts to represent breaking a bond in the "Reaction being modeled" area.
    2. Place four red bingo chips, arranged as two diatomic molecules, in the "Molecular-level view" box.
    3. Place 100 kJ markers on the thermometer up to 25°C.
    4. Put the initial temperature marker next to the thermometer at 25°C.

Classroom Ideas
You can show your manipulations using a document camera so all students can see the demonstration.

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9
Pre-AP Chemistry
TEACH

Instructional Rationale:
Insight into the strategic design and purpose of the instructional choices, flow, and scaffolding within the model lesson. Rationales often describe how a concept is continued later in the lesson or unit.

Classroom Ideas:
Tips related to the logistics of the instruction, such as suggestions for alternative laboratory materials, or ways to alleviate pacing concerns.

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Pre-AP Chemistry Assessments for Learning

Pre-AP Chemistry assessments function as a component of the teaching and learning cycle. Progress is not measured by performance on any single assessment. Rather, Pre-AP Chemistry offers a place to practice, to grow, and to recognize that learning takes time. The assessments are updated and refreshed periodically.

LEARNING CHECKPOINTS

Based on the Pre-AP Chemistry Course Framework, the learning checkpoints require students to examine data, models, diagrams, and short texts—set in authentic contexts—and to use quantitative reasoning in order to respond to a targeted set of questions that measure students' application of the key concepts and skills from the unit. All eight learning checkpoints are automatically scored, with results provided through feedback reports that contain explanations of all questions and answers as well as individual and class views for educators. Teachers also have access to assessment summaries on Pre-AP Classroom, which provide more insight into the question sets and targeted learning objectives for each assessment event.

The following tables provide a synopsis of key elements of the Pre-AP Chemistry learning checkpoints.

Format	Two learning checkpoints per unit Digitally administered with automated scoring and reporting Questions target both concepts and skills from the course framework
Time Allocated	Designed for one 45-minute class period per assessment
Number of Questions	11–14 questions per assessment ▪ 9–12 four-option multiple choice ▪ 2–5 technology-enhanced questions

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Domains Assessed	
Learning Objectives	Learning objectives within each key concept in the course framework
Skills	Three skill categories aligned to the Pre-AP science areas of focus are assessed regularly across all eight learning checkpoints: ▪ emphasis on analytical reading and writing ▪ strategic use of mathematics ▪ attention to modeling

Question Styles	Question sets consist of two to three questions that focus on a single stimulus or group of related stimuli, such as texts, graphs, or tables. Questions are set in authentic chemistry contexts. *Please see page 51 for a sample question set that illustrates the types of questions included in Pre-AP learning checkpoints and the Pre-AP final exam.*

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PERFORMANCE TASKS

Each unit includes one performance-based assessment designed to evaluate the depth of student understanding of key concepts and skills that are not easily assessed in a multiple-choice format.

Some performance tasks mirror the AP free-response question style. Others engage students in hands-on data collection and analysis in the laboratory. Students demonstrate their understanding of content by analyzing scientific texts, data, and models in order to develop analytical written responses to open-ended questions. Students also use mathematics to support their chemical reasoning.

The performance tasks give students an opportunity to closely observe and analyze real-world chemistry scenarios and apply the skills and concepts from across the course units.

These tasks, developed for high school students across a broad range of readiness levels, are accessible while still providing sufficient challenge and the opportunity to practice the analytical skills that will be required in AP science courses and for college and career readiness. Teachers participating in the official Pre-AP Program will receive access to online learning modules to support them in evaluating student work for each performance task.

Format	One performance task per unit Administered in print Educator scored using scoring guidelines
Time Allocated	Approximately 45 minutes or as indicated
Number of Questions	An open-response task with multiple parts

Domains Assessed	
Key Concepts	Key concepts and prioritized learning objectives from the course framework
Skills	Three skill categories aligned to the Pre-AP science areas of focus: ▪ emphasis on analytical reading and writing ▪ strategic use of mathematics ▪ attention to modeling

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PRACTICE PERFORMANCE TASKS

A practice performance task in each unit provides students with the opportunity to practice applying skills and knowledge in a context similar to a performance task, but in a more scaffolded environment. These tasks include strategies for adapting instruction based on student performance and ideas for modifying or extending tasks based on students' needs.

Performance Assessments At-a-Glance

Unit	Performance Assessment	Title	Teacher Access	Student Access
Unit 3 Chemical Quantities	Practice Performance Task	Molar Challenges	Teacher Resources: Units 3 & 4	Student Resources: Unit 3
	Performance Task	The Chemistry of Respiration		Teacher-distributed handout
Unit 4 Chemical Transformations	Practice Performance Task	Reactions of Copper and Aluminum	Teacher Resources: Units 3 & 4	Student Resources: Unit 4
	Performance Task	Applications of Chemical Transformations		Teacher-distributed handout

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FINAL EXAM

Pre-AP Chemistry includes a final exam featuring multiple-choice and technology-enhanced questions as well as an open-response question. The final exam is a summative assessment designed to measure students' success in learning and applying the knowledge and skills articulated in the Pre-AP Chemistry Course Framework. The final exam's development follows best practices such as multiple levels of review by educators and experts in the field for content accuracy, fairness, and sensitivity. The questions on the final exam have been pretested, and the resulting data are collected and analyzed to ensure that the final exam is fair and represents an appropriate range of the knowledge and skills of the course.

The final exam is designed to be delivered on a secure digital platform in a classroom setting. Educators have the option of administering the final exam in a single extended session or two shorter consecutive sessions to accommodate a range of final exam schedules.

Multiple-choice and technology-enhanced questions are delivered digitally and scored automatically with detailed score reports available to educators. This portion of the final exam is designed to build on the question styles and formats of the learning checkpoints; thus, in addition to their formative purpose, the learning checkpoints provide practice and familiarity with the final exam. The open-response question, modeled after the performance tasks, is delivered as part of the digital final exam but is designed to be scored separately by educators using scoring guidelines that are designed and vetted with the question.

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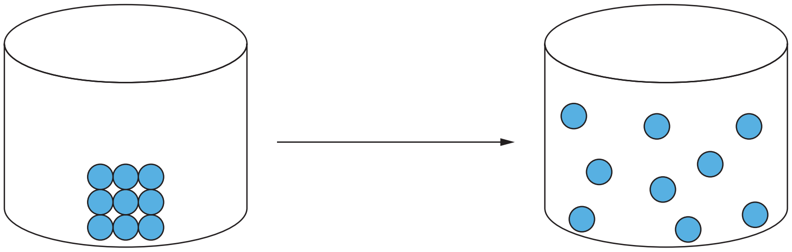
SAMPLE ASSESSMENT QUESTIONS

The following questions are representative of what students and educators will encounter on the learning checkpoints and final exam.

1.



A student places 2.0 g of an unknown substance in a sealed container with no other contents. The student observes the container for 10 minutes and then draws the two particle diagrams shown to represent his observations of the initial and final states.

Which of the following descriptions of the observed change is most consistent with the model?

(A) The unknown substance underwent a phase change from solid to liquid and the mass at the end of the experiment was 2.0 g.

(B) The unknown substance underwent a phase change from solid to liquid and the mass at the end of the experiment was 1.5 g.

(C) The unknown substance underwent a phase change from solid to gas and the mass at the end of the experiment was 2.0 g.

(D) The unknown substance underwent a phase change from solid to gas and the mass at the end of the experiment was 1.5 g.

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Assessment Focus

Question 1 requires students to interpret a model of a phase change from solid to gas and to reason based on their understanding of the conservation of mass.

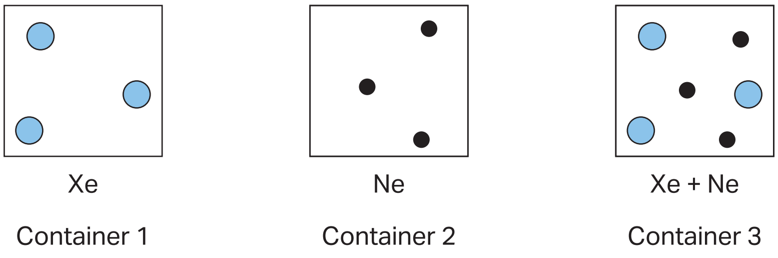
Correct Answer: C

Learning Objective:

1.1.A.2 Describe how the properties of solids, liquids, and gases are related to particle arrangement.

Area of Focus: Attention to Modeling

2.



The figure represents three containers of equal volume at the same temperature, each containing a different gas or mixture of gases.

Which TWO statements best describe the pressure in the containers?

(A) The pressure in Container 1 is greater than the pressure in Container 2 because the Xe atoms are larger than Ne atoms.

(B) The pressure in Container 1 is equal to the pressure in Container 2 because they have the same number of atoms.

(C) The pressure in Container 3 is twice the pressure in Container 2 because Container 3 has twice the number of atoms.

(D) The pressure in all three containers is the same because the containers are at the same temperature.

(E) The pressure in all three containers is the same because the containers have the same volume.

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Assessment Focus

In question 2, students use a model to describe the relationship between the quantity of a gas, or mixture of gases, and the resulting pressure. The question assesses students' understanding of partial pressure and the effect of temperature and volume on gas pressure. This question also demonstrates the multiple-select question type that students will encounter in learning checkpoints and the final exam.

Correct Answers: B and C

Learning Objective:

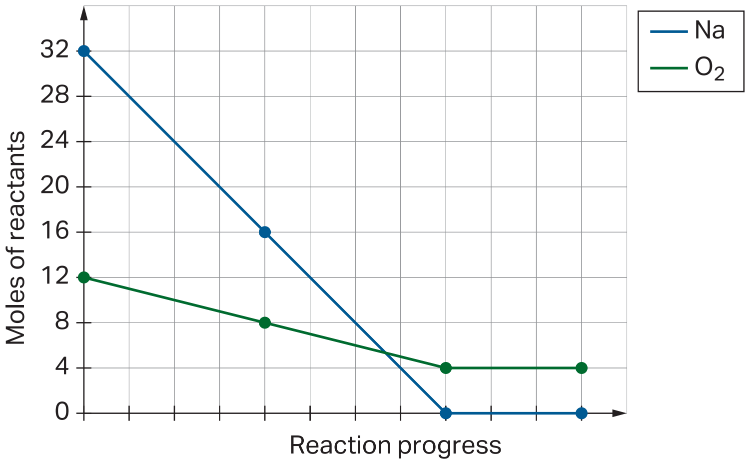
2.1.C.1 Relate the total and partial pressure of a gas mixture to the number of particles and their proportions.

Area of Focus: Attention to Modeling

3.

$$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$$

Sodium oxide is produced by the reaction of sodium metal with oxygen gas. The reaction is represented by the chemical equation above. A chemical reaction is set up with 32 moles of Na and 12 moles of O_2 in a reaction vessel. As the reaction proceeds to completion, the number of moles of Na and O_2 are monitored and plotted on a graph as shown in the figure.



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Which of the following best explains the steeper slope of the line that represents moles of Na compared to the line that represents moles of O_2?

(A) The initial mass of Na is greater than the initial mass of O_2.

(B) For every mole of O_2 consumed in the reaction, 4 moles are Na are needed.

(C) The mass of 4 Na atoms is greater than the mass of 1 O_2 molecule.

(D) The initial number of moles of Na is greater than the initial number of moles of O_2.

Assessment Focus

In question 3, students analyze data about the rate at which reactants in a chemical reaction are used and explain the difference based on the stoichiometry of the balanced chemical equation. All four multiple-choice options are correct statements, but only option B provides an explanation for the difference in slope.

Correct Answer: B

Learning Objective:

3.2.B.1 Explain the relationship between the quantity of reactants consumed and the quantity of products formed in a chemical transformation.

Area of Focus: Strategic Use of Mathematics

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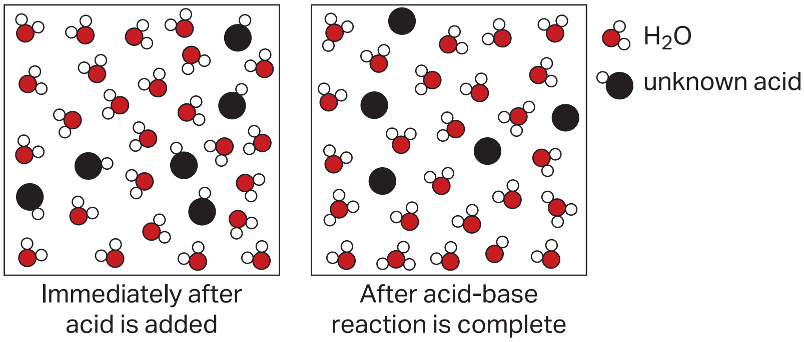
4.



The figure shows particle diagrams representing a 13*M* solution of an unknown acid after the acid was added to water.

Based on the particle diagrams, which of the following claims about the unknown acid is most likely correct?

(A) The acid is strong because there are 13 moles of acid in every liter of water.

(B) The acid is strong because all the acid molecules dissociate in solution.

(C) The acid is weak because it produces only one hydronium ion per acid molecule in solution.

(D) The acid is weak because there are fewer acid molecules than water molecules in the solution.

Assessment Focus

In question 4, students evaluate a model of a dissociated acid and use the model to support a claim about the strength of the acid. The question is designed to address the common challenge students have in distinguishing between strong acids and concentrated acids.

Correct Answer: B

Learning Objectives:

4.3.A.1 Create and/or evaluate models of strong and weak acids and bases.

4.3.A.2 Distinguish between strong and weak acids in terms of degree of dissociation in aqueous solution.

Area of Focus: Attention to Modeling

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Pre-AP Chemistry Course Designation

Schools can earn an official Pre-AP Chemistry course designation by meeting the requirements summarized below. Pre-AP Course Audit Administrators and teachers will complete a Pre-AP Course Audit process to attest to these requirements. All schools offering courses that have received a Pre-AP Course Designation will be listed in the Pre-AP Course Ledger, in a process similar to that used for listing authorized AP courses.

PROGRAM REQUIREMENTS

- The school ensures that Pre-AP frameworks and assessments serve as the foundation for all sections of the course at the school. This means that the school must not establish any barriers (e.g., test scores, grades in prior coursework, teacher or counselor recommendation) to student access and participation in the Pre-AP Chemistry coursework.
- Teachers have read the most recent *Pre-AP Chemistry Course Guide*.
- Teachers administer each performance task and at least one of two learning checkpoints per unit.
- Teachers and at least one administrator per site complete a Pre-AP Summer Institute or the Online Foundational Module Series. Teachers complete at least one Online Performance Task Scoring Module.
- Teachers align instruction to the Pre-AP Chemistry Course Framework and ensure their course meets the curricular requirements summarized below.
- The school ensures that the resource requirements summarized below are met.

CURRICULAR REQUIREMENTS

- The course provides opportunities for students to develop understanding of the Pre-AP Chemistry key concepts and skills articulated in the course framework through the four units of study.
- The course provides opportunities for students to engage in the Pre-AP shared instructional principles.
    - close observation and analysis
    - evidence-based writing
    - higher-order questioning
    - academic conversation

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- The course provides opportunities for students to engage in the three Pre-AP science areas of focus. The areas of focus are:
  - emphasis on analytical reading and writing
  - strategic use of mathematics
  - attention to modeling
- The instructional plan for the course includes opportunities for students to continue to practice and develop disciplinary skills.
- The instructional plan reflects time and instructional methods for engaging students in reflection and feedback based on their progress.
- The instructional plan reflects making responsive adjustments to instruction based on student performance.

RESOURCE REQUIREMENTS

- The school ensures that participating teachers and students are provided computer and internet access for completion of course and assessment requirements.
- Teachers should have consistent access to a video projector for sharing web-based instructional content and short web videos.
- The school ensures teachers have access to laboratory equipment and consumable resources so that students can engage in the Pre-AP Chemistry inquiry-based model lessons.

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Accessing the Digital Materials

Pre-AP Classroom is the online application through which teachers and students can access Pre-AP instructional resources and assessments. The digital platform is similar to AP Classroom, the online system used for AP courses.

Pre-AP coordinators receive access to Pre-AP Classroom via an access code delivered after orders are processed. Teachers receive access after the Pre-AP Course Audit process has been completed.

Once teachers have created course sections, student can enroll in them via access code. When both teachers and students have access, teachers can share instructional resources with students, assign and score assessments, and complete online learning modules; students can view resources shared by the teacher, take assessments, and receive feedback reports to understand progress and growth.

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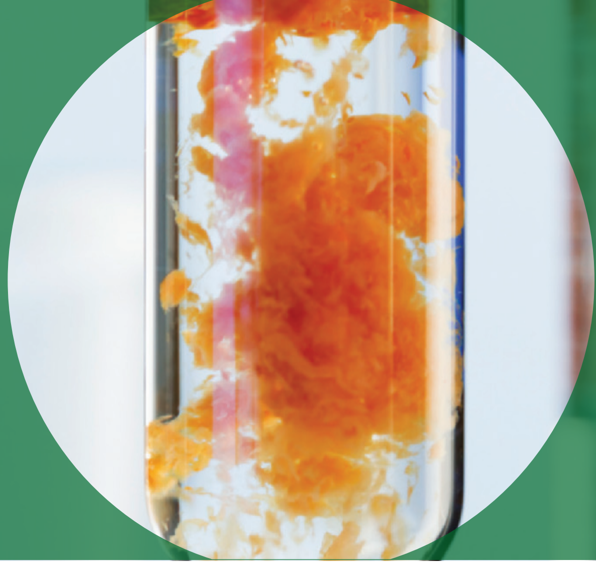
Unit 3

Unit 3
Chemical Quantities



Overview

SUGGESTED TIMING: APPROXIMATELY 6 WEEKS

This unit explores chemical transformations of matter by building on the physical transformations studied in Units 1 and 2. Leveraging what has been learned about particles in Units 1 and 2, this unit introduces students to the importance of the mole concept for collecting data about particles and chemical reactions. Since chemistry deals with large numbers of particles, students are introduced to the idea of counting by weighing. To reinforce the particle nature of matter studied in Units 1 and 2, students use particulate representations of reactions to connect the amount of reactant consumed and the amount of product formed to the rearrangement of particles on the molecular level. Students will also use balanced chemical equations and mathematics to reason about amounts of reactants and products in chemical reactions.

ENDURING UNDERSTANDINGS

This unit focuses on the following enduring understandings:

- The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.
- In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.

KEY CONCEPTS

This unit focuses on the following key concepts:

- 3.1: Counting Particles in Substances
- 3.2: Counting Particles in Chemical Reactions

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UNIT 3

UNIT RESOURCES

The tables below outline the resources provided by Pre-AP for this unit.

Lessons for Key Concept 3.1: Counting Particles in Substances				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
3.1: Relative Mass and the Mole	3.1.A.1, 3.1.A.2	3.1.A.a, 3.1.A.b	~105 minutes	Attention to Modeling, Strategic Use of Mathematics
3.2: Moles, Molecules, and Mass Card Sort	3.1.A.1, 3.1.A.2	3.1.A.a, 3.1.A.b	~45 minutes	Strategic Use of Mathematics

The following Key Concept 3.1 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: 3.1.B.1, 3.1.B.2, 3.1.B.3
- Essential Knowledge Statements: 3.1.B.a, 3.1.B.b, 3.1.B.c

Practice Performance Task for Unit 3 (~45 minutes)
This practice performance task assesses learning objectives and essential knowledge statements addressed up to this point in the unit.

Learning Checkpoint 1: Key Concept 3.1 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements for Key Concept 3.1. For sample items and learning checkpoint details, visit Pre-AP Classroom.

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Lessons for Key Concept 3.2: Counting Particles in Chemical Reactions				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
3.3: Candy That Pops – A Stoichiometry Lab	3.1.A.2, 3.2.A.1, 3.2.B.2, 3.2.D.1	3.1.A.b, 3.2.A.a, 3.2.A.b, 3.2.B, 3.2.D	~105 minutes	Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing
3.4: Limiting Reactants	3.2.C.1	3.2.C	~45 minutes	Attention to Modeling, Strategic Use of Mathematics

The following Key Concept 3.2 learning objective is not addressed in Pre-AP lessons. Address this in teacher-developed materials.

- Learning Objectives: 3.2.B.1

Learning Checkpoint 2: Key Concept 3.2 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concept 3.2. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 3 (~45 minutes)

This performance task assesses learning objectives and essential knowledge statements from the entire unit.

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LESSON 3.1

Relative Mass and the Mole

UNIT 3

OVERVIEW

LESSON DESCRIPTION

Part 1: Using Relative Mass

In this part of the lesson, students explore the concept of relative mass by constructing a table to calculate the relative masses of two sizes of beads. They explore relative mass using a balance and discover that the number of beads required to produce this mass is the same regardless of which type of bead is used. Students then use this idea to group beads in subsequent questions.

Part 2: Relative Mass, the Periodic Table, and the Mole

The concept of relative mass is extended to the periodic table, where students examine the masses of various elements and compounds. Using only relative masses determined from the periodic table, students rank which given samples contain more particles. Students then "group" particles, calling the number of particles in a relative mass a *mole*. Finally, they calculate and compare the number of moles of each element or compound presented to verify that working with units of moles is simpler than and consistent with their earlier calculations.

CONTENT FOCUS

This lesson introduces and reinforces the idea that atomic masses are relative and allows students to see the utility of counting by weighing, using the mole. Since the mole is an abstract concept, grounding it with comparisons to mass and macroscopic observations makes it more concrete for students. This exercise is

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~105 minutes

HANDOUTS

- 3.1.A: Measuring Relative Mass
- 3.1.B: Relative Mass and the Mole

MATERIALS

For each student group:

- beads of two different sizes and masses (100 of each size per group)
- additional 200–600 large beads
- balance that measures in increments of at least 0.1 gram
- 2 cups or 2 beakers
- opaque containers with lids (for the additional large beads)
- periodic table

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the introduction to the idea of counting particles by weighing and sets the stage for the introduction of the mole.

Students then turn their focus to the periodic table, exploring how to use the atomic masses given in the table to investigate three elements and several compounds that can be made from them. The conceptual nature of the introduction to the mole sets students up for success later in the course when they'll use molar mass and mole ratios in calculations and when representing reactions using particle diagrams.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.	
Learning Objectives	**Essential Knowledge**
3.1.A.1 Explain the relationship between the mass of a substance, the number of particles of that substance, and the number of moles of that substance. **3.1.A.2** Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **a.** A mole of a substance contains Avogadro's number (6.02×10^{23}) of particles. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.

SETUP AND PREPARATION NOTES

- For the first part of the lesson, each group will need 200 beads—100 each of two different sizes and masses.
- For the relative mass section of the lesson you will need to set up a few containers that students can't see inside of for the larger beads. You could use coffee cups with lids or small boxes with lids. Be sure to write the mass of each empty container on its side. Rather than taking the time to set up different containers with unknown contents for each group, you could just make a few containers for groups to share. You will want to test this part of the lesson with the beads you have in order to set a reasonable error range for student answers to be evaluated as correct.
- Although beads work well in this lesson, you could use any two sets of objects whose masses are consistent within each set, but are significantly different between objects of different sets. For example, two types of beans may work well. However, there will be more variation between masses of beans than there would be with beads.

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PART 1: USING RELATIVE MASS

This part of the lesson provides a crucial introduction to the concept of the *mole* that students will use for the remainder of this course. Students are introduced to the idea of relative mass, grouping objects, and counting by weighing using two sizes of beads. They then learn to convert between relative mass and actual mass by determining the numbers of beads that need to be placed on a balance to obtain the relative mass. The key takeaway for this part of the lesson is that each relative mass, when weighed in grams, contains equal numbers of beads. Students then use this concept to group beads in subsequent questions.

- Ask students to locate **Handout 3.1.A: Measuring Relative Mass** and have them work in small groups to follow the steps of the procedure that it details.
- The experimental part of this lesson is largely self-directed, but caution students to make sure they are weighing exactly 100 beads of each size, as miscounting will skew the results.

Guiding Student Thinking

You may need to spend some time with students on the concept of relative mass. A simple calculation that can help students understand the concept requires weighing two different objects on a balance and comparing their weights in two different units, such as pounds and kilograms. Show that although the masses have different values within each unit of measurement, the ratio of the masses of one object to the other is the same. This ratio defines the relative mass of the heavier object to the lighter object.

- When students get to step 9 of the procedure and have selected a claim with their group, you could stop for a brief whole-class discussion and ask groups to share their justifications.
- During step 10 students will likely be surprised that the same number of objects make up the relative mass for each type of object. The analysis questions that follow confirm this result and support this critical conclusion.
- Circulate around the room as groups answer the analysis questions after building the table of relative masses. To support the idea that a group is not limited to just beads (or later atoms or molecules), you can ask questions such as "How many pencils are in a group of pencils?"

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Guiding Student Thinking

Many students will want to think about mass *per bead*, and the data in the table certainly allows students to answer the question that way. However, strongly encourage students to think about the mass *per group* as this significantly foreshadows the mole concept that is the focus of the rest of this and many subsequent lessons.

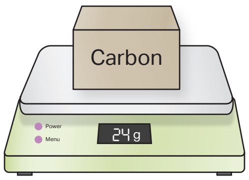
- For analysis question 6, each group will need an additional container of an unknown number of large beads you have prepared.

PART 2: RELATIVE MASS, THE PERIODIC TABLE, AND THE MOLE

This part of the lesson expands on students' work in Part 1 by having them measure groups of particles using units of moles. The goal of this part of the lesson is for students to become proficient in relating the mass of a sample of an element or compound to the number of particles in that sample. Using only relative masses from the periodic table, they rank which given samples contain more particles. The focus is on having students develop a conceptual definition of the mole as opposed to just telling them the relationship between moles and molar mass.

- Begin this part of the lesson by posing the following scenario to students.

Imagine that you have a "massless" box on a balance, and you put carbon atoms in it until the mass on the balance reads 24 g, as shown.



- Ask students to determine the number of carbon atoms in the box, based on their work with the beads earlier in the lesson. Show students the five claims below and ask them to discuss in groups which claim they think best describes the situation. Each group should write a brief statement justifying the claim they choose.

  (a) There is 1 atom in the box.

  (b) There are 12 atoms in the box.

  (c) There are 24 atoms in the box.

  (d) There are 2 atoms in the box.

  (e) There is no way to tell the number of atoms in the box.

- After all groups have had time to discuss the claims and write their justifications, ask each group to share which claim they chose and their justification for it.

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Instructional Rationale

Many students will believe they can determine the number of atoms directly just from the mass on the scale and the periodic table alone, without "bundling" the atoms in groups (i.e., moles). During this lesson, students first use relative mass data to rank numbers of particles in different samples. Then students redo these calculations with the mole concept, observing that it is an easier way to draw the same conclusions.

- Next, have students find **Handout 3.1.B: Relative Mass and the Mole**. Guide them on how to calculate the table of relative masses for carbon, oxygen, and fluorine. As with the beads, it is best to rescale the masses to the lightest element, in this case carbon, giving it a relative mass of 1. Explain that the masses of the other elements are then expressed relative to the mass of carbon.
- Six different scenarios are then presented for which students need to rank the number of particles represented by each mass. Have students work with a partner on each of the scenarios.
- Here is some guidance for several of the questions:
  - Question 2: It might be best to work through this question as a class, as there are many ways students could make comparisons via relative masses. The most straightforward way is to "rescale" the relative mass table, setting carbon to 24. On such a table oxygen would then be $24 \times 1.33 = 32$. Thus, one would need 32 g of oxygen to have the same number of particles as 24 g of carbon. Since there are only 18 g of oxygen in the sample, the number of particles of carbon is greater than the number of particles of oxygen.
  - Questions 3–4: These questions are designed to illustrate that equal numbers of grams are not equivalent to equal numbers of particles (question 3) and that specific sets of masses of substances could contain the same number of particles (question 4). For these questions, you could ask each pair to determine their ranking

Classroom Ideas

Rather than writing on the handout, students could do their initial work on whiteboards using dry-erase markers, or even on the lab desks using neon dry-erase markers since both are easily erasable. This allows for revision as students gain new insights and understanding about relative mass. Because whiteboards and the table feel less permanent, students may be more likely to take a chance on being incorrect. Once groups have discussed and made revisions, they can record the information on their handout.

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and justification, and then join two sets of student pairs to make small groups and allow them to discuss the rankings and justifications they decided on. After the discussion, groups should make revisions to their rankings and justifications.

- Depending on how confident your students are with question 3, you may want to have a quick whole-class debrief.

Instructional Rationale

Having students discuss their answers first with a partner and then with a larger group lets them wrestle with the content in order to deepen their understanding. This peer-to-peer dialogue allows students to refine their thinking in a low-stakes environment.

- Question 5: This question introduces the concept of the relative mass of a compound. Before having students answer question 5, it would be best to bring small groups back together to discuss how to determine this value. As the mass of a compound is just the sum of the masses of its constituent elements, it should be very straightforward to calculate the relative mass of CO as $\frac{28}{12} = 2.33$ times the relative mass of carbon. You could display this information in a table similar to the one on the bottom of the first page of Handout 3.1.B.

Substance	Mass of Substance Relative to Carbon
C	1.00
CO	2.33

As with questions 3 and 4, allow students to first work with a partner, then with groups made up of two student pairs. You can have a whole-class discussion if you feel it is necessary based on your observations of the group discussions.

Classroom Ideas

You could have student pairs post their final claims and justifications on poster paper around the room and conduct a gallery walk to examine the answers. Students could use markers to put check marks next to claims, using green markers for claims they agree with, red markers for claims they disagree with, and yellow markers for claims they're unsure about. The whole-class discussion can center on these statements, and students can discuss the reasoning for their check marks.

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UNIT 3

Guiding Student Thinking

When calculating various relative masses, it can be beneficial to set up a table that allows students to see the masses of substances relative to carbon for different masses of carbon. For example:

Relative Mass of Carbon	Relative Mass of CO	Ratio of Mass of CO to Mass of C
1	2.33	2.33
10	23.3	2.33
12	28	2.33
50	116.5	2.33

This quickly allows students to see that, regardless of the initial mass of carbon, a mass of C multiplied by 2.33 gives a mass of CO that contains the same number of particles as the mass of carbon.

- Questions 6–7: These questions allow for additional practice with the relative mass of compounds. Continue the process of having students work with partners and then in small groups, checking in with the whole class as necessary.

- After these six questions, students should understand the process of comparing numbers of particles, but they may find it tedious. Explain to students that they can use the results of the bead experiment to come up with an easier process. Point out that since the masses on the periodic table are relative, the number of atoms in 12 g of carbon **must** be the same as the number of atoms in 16 g of oxygen or 19 g of fluorine. We may not be able to count that number directly, but we know they are the same and can bundle the particles accordingly. Explain to students that this is what a *mole* is: the number of particles that, when placed on a balance, will have a mass equal to the relative mass in grams. This mass is called the *molar mass*. The following paragraph from Part 2 of Handout 3.1.B emphasizes this for students.

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PART 2: THE MOLE

Although the relative masses given in the periodic table can be used to rank the numbers of particles in samples of elements and compounds, comparing masses in this way can be cumbersome. Fortunately, there is another way to make this comparison. Recall the critical conclusion from our bead activity: when we weighed out the relative mass of each type of bead in grams on the balance, **the same number of beads was needed** (which we called a group). This relationship must also hold for atoms, as **a relative mass of any element as shown on the periodic table and expressed in grams contains the same number of atoms**. Consequently, 24.30 grams of magnesium contain the same number of atoms as 207.2 g of lead, 12.01 g of carbon, and 4.00 g of helium. This number of atoms is called the *mole*.

Handout 3.1.B

- Show students where to find the atomic mass of each element on a periodic table, and explain how it corresponds to its molar mass. Then ask them to determine how much of each element listed in question 8 they would have to weigh out to have a mole of each.
- Next, have students answer question 9, determining the molar masses of the elements and compounds listed in the table.
- Questions 10 and 11 ask students to determine the number of moles of each element present on the balances that were shown in questions 2 and 3. Before letting students work on these questions, you may want to guide them through a sample calculation for the number of moles of carbon.

Guiding Student Thinking

Students may not see the value in always showing their work to determine the number of moles since the values used in some of the questions on the handout are round numbers. Encourage them to get into the habit of being systematic about their work, perhaps by discussing dimensional analysis, so they are prepared to tackle more complicated questions in the future.

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- The scenarios in questions 10–13 are the same as the ones in questions 2–4 and 6. The purpose of having students do these calculations is so they can compare the processes of using relative mass and using molar mass to rank how many of each kind of particle is present. As students work, circulate to check their work and ask them to compare their values for moles with their rankings of the numbers of particles. For this exercise, encourage students to use the whole number values given on the portion of the periodic table printed on their handout, rather than the exact values given on the full periodic table. The simpler numbers will allow students to focus on the process rather than the numbers.
- Finally, have students decide which process they think is easier for ranking the number of particles: using relative masses or using molar masses. You can end the lesson by asking a few students to share which method they prefer and why.

Meeting Learners' Needs

Students are only asked to calculate the number of moles of each substance for the scenarios in questions 2–4 and 6. If your students need additional practice, you can ask them to determine the number of moles of each substance in questions 5 and 7 as well.

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ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 3.1.A: Measuring Relative Mass

Procedure

Answers will vary depending on the masses of each bead type and container selected. Answers are based on sample data.

For answers to questions 2, 4–6, 8, and 10, see the table below under *Data*.

7. Relative mass of small bead: $\frac{0.0890 \text{ g}}{0.0890 \text{ g}} = 1.00$

   Relative mass of large bead: $\frac{0.2460 \text{ g}}{0.0890 \text{ g}} = 2.76$

9. Answers will vary as some students may believe that the number of large beads will be greater because the mass is greater.

Data

	Small Beads	Large Beads
Mass of empty cup (g)	2.50	2.50
Mass of cup with 100 beads (g)	11.40	27.10
Mass of 100 beads (g)	8.90	24.60
Mass of one bead (g)	0.0890	0.2460
Relative mass of a bead	1.00	2.76
Number of beads in a relative mass	11–12	11–12

Analysis

1. The number of beads in each case is the same or within the same range of beads (to within the precision of the balance).
2. From the sample data above, a group would be defined as 11–12 small beads.
3. The student has either 275 or 300 large beads.

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If there are 11 large beads in a group, the student would have

$$25 \text{ groups} \times \frac{11 \text{ beads}}{1 \text{ group}} = 275 \text{ beads}$$

If there are 12 large beads in a group, the student would have

$$25 \text{ groups} \times \frac{12 \text{ beads}}{1 \text{ group}} = 300 \text{ beads}$$

4. The student has between 125 and 136 groups.

$$1{,}500 \text{ beads} \times \frac{1 \text{ group}}{11 \text{ beads}} = 136.4 \text{ groups} = 136 \text{ groups}$$

You can only have a whole number so it's best to round to the nearest bead.

$$1{,}500 \text{ beads} \times \frac{1 \text{ group}}{12 \text{ beads}} = 125 \text{ groups}$$

5. There are two possible ways to calculate this:

$$5.3 \text{ groups} \times \frac{11 \text{ beads}}{1 \text{ group}} \times \frac{0.0896 \text{ g}}{1 \text{ bead}} = 5.2 \text{ g}$$

or

$$5.3 \text{ groups} \times \frac{1 \text{ g}}{1 \text{ group}} = 5.3 \text{ g}$$

6. Answers will vary depending on the number of beads in the container. The successful student will weigh the container with the beads and then subtract the mass of the empty container to get the mass of the beads themselves. These can be easily "grouped" using the group mass, and the number of groups can then by multiplied by the number in each group to obtain the total number of beads in the container. For example:

Mass of empty container: 2.50 g

Mass of container with large beads: 16.30 g

Mass of large beads: 13.80 g

Number of groups: $13.80 \text{ g} \times \frac{1 \text{ group}}{2.76 \text{ g}} = 5 \text{ groups}$

Number of large beads: $5 \text{ groups} \times \frac{11 \text{ beads}}{1 \text{ group}} = 55 \text{ beads}$

or

$$5 \text{ groups} \times \frac{12 \text{ beads}}{1 \text{ group}} = 60 \text{ beads}$$

There are between 55 and 60 beads in the container.

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7. (a) 11–12

   (b) Since the relative mass is 4 times that of a large bead, the mass of a group of extra-large beads would be 4 times the mass of a group of large beads as well. Using the sample data above, $4 \times 2.76\ \text{g} = 11.0\ \text{g}$.

Handout 3.1.B: Relative Mass and the Mole

1.

Element	Mass of Element Relative to Carbon
Carbon	1.00
Oxygen	1.33
Fluorine	1.58

Relative mass of carbon: $\frac{12}{12} = 1.00$

Relative mass of oxygen: $\frac{16}{12} = 1.33$

Relative mass of fluorine: $\frac{19}{12} = 1.58$

2. C > O

   With a mass of 24 g for carbon, you would need $24 \times 1.33 = 32$ g of oxygen for the number of particles to be the same. Because there are only 18 g of oxygen, the number of particles of carbon is greater.

3. C > O > F

   Oxygen has 1.33 times the relative mass of carbon, and fluorine has 1.58 times the relative mass of carbon, so if you have 15 g of carbon, you would need $15 \times 1.33 = 20$ g of oxygen and $15 \times 1.58 = 24$ g of fluorine to have equal numbers of particles of each. Therefore, the number of carbon particles is the greatest. Fluorine has a greater relative mass than oxygen, so with equal masses there are more oxygen atoms than fluorine atoms. Thus, C > O > F.

4. F > C = O

   Oxygen has 1.33 times the relative mass of carbon, so $6 \times 1.33 = 8$ g means the number of oxygen atoms equals the number of carbon atoms in these samples. Fluorine has 1.58 times the relative mass of carbon, so $6 \times 1.58 = 9.5$ g means the number of fluorine atoms is greater than the number of carbon atoms in these samples. Therefore, F > C = O.

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5. $CO > C$

   A CO molecule has 2.33 times the relative mass of a carbon atom. Thus, for 25 g of carbon, one would need $25 \times 2.33 = 58.3$ g of CO to have the same number of particles. Because 75 g is larger than this mass, there are more CO molecules than carbon atoms in these samples.

6. $CO > CF_4$

   A CF_4 molecule has a relative mass approximately 3.14 times that of a CO molecule, so for 85 g of CO one would need $85 \times 3.14 = 267$ g of CF_4 for the two samples to have the same number of particles. Since 125 g is much less than 267 g, the number of particles in the CO sample is greater than the number of particles in the CF_4 sample.

7. $CO_2 > COF_2 > CF_4$

   From the relative masses, a COF_2 molecule has 1.5 times the relative mass of a CO_2 molecule, and CF_4 has 2 times the relative mass of a CO_2 molecule. For 55 g of CO_2, there would need to be 82.5 g of COF_2 and 110 g of CF_4 for them to have the same number of particles. Since the masses of both of the other compounds are less than these values, the CO_2 sample has the greatest number of particles. Comparing COF_2 and CF_4, CF_4 has 1.33 the relative mass of COF_2, so for 65 g of COF_2 there would have to be 86.5 g of CF_4 to have the same number of particles. Thus, the COF_2 sample contains slightly more particles than the CF_4 sample.

8. 20.18

   40.08

   22.99

   39.10

9.

Substance	Molar Mass (g/mol)
C	12.01
O	16.00
F	19.00
CO	28.01
CO_2	44.01
CF_4	88.01
COF_2	66.01

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10. $\text{mol C} = 24\text{ g} \times \dfrac{1\text{ mol}}{12\text{ g}} = 2\text{ mol C}$

    $\text{mol O} = 18\text{ g} \times \dfrac{1\text{ mol}}{16\text{ g}} = 1.1\text{ mol O}$

11. $\text{mol C} = 15\text{ g} \times \dfrac{1\text{ mol}}{12\text{ g}} = 1.3\text{ mol C}$

    $\text{mol O} = 15\text{ g} \times \dfrac{1\text{ mol}}{16\text{ g}} = 0.94\text{ mol O}$

    $\text{mol F} = 15\text{ g} \times \dfrac{1\text{ mol}}{19\text{ g}} = 0.79\text{ mol F}$

12. $\text{mol C} = 6\text{ g} \times \dfrac{1\text{ mol}}{12\text{ g}} = 0.5\text{ mol C}$

    $\text{mol O} = 8\text{ g} \times \dfrac{1\text{ mol}}{16\text{ g}} = 0.5\text{ mol O}$

    $\text{mol F} = 12\text{ g} \times \dfrac{1\text{ mol}}{19\text{ g}} = 0.63\text{ mol F}$

13. $\text{mol CF}_4 = 125\text{ g} \times \dfrac{1\text{ mol}}{88\text{ g}} = 1.4\text{ mol CF}_4$

    $\text{mol CO} = 85\text{ g} \times \dfrac{1\text{ mol}}{28\text{ g}} = 3.0\text{ mol CO}$

14. Yes. In all cases the substance with the greater number of moles had the greater number of particles. Using molar masses is easier because rather than comparing one substance to another using ratios, you can just use the values from the periodic table.

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LESSON 3.2

UNIT 3

Moles, Molecules, and Mass Card Sort

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Ranking Mass and Molecules
Students calculate molar masses for three hydrocarbons and then rank the masses and numbers of molecules in equimolar samples.

Part 2: Moles, Molecules, and Mass Card Sort Game
Students play a game in which they rank different quantities of three hydrocarbons in terms of total mass, mass of individual elements, number of particles, number of atoms of individual elements, number of moles, or number of moles of individual elements.

Part 3: Synthesis and Discussion
Students work with partners to answer synthesis questions; a whole-class discussion follows.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 3.2.A: Ranking Moles, Molecules, and Mass
- 3.2.B: Moles, Molecules, and Mass Cards (with cards cut out, one set for each student pair)

MATERIALS

For each student:

- periodic table
- calculator

CONTENT FOCUS

This lesson uses ranking tasks to promote conceptual understanding of the mole and how it connects the particulate and macroscopic scales. In Part 1, students are given three quantities of a hydrocarbon reported in different units (e.g., 12 grams CH_4, 2 moles C_3H_8, and 8 molecules C_2H_2), which they rank using a different unit of measure, such as total mass or total number of hydrogen atoms. This encourages quantitative and proportional reasoning, rather than reliance on algorithmic routines that simply convert quantities between units of grams, moles, and molecules. The use of easily divisible numbers helps students understand the proportional relationships involved before they are confronted with data that are not easily manipulated without the use of a calculator.

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UNIT 3

Part 2 of the lesson has students rank quantities in a card-sorting game, offering a fun way to practice working with the relationships between moles, molecules, and mass. Part 3 involves a discussion that requires students to explain both how the mole is used to relate particulate and macroscopic quantities, and how it can be used to compare amounts of different substances to each other.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.	
Learning Objectives	**Essential Knowledge**
3.1.A.1 Explain the relationship between the mass of a substance, the number of particles of that substance, and the number of moles of that substance. **3.1.A.2** Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **a.** A mole of a substance contains Avogadro's number (6.02×10^{23}) of particles. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.

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PART 1: INTRODUCTION TO RANKING MASS AND MOLECULES

Students calculate molar masses for three hydrocarbons and then rank the masses and numbers of molecules in equimolar samples. This initial set of questions introduces students to ranking and familiarizes them with the three substances that will be used throughout the lesson.

- To begin the lesson, ask students to work on their own to complete Part 1 of **Handout 3.2.A: Ranking Moles, Molecules, and Mass**. They should use a copy of the periodic table and a calculator to answer question 1. For questions 2 and 3, you may want to let students know that some samples may be equal in value.
- Next, have students work in groups of two or three and discuss their answers, attempting to reach a consensus.

Meeting Learners' Needs
A common practice in ranking task responses is to use the greater than, less than, and equals symbols to communicate the relationships between items. If you think students are likely to encounter this notation in the future, you may want to instruct them to practice using it here.

Guiding Student Thinking

As students discuss their solutions to question 2, encourage them to think about how it is possible to rank the samples without calculating the mass of each sample. Ideally students will recognize that the sample with the largest mass per mole must have the greatest mass, and therefore molar mass can be used to compare the relative masses of equimolar samples.

If students are struggling with question 3, ask them how the numbers of molecules in the samples compare to get them to see that all three samples have the same number of molecules.

- Once students have had time to discuss their answers within their small groups, bring them back together for a whole-class discussion.

PART 2: MOLES, MOLECULES, AND MASS CARD SORT GAME

In this part of the lesson, students play a game in which they rank different quantities of three hydrocarbons in terms of total mass, mass of individual elements,

Classroom Ideas
You can keep the game cards and play the game periodically in the future when you feel students need to review their skills. For durability and ease of use, consider laminating the cards or printing them on card stock.

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number of particles, number of atoms of individual elements, number of moles, or number of moles of individual elements.

- Direct students to work in groups of four to six. Each group will break into two teams. Give each group a complete set of cut-out cards from **Handout 3.2.B: Moles, Molecules, and Mass Cards** and have students follow the directions on Handout 3.2.A to play the card sort game.

Classroom Ideas
You could consider offering a small incentive for the team that earns the most points.

Instructional Rationale

The quantities chosen for the cards were designed to make this exercise less about rote mathematical calculations and more about proportional reasoning. Rather than focusing on algorithmic problem solving, this lesson engages students in thinking about what a mole represents and how it can be used to compare different substances.

Meeting Learners' Needs
If your students require more support with ranking samples, consider one of the following variations, alone or in combination:

1. Tell students which cards to use for each round so that all groups are working with the same cards. Then review and discuss the answer with the whole class at the end of the round. You can choose to do this for one round, a few rounds, or all rounds, depending on how students do.
2. Give students only cards with macroscopic-sized samples (#1–#8) for a few rounds. Then use only cards with particulate-sized samples (#9–#12) for a few rounds. Finally, give them all the cards for a few rounds.

- Give students an initial criterion for ranking the values on the cards (total mass is a good first choice, but you can choose any of the units indicated on the back of the cards). To make the math easier, encourage them to use whole numbers for the molar masses and 6×10^{23} for Avogadro's number.
- Give student teams 2–3 minutes to decide on their ranking and write an explanation.
- As you circulate among the groups, listen for students' explanations of their strategies for determining the relative value on each card in terms of the relationships between molar mass, sample mass, sample moles, chemical formula, and/or Avogadro's number, as appropriate.
- At the end of the given time, tell students to turn the cards over and check their answers. Since students are "competing" against another team that is sharing the same set of cards, they can keep each other honest about not looking at the answers early.

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- Repeat this sequence for up to seven rounds, selecting a different criterion for ranking in each round. Be sure students shuffle their deck of cards and choose three cards for each round. See the Handout Answers and Guidance section at the end of the lesson for sample rounds you can use with students.

PART 3: SYNTHESIS AND DISCUSSION

In this final part of the lesson, students work with partners to answer some synthesis questions and then participate in a whole-class discussion. This discussion is an opportunity for students to explain both how the mole is used to relate particulate and macroscopic quantities and how it can be used to compare amounts of different substances to each other.

- Instruct students to work with partners to answer the synthesis questions.
- Finally, lead a whole-class discussion in which students explain how they arrived at their answers. During the discussion, encourage students to debate and challenge each other until a consensus is reached.

Classroom Ideas

To facilitate the discussion, have student pairs write their answers and explanations to one or more of the questions on whiteboards, then have them do a gallery walk to see each other's answers before discussing. This will spark debate and engage students in figuring out the right answers as well as support them in recognizing complete versus incomplete explanations.

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ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 3.2.A: Relating Moles, Molecules, and Mass

Part 1: Warm-Up

1. CH_4: 16 g C_2H_2: 26 g C_3H_8: 44 g
2. Ranking from greatest to least: C_3H_8, C_2H_2, CH_4

   Explanation of ranking: Since the samples have equal moles of molecules, the sample with the largest mass per mole must have the greatest mass, and molar mass can be used to compare the relative masses of the equimolar samples. Therefore, since C_3H_8 has the greatest molar mass, its sample mass is greatest. C_2H_2 has the second greatest molar mass and thus the second greatest sample mass, and CH_4 has the least molar mass and therefore the least sample mass.
3. Ranking from greatest to least: $C_3H_8 = C_2H_2 = CH_4$

   Explanation of ranking: A mole is a defined number of particles regardless of the substance, so if all the samples contain equal moles, they all contain equal numbers of particles.

Part 2: Card Sort Game

Below are some sample rounds for the game. You can choose to use these if you wish to guide students through individual rounds. Note that sample rounds 1–3 are macroscopic-scale cards only, sample rounds 4–5 are particulate-scale cards only, and sample round 6 contains cards of both scales.

Round 1

Criterion: total mass   Cards: 1, 6, 7

Ranking from greatest to least: Card 6, Card 7, Card 1

Explanation: Card 6—1 mole C_3H_8 has a mass of 44 g; Card 7—22 g C_3H_8 has a mass of 22 g; and Card 1—16 g Ch_4 has a mass of 16 g.

Round 2

Criterion: number of molecules   Cards: 2, 4, 5

Ranking from greatest to least: Card 5, Card 4 = Card 2

Explanation: Card 5—26 g C_2H_2 is one mole or 6×10^{23} molecules, while Card 4—0.5 mol C_2H_2 and Card 2—8 g CH_4 are each half a mole or 3×10^{23} molecules.

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Round 3

Criterion: number of moles of molecules Cards: 1, 3, 8

Ranking from greatest to least: Card 3, Card 1 = Card 8

Explanation: Card 3—2 moles CH_4 is 2 moles of molecules, while Card 1—16 g CH_4 and Card 8—44 g C_3H_8 are each 1 mole of molecules.

Round 4

Criterion: mass of hydrogen Cards: 9, 11, 12

Ranking from greatest to least: Card 12, Card 11 = Card 9

Explanation: The more hydrogen atoms a sample has, the greater the mass of hydrogen it contains. Card 12—6 molecules CH_4 contains 24 hydrogen atoms; Card 11—2 molecules C_3H_8 contains 16 hydrogen atoms; and Card 9—4 molecules CH_4 contains 16 hydrogen atoms.

Round 5

Criterion: atoms of carbon Cards: 10, 11, 12

Ranking from greatest to least: Card 10, Card 11 = Card 12

Explanation: Card 10—8 molecules C_2H_2 has 16 atoms of carbon; Card 11—2 molecules C_3H_8 has 6 atoms of carbon; and Card 12—6 molecules CH_4 has 6 atoms of carbon.

Round 6

Criterion: moles of carbon Cards: 5, 6, 12

Ranking from greatest to least: Card 6, Card 5, Card 12

Explanation: Card 6—1 mole of C_3H_8 contains 3 moles of carbon; Card 5—26 g of C_2H_2 is 1 mole of C_2H_2, which contains 2 moles of carbon; and Card 12—6 molecules of CH_4 contains only 6 atoms of carbon, which is far less than 1 mole (6.0×10^{23} atoms).

Part 3: Synthesis

1. The relationship between the number of moles and the number of molecules is constant for all substances, while the relationship between mass and the number of moles varies from one substance to another. For example, a mole of CH_4 and a mole of C_2H_2 both contain the same number (about 6×10^{23}) of molecules. However, a mole of CH_4 has a mass of about 16 g while a mole of C_2H_2 has a mass of about 26 g.

2. (a) I disagree. Since one mole of substance A has a larger mass than one mole of substance B, any number of moles of substance A will have a greater mass than the same number of moles of substance B.

   (b) I agree. If substance A has a larger molar mass than substance B, that means that a molecule of substance A has a greater mass than a molecule of substance B. Therefore it will take more molecules of substance B than of substance A to make up the same mass.

   (c) I disagree. Equal molecules implies equal moles, since the number of molecules in a mole is the same for every substance.

   (d) I disagree. Ten moles of any substance has a much larger mass than 10 molecules of that substance. A mole contains about 600,000,000,000,000,000,000,000 molecules, so a mole of substance A has a mass 600,000,000,000,000,000,000,000 times larger than a molecule of substance A.

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PRACTICE PERFORMANCE TASK

Molar Challenges

OVERVIEW

DESCRIPTION

In this practice performance task, students are assessed on their understanding of conversions between mass, number of particles, and number of moles. The tasks consist of three parts, two of which allow students to work with calculations on elements and ionic compounds. The third part is a laboratory practical in which students measure masses and volumes of the elemental components of paraffin wax.

CONTENT FOCUS

This task challenges students to apply their knowledge of moles, particles, and mass in three distinct scenarios. One scenario is at the atomic scale and requires students to use Avogadro's number. The two remaining scenarios are macroscopic in scale and require students to use their knowledge of moles to determine mole ratios within a compound and to measure out a specific number of moles of two substances in the laboratory. Allowing students to use their knowledge of moles across scales reinforces why moles are a useful unit in chemistry.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 3 Practice Performance Task: Molar Challenges

MATERIALS

- calculator
- equation sheet
- periodic table

For Part 3:

- cut-out task cards (one per student)
- crayons
- charcoal (granular from a pet store works best)
- water
- balances
- graduated cylinders
- container for sample of charcoal

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COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.	
Learning Objectives	**Essential Knowledge**
3.1.A.1 Explain the relationship between the mass of a substance, the number of particles of that substance, and the number of moles of that substance. **3.1.A.2** Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **a.** A mole of a substance contains Avogadro's number (6.02×10^{23}) of particles. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.

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SUPPORTING STUDENTS

BEFORE THE TASK

If you feel students need additional support before working on this practice performance task, you might consider one or more of the following:

- Students may need a refresher on the idea of relative mass between elements as illustrated by the periodic table. This is illustrated in Lesson 3.1: Relative Mass and the Mole. Reminding students that there are multiple paths to solving a problem is beneficial.
- Students may need to be reminded that density is the ratio of mass to volume.
- Students may need refresher work on how to enter numbers written in scientific notation into their calculators, as Parts 1 and 3 involve very large and very small numbers.

DURING THE TASK

Because this is a practice performance task, you could structure this formative assessment to provide more supports to students.

- You could allow students to work in pairs or individually to complete all tasks. It is not recommended that students work in small groups. There is ample work and enough potential discussion opportunity for two students, but in larger groups, there may not be quite enough for everyone to meaningfully engage in the task.
- You might break up the task over two days, with one day devoted to pencil and paper portions (Parts 1 and 2), followed by the lab task on a subsequent day. However, Part 3 alone will not require a full period. You could also give students their task cards for Part 3 and allow them to do the calculations for homework, and then use class time the next day to measure the required quantities of charcoal and water.
- While students should complete Part 1 before Part 2, Part 3 can be assigned at any point during this formative assessment.

Notes specific to Part 1:

- If students struggle with interpreting the very small numbers in this task, ask them how they would approach the problem if 10 g of atoms were present instead.
- Question (c) can be challenging for students. To guide their thinking, ask them how they would calculate the mass of two atoms, then of three atoms, then of a dozen atoms, then of 100 atoms, and so forth. If they still struggle, ask them how many atoms are in a mole of atoms to help them recall Avogadro's number.

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Notes specific to Part 2:

- Question (e) can be challenging for students, so you may want to consider how to scaffold it to allow your students to be successful. For example, you could ask students to first determine the mole ratio between Cu and X and then determine the number of moles of X. Once they have the number of moles of each element, ask them to determine the mass of each element.

Notes specific to Part 3:

- At the end of the teacher resource for this performance task, you will find reproducible task cards for Part 3. The task cards are customizable, as is the amount of crayon you can give each student. An example of a task card is shown here for reference.

CARDS FOR PART 3

UNIT 3

For Part 3, give each student (or group of students) a card with a quantity of carbon and water filled in.

Crayon Task	Crayon Task
Return to your instructor: A mass of carbon that contains ________ times the moles of carbon in your crayon sample. A volume of water that contains ________ times the number of hydrogen atoms in your crayon sample.	Return to your instructor: A mass of carbon that contains ________ times the moles of carbon in your crayon sample. A volume of water that contains ________ times the number of hydrogen atoms in your crayon sample.

Handout 3.1

- You can easily tailor this task to challenge all ability levels. The simplest task card would require the students to weigh out charcoal so that they deliver the mass of the carbon in the crayon sample. Similarly, they can measure out a volume of water in which the number of hydrogen atoms is equal to the number of hydrogen atoms in the crayon sample.
- This task is fairly open-ended. You may want to scaffold it for your students. Specifically, consider asking students the following guiding questions:
    - How could you determine the number of moles of paraffin in the crayon sample?
    - How could you determine the number of moles of carbon in the crayon sample?
    - Would knowing the molar mass of paraffin be useful?

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- Write down the molecular formula for water. What is the proportional relationship between the number of hydrogen atoms in one mole of water and the number of hydrogen atoms in one mole of paraffin?
- What is the density of water? Is knowing this value useful for the task?

AFTER THE TASK

- Whether you decide to have students score their own solutions, have them score a classmate's solution, or score the solutions yourself, the results of the practice performance task should be used to inform instruction.

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UNIT 3

SCORING GUIDELINES

There are 23 possible points for this performance task.

Part 1(a)

Sample Solutions	Points Possible
$9 \text{ atoms} \times \dfrac{1 \text{ mol}}{6.02 \times 10^{23} \text{ atoms}}$ $= 1.50 \times 10^{-23}$ moles of atoms	**1 point maximum** 1 point for correct calculation of the number of moles of atoms

Targeted Feedback for Student Responses
Students may have difficulty remembering that there are 6.02×10^{23} particles in a mole and that a mole always contains the same number of particles. Thus, it may be necessary to prompt students by asking how many particles are in a mole as they determine how many moles of atoms are represented in the letter in the picture.

TEACHER NOTES AND REFLECTIONS

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Part 1(b)

Sample Solutions	Points Possible
$\frac{1.963 \times 10^{-21}\ \text{g}}{9\ \text{atoms}} = 2.181 \times 10^{-22}\ \text{g/atom}$	**1 point maximum** 1 point for correct calculation of the mass of one atom

Targeted Feedback for Student Responses
Some students may be uncomfortable working with and making sense of the small values of the masses involved. If this is the case, you can help them think through this by asking how they would approach the problem if the total mass of all the atoms in the letter were 10 g as opposed to 1.963×10^{-21} g.

TEACHER NOTES AND REFLECTIONS

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UNIT 3

Part 1(c)

<table>
<tr><th>Sample Solutions</th><th>Points Possible</th></tr>
<tr><td>

$$\frac{2.181\times10^{-22}\ \text{g}}{1\ \text{atom}}\times\frac{6.02\times10^{23}\ \text{atoms}}{1\ \text{mol}}$$
$$=131.3\ \text{g/mol}$$

Based on the periodic table, this molar mass is closest to that of xenon, which is 131.29 g/mol. The letter is made of xenon atoms.

</td><td>

2 points maximum

1 point for correct calculation of molar mass

1 point for correct identification of the element

Scoring notes:

- If the student incorrectly calculated the mass of one atom in question (b), but correctly used that answer to determine the molar mass in this part, they should receive full credit for question (c).
- If the student incorrectly calculated the molar mass, but correctly identified an element based on that mass, they should receive 1 point.

</td></tr>
<tr><th colspan="2">Targeted Feedback for Student Responses</th></tr>
<tr><td colspan="2">Students may have difficulty realizing that they can obtain the molar mass by simply multiplying the mass of one atom by Avogadro’s number. Asking how they would determine the mass of a dozen atoms can aid in their thinking about how to scale up to a mole of particles.</td></tr>
</table>

TEACHER NOTES AND REFLECTIONS

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Part 1(d)

Sample Solutions	Points Possible
$4.50 \text{ mol} \times \frac{131.29 \text{ g}}{1 \text{ mol}} = 591 \text{ g}$	**1 point maximum** 1 point for correct calculation of mass of 4.50 moles of the sample *Scoring note:* If the student incorrectly calculated the molar mass in question (c) but used that mass correctly here, they should receive full credit.

Targeted Feedback for Student Responses
If students invert the calculation, ask them what the mass of one mole of xenon is. Then ask them if the mass of 4.50 moles of xenon would be greater than or less than that amount. Then ask them if they should multiply or divide the numbers.

TEACHER NOTES AND REFLECTIONS

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UNIT 3

Part 2(a)

Sample Solutions	Points Possible
$15.00 \text{ g Cu} \times \frac{1 \text{ mol Cu}}{63.55 \text{ g Cu}} = 0.2360 \text{ mol Cu}$ $2 \times \text{mol Cu} = 2 \times 0.2360 = 0.4720 \text{ mol X}$	**2 points maximum** 1 point for correct calculation of the number of moles of Cu 1 point for correct calculation of the number of moles of X *Scoring note:* If a student incorrectly calculates the moles of copper but uses that information correctly to calculate the moles of X, they should receive 1 point.
Targeted Feedback for Student Responses	
Students may need additional guidance to help them recall the molar relationships within a compound. Since the formula is CuX_2, 2 moles of X must be present for every mole of Cu.	

TEACHER NOTES AND REFLECTIONS

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Part 2(b)

Sample Solutions	Points Possible
There are multiple ways students can determine the answer using proportional reasoning. Two examples are shown below, but students should receive credit for any logical explanation with correct chemistry. Sample solution 1: Since the number of moles of X per mole of Cu in compound C are half as many as in compound A, there should be half as much mass of X in the sample of C as there is in the sample of A. Therefore, $\frac{8.969}{2} = 4.485$ g X should be in compound C. Sample solution 2: The molar mass of element X can be determined from compound A. $\frac{8.969 \text{ g X}}{0.4720 \text{ mol X}} = 19.00 \text{ g/mol}$ Compounds A and C have the same mass of Cu, therefore they have the same number of moles of Cu (0.2360 mol). Compound C has the same number of moles of Cu and X. $0.2360 \text{ mol X} \times \frac{19.00 \text{ g X}}{\text{mol X}} = 4.484 \text{ g X}$	**1 point maximum** 1 point for correct answer with supporting logic

Targeted Feedback for Student Responses
The strategy that will resonate with most students will be using the mass of Cu and the fact that the formula of compound C is CuX. Have students focus on the fact that the grams (and hence moles) of Cu are the same in compounds A and C. If this is the case, and the formula of compound C is CuX, ask students what must be true about the number of moles (and hence grams) of X in compound C relative to A.

TEACHER NOTES AND REFLECTIONS

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UNIT 3

Part 2(c)

Sample Solutions	Points Possible
There are multiple ways students can determine the answer using proportional reasoning. One example is shown below, but students should receive credit for any logical explanation with correct chemistry. In compound B, the ratio of grams of Cu to X is $\frac{25.00}{14.95} = 1.672$. In compound A, the ratio of grams of Cu to X is $\frac{15.00}{8.969} = 1.672$. In compound C, the ratio of grams of Cu to X is $\frac{15.00}{4.485} = 3.344$. Since the ratios are the same, compounds A and B have the same chemical formula.	**2 points maximum** 1 point for determining that compounds A and B have the same formula 1 point for providing a mathematical justification

Targeted Feedback for Student Responses
If students struggle with this question, ask them to consider what must be true about the ratios of elements in each unique compound. Ask students if information about the ratios of the elements would help to distinguish one compound from another.

TEACHER NOTES AND REFLECTIONS

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Part 2(d)

Sample Solutions	Points Possible
In compound A, the mass of X is 8.969 g and the number of moles is 0.4720. Thus, the molar mass of X is $\frac{8.969 \text{ g}}{0.4720 \text{ mol}} = 19.00 \text{ g/mol}$. The element is fluorine.	**2 points maximum** 1 point for correct calculation of molar mass 1 point for correct identification of the element *Scoring notes:* ▪ The two points should be awarded independently. If the student incorrectly calculated the number of moles of X in question (a) but correctly uses that information here, they should receive 1 point. ▪ If a student incorrectly calculates the molar mass but correctly identifies an element based on that mass, they should receive 1 point.

Targeted Feedback for Student Responses
You may need to remind students that the definition of molar mass is the ratio of the mass of a sample to the number of moles of a sample. Suggest they think about whether they have what they need to complete the problem: Do they know the mass in grams? Do they know the number of moles? Do they have access to a table of information that lists the molar mass of elements?

TEACHER NOTES AND REFLECTIONS

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UNIT 3

Part 2(e)

Sample Solutions	Points Possible
If the sample has 1.50 moles of copper, it must have 3.00 moles of fluorine because of the formula CuX_2 (or CuF_2). Therefore, the mass of the compound is $1.50 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 95.3 \text{ Cu}$ $3.00 \text{ mol F} \times \frac{19.0 \text{ g F}}{1 \text{ mol F}} = 57.0 \text{ g F}$ Total mass = 95.3 g Cu + 57.0 g F = 152.3 g	**3 points maximum** 1 point for correct calculation of the number of moles of F 1 point for conversion of the number of moles to mass values (can be implicit) 1 point for correct final mass of compound
Targeted Feedback for Student Responses	
Guide students to think about whether they can calculate the number of moles of each element from the data and formulas given. Ask students how they can use the number of moles to calculate the number of grams of each element.	

TEACHER NOTES AND REFLECTIONS

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Part 3

Sample Solutions	Points Possible
These will vary depending on task. Sample tasks and solutions shown below. Assume the student is given a sample of 5.0 g of crayon and is asked to return 0.50 times the number of moles of carbon and 3 times the number of atoms of hydrogen in the crayon sample. $5.0 \text{ g crayon} \times \frac{1 \text{ mol paraffin(crayon)}}{436.82 \text{ g crayon}} = 0.011 \text{ mol paraffin}$ The number of moles of carbon in the sample is: $0.011 \text{ mol paraffin} \times \frac{31 \text{ mol C}}{1 \text{ mol paraffin}} = 0.341 \text{ mol C}$ The student needs to measure out 0.5 times this number of moles of carbon. $\text{mol C needed} = 0.5 \times 0.341 \text{ mol} = 0.171 \text{ mol}$ $0.171 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 2.05 \text{ g charcoal}$ The number of moles of hydrogen in the sample is: $0.011 \text{ mol paraffin} \times \frac{64 \text{ mol H}}{1 \text{ mol paraffin}} = 0.70 \text{ mol H}$ The student needs to measure out a volume of water that contains 3.0 times this amount of hydrogen atoms. $\text{mol H needed} = 3.0 \times 0.70 \text{ mol} = 2.1 \text{ mol H}$ $2.1 \text{ mol H} \times \frac{1 \text{ mol } H_2O}{2 \text{ mol H}} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} \times \frac{1 \text{ mL } H_2O}{1 \text{ g } H_2O} = 19 \text{ mL } H_2O$	**8 points maximum** 1 point for correct calculation of the number of moles of paraffin (can be implicit) For carbon: 1 point for correct calculation of the requested number of moles of carbon 1 point for correct calculation of the mass of carbon, taking into account proportionality 1 point for delivery of the correct mass of carbon to the teacher For water: 1 point for correct calculation of the number of moles of hydrogen 1 point for correct calculation of the number of moles of H_2O, taking into account proportionality 1 point for correct calculation of the requested volume of water 1 point for delivery of the correct volume of water to the teacher

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Targeted Feedback for Student Responses

There are multiple approaches to solve this problem. Please refer to "Notes specific to Part 3" in the Supporting Students section for additional suggestions. However, it is easy to scaffold the difficulty of this activity as you can determine the values on the task card for each student. For students you think will have difficulty, it would be reasonable to make the requested mass and volume equal to (i.e., 1 time) the number of moles of carbon and the number of hydrogen atoms in the given compound. For students better prepared for a challenge, consider making the multiples larger or even decimal values (e.g., 3.5 times).

TEACHER NOTES AND REFLECTIONS

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CARDS FOR PART 3

For Part 3, give each student (or group of students) a card with a quantity of carbon and water filled in.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

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Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

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Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

Crayon Task

Return to your instructor:

A mass of carbon that contains ______________ times the moles of carbon in your crayon sample.

A volume of water that contains ______________ times the number of hydrogen atoms in your crayon sample.

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LESSON 3.3

Candy That Pops – A Stoichiometry Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Designing an Experimental Procedure to Determine the Mole Ratio in a Mixture

Students use their knowledge of stoichiometry and their lab skills to plan how to experimentally determine the quantity of baking soda in a given mixture of citric acid and baking soda. Students also apply concepts they learned earlier in the course, such as the understanding that homogeneous mixtures are evenly distributed and that solid mixtures tend not to react until water is added.

Part 2: Data Collection

Students determine the mass of the mixture before and after the reaction. Students need to decide when enough water has been added to obtain the greatest volume of carbon dioxide that can be produced.

Part 3: Data Analysis

Students calculate the amount of baking soda that was in the mixture. They use the total mass of the mixture to calculate the mass of citric acid. Finally, students are given the actual mass of baking soda in the mixture to determine their percent yield of carbon dioxide gas.

CONTENT FOCUS

This lab uses a real-world stoichiometric context, the chemistry of popping candy, to engage and motivate students. The lab is designed to ensure that students develop not only procedural fluency in stoichiometry

AREAS OF FOCUS

- Strategic Use of Mathematics
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~105 minutes

HANDOUT

- 3.3: Candy that Pops – A Stoichiometry Lab

MATERIALS

For each group:

- beaker or other container for the reaction
- citric acid (available as sour salt at a local grocery store)
- baking soda
- water
- graduated cylinder
- dropper
- balance
- stirring rod
- goggles

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but also an understanding of the principles of stoichiometry and how and why it can be used. To successfully answer the lab question, which pertains to a mixture of baking soda and citric acid, students must apply both laboratory and mathematical skills to deepen their conceptual understanding of stoichiometry.

This lab reinforces content from earlier in the unit, such as molar mass, while allowing students to practice calculations with stoichiometric ratios. This lab also sets up a future discussion of limiting reactants.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction. ▪ In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.	
Learning Objectives	**Essential Knowledge**
3.1.A.2 Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.
3.2.A.1 Create and/or evaluate models of chemical transformations.	**3.2.A** All chemical transformations involve the rearrangement of atoms to form new combinations. **a.** Since the atoms are not created or destroyed, the total numbers of each atom must remain constant. **b.** Chemical transformations can be modeled by balanced chemical equations and particulate representations.
3.2.B.2 Perform stoichiometric calculations involving the quantity of reactants and products in a chemical system.	**3.2.B** A balanced chemical reaction equation, combined with the mole concept, can be used to quantify the amounts of reactants consumed and products formed during a chemical transformation.

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3.2.D.1 Calculate the theoretical yield and/or percent yield of a chemical reaction.	**3.2.D** A balanced chemical reaction equation, combined with the mole concept, can be used to calculate the theoretical and percent yield of a reaction.

SETUP AND PREPARATION NOTES

- Put samples of baking soda and citric acid in sandwich bags for students to observe.
- Each group will need a different mixture of citric acid and baking soda in a sandwich bag. Since the concept of limiting reactants has not been introduced yet, be sure to make baking soda the limiting reactant in each mixture. One gram of baking soda for every 0.76 grams of citric acid is a stoichiometric equivalent; therefore, consider making mixtures with about 9 grams of baking soda and increasing the amount of citric acid in each mixture so the citric acid is always in excess. The table below has combinations you can use.

Bag Number	Mass of Baking Soda (g)	Mass of Citric Acid (g)
1	9.00	7.00
2	9.00	8.00
3	9.00	9.00
4	9.00	10.00
5	9.00	11.00
6	9.00	12.00
7	9.00	13.00
8	9.00	14.00

- Number each sandwich bag and be sure to record the quantities of baking soda and citric acid in each mixture if you use something other than the quantities in the table above. Students are asked to record their bag number on their handout and will need to know the actual quantities of baking soda and citric acid in their mixture.

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SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear chemical splash goggles.
- Remind students never to eat anything in the lab. Although this lab involves some of the ingredients used in making candy that pops, the lab does not involve making or eating candy.

FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

Iron metal rusts in the presence of oxygen gas according to the following balanced equation:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

1. If x moles of iron react with oxygen gas, how many moles of iron(III) oxide will be produced?
   (a) $2x$
   (b) $\frac{1}{2}x$
   (c) $\frac{2}{3}x$
   (d) $1.5x$
2. The mass of an iron nail is measured before and after being placed in a beaker of water for 2 days. It is found that 0.059 g of iron(III) oxide (rust) was produced over the 2-day period. What mass of iron in the nail reacted with the water? Assume the nail is pure iron.
3. If the nail is placed in the beaker of water at a temperature of 22°C and pressure of 1.01 atm, what volume of oxygen gas reacted?

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PART 1: DESIGNING AN EXPERIMENTAL PROCEDURE TO DETERMINE THE MOLE RATIO IN A MIXTURE

Students use their knowledge of stoichiometry and their lab skills to plan how to experimentally determine the quantity of baking soda in a given mixture of citric acid and baking soda. Students also apply concepts they learned earlier in the course, such as that homogeneous mixtures are evenly distributed and that solid mixtures tend not to react until water is added.

- Have students read the introduction on **Handout 3.3: Candy That Pops – A Stoichiometry Lab** individually or out loud as a class. If some of your students are unfamiliar with Pop Rocks or similar candies, you can have a few volunteers describe it, or you can bring a package to show.
- Then, ask a student to read aloud the challenge statement, which describes the goal of this lab. Make sure students understand generally what they are being asked to do.

THE CHALLENGE

In this lab, you will analyze a mixture of two key ingredients in popping candy: citric acid and baking soda. You must design and perform a procedure to determine how much of each ingredient is in your mixture.

- Next, with students in their lab groups, prompt the class to start thinking about the nature of this challenge by passing around labeled sandwich bags of baking soda so students can make observations of it. Do the same with bags of citric acid and a mixture of the two substances. Students should record their observations on their handouts for questions 1(a) through 1(c) in the Pre-Lab Questions section. They should also record the number of their assigned mixture.

Instructional Rationale

The observations of the three substances should lead students to understand that the mixture of citric acid and baking soda cannot be separated by physical means, so a more complex method of answering the question will be required.

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- The remaining pre-lab questions are scaffolded to support students in thinking about how to develop their procedure. You might want to have students answer these questions individually first and then discuss them as a class to come to a consensus. Question 6 is designed to have students start thinking about the measurements they will need to take as part of their procedure.
- Based on the conversations you hear and what you observe of your students, discuss some the pre-lab questions with the whole group. Focus on students having a correct balanced equation and what measurements they must make both before and after the reaction. You can also use questions such as the following to gauge student understanding:
  - How do we know the two solids have not reacted yet?

    There is no evidence of a chemical change. The lemon scent is still present in the mixture.

  - When you eat candy like Pop Rocks, what chemical is being added to the candy? How is that similar to the reaction we will conduct?

    Water from our mouths releases the carbon dioxide so we will add water to the mixture in an open container to release the gas. Though water is not an “active ingredient” in the Pop Rocks, it is required to make them pop at the right time.

  - How will you know when the reaction has ended? How will you know when you’ve added enough water? What happens if you add too much water?

    The mixture will stop bubbling. The mixture will not bubble when more water is added. There is no problem with adding too much water. The extra water will just stay in the container, unreacted.

Meeting Learners’ Needs

For Question 5, some students may need support in understanding that the carbon dioxide produced is directly related to the amount of baking soda used as a reactant. You may choose to use a highlighter on the reaction shown in question 2 to trace the CO_2 atoms from the products back through the reaction. If students think some of the CO_2 is created from the citrate, encourage them to look at the balanced equation. They will see that the citrate ion remains unchanged during the reaction.

Meeting Learners’ Needs

To stimulate thinking, you can have students brainstorm their ideas on whiteboards and share with the class. Once groups have heard different approaches, allow them to revise their procedures and then record them on their handouts.

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- Once you are confident that students have an understanding of the basics of the lab, ask them to work with their lab group to design a procedure for the lab. The amount of support you provide your students during this portion of the lesson will depend on how much experience your students have had in the lab, as well as your own comfort level.

You can also point out that at the end of the lab, students will calculate a "challenge score" that is related to their percent yield. Consider rewarding groups with high challenge scores and use that to motivate them as they design their procedure.

Guiding Student Thinking

One approach to consider if students need support in designing their procedure and determining what data to collect is to have them look at the Data Analysis questions 1–6 and work backward to determine what data are necessary for the calculations.

Instructional Rationale

Having groups design their own procedures makes students think critically about the relationships between the reactants and products and what data they need to collect. This approach can make the stoichiometric calculations less algorithmic and help build conceptual understanding.

- You will likely want to approve procedures before allowing students to carry them out. It is best to provide guidance when student groups submit their procedures as a way to support a plan that has a reasonable chance of producing useful data. Focus on ensuring that students have a plausible plan for collecting the measurements they will need for their calculations. Even in student-led investigations, it is not productive to allow students to run investigations in which the potential for success is low or nonexistent. However, that does *not* mean you should help students make their plans flawless. There is educational value in allowing students to carry out their design and discover its flaws on their own. It is even better if you can provide students with enough time to correct these flaws and run the experiment again.
- Once you have approved their procedures, ask each group to design a table to record their data.

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PART 2: DATA COLLECTION

Students work in lab groups to collect the data necessary to determine the amounts of each ingredient in their mixture.

- While students are working, circulate among the groups to ask guiding questions and help students who need extra support.
- About 10 mL of water is needed for a reaction of 9 g of baking soda and 6 g of citric acid to go to completion. However, students may choose to add more water if they feel it has not reacted to completion.
- If students are unsure of how much water to add, ask them what they will observe if the reaction has gone to completion. Encourage the students to add water until no more bubbles evolve. They can use a stirring rod to ensure the mixture has completely reacted. Make sure they always record the entire mass of the system.
- While circulating, check to see that all students have clearly labeled their data throughout the challenge in the proper space on the handout. They should also record observations during the challenge.

PART 3: DATA ANALYSIS

Students calculate the quantities of baking soda and citric acid that were in their mixture using data collected in the lab. The students will then be given the actual mass of baking soda in their mixture to determine their percent yield of carbon dioxide gas produced.

- Have students work through data analysis questions 1–9 with their group. Tell students the actual quantity of baking soda that was added to their mixture based on the mixture number as recorded in your notes, which allows them to work on questions 7 and 8.
- Some guidance for specific questions follows.
  - Questions 1 and 2: These questions are designed to have students think about conservation of mass and that even though they couldn't directly measure the mass of carbon dioxide gas produced, they have the information they need to calculate the mass. You may have to prompt students to think about the mass of water that was added and then to use the density of water to determine the mass.
  - Question 3: This question is where it is important for students to understand that all the carbon dioxide that is produced comes from the baking soda that reacted. If you traced the CO_2 through the reaction with a highlighter earlier, point students back to the marked-up reaction. If not, encourage students to think

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about where the CO_2 comes from. Some students may think some of the CO_2 comes from the citric acid since it contains both carbon and oxygen. Encourage students to look closely at the formulas for both citric acid and sodium citrate and emphasize that the citrate ion is unchanged during the reaction to help students understand that the CO_2 resulted from a change in the bicarbonate ion in baking soda. You can refer them back to Pre-Lab Question 4 for support.

- Question 5: Remind students that the only two components of the mixture were baking soda and citric acid.
- Question 7: Some students have the misconception that the mole ratio from the balanced equation tells them how much of each reactant is present. This question is designed to directly address that misconception since the actual ratio of reactants used does not match the mole ratio in the balanced equation. You can also return to this question once the concept of limiting reactants has been introduced.
- Question 8: If your students have a low percent yield, take this opportunity to discuss experimental error and what they could do to minimize their error. If time permits, allow these students to run the experiment again with an improved procedure.

- Finally, have each student individually write a paragraph as the conclusion of the lab. Students should include a claim about how much baking soda and citric acid were present in their mixture and use the data they collected and their calculations to support their claim. Once students have written their paragraphs, have them engage in peer review. Students should read each other's paragraphs and note similarities and differences and ways other students could strengthen their arguments. Allow students time to make these revisions. If time is limited, consider having students write and revise their conclusions out of class.
- Conclude the lesson with a whole-class discussion of ways students could increase their percent yield or what might account for a low percent yield. Some examples include:
  - Measure the mass of the original container with the reactants, then pour the reactants into a reaction beaker, and then measure the mass of the container to ensure that all of the reacted solid was accounted for.
  - Some reaction mixture may stay on the stirring rod, so students could include their stirring rod in the mass of the system and then subtract it out at the end. Then, any reactant or product stuck to the stirring rod would be measured.
  - Conduct the entire procedure on a balance to track the mass as the reaction progresses, and then record the lowest mass observed on the balance as the mass of the product.

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- You could have the groups with the largest and smallest percent yields share their procedures and have the class brainstorm the advantages and disadvantages of those procedures and ways in which they could be improved.

EXTENDING THE LESSON

Later in this unit, students will learn about limiting and excess reactants. Students can return to this reaction to observe stoichiometric equivalents. The reaction can be carried out with varying amounts of citric acid and baking soda in which each team has a different mole ratio. Students can perform the experiment within a baggie to trap the carbon dioxide gas generated. Students would add the two measured solids to the baggie and use a twist tie to close the baggie. Then they would add water to the baggie above the twist tie and close the baggie with the zip seal. Next, they would remove the twist tie to allow the water and solids to combine. The bag that creates the most gas would represent the best stoichiometric equivalent.

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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

Iron metal rusts in the presence of oxygen gas according to the following balanced equation:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

1. If x moles of iron react with oxygen gas, how many moles of iron(III) oxide will be produced?

   (a) $2x$
   (b) $\frac{1}{2}x$
   (c) $\frac{2}{3}x$
   (d) $1.5x$

   The correct answer is (b).

2. The mass of an iron nail is measured before and after being placed in a beaker of water for 2 days. It is found that 0.059 g of iron(III) oxide (rust) was produced over the 2-day period. What mass of iron in the nail reacted with the water? Assume the nail is pure iron.

$$0.059 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.70 \text{ g } Fe_2O_3} \times \frac{4 \text{ mol Fe}}{2 \text{ mol } Fe_2O_3} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 0.041 \text{ g Fe}$$

3. If the nail is placed in the beaker of water at a temperature of 22°C and pressure of 1.01 atm, what volume of oxygen gas reacted?

$$0.059 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.70 \text{ g } Fe_2O_3} \times \frac{3 \text{ mol } O_2}{2 \text{ mol } Fe_2O_3} = 5.5 \times 10^{-4} \text{ mol } O_2$$

Solve the ideal gas law, $PV = nRT$, for V.

$$V = \frac{nRT}{P} = \frac{(5.5 \times 10^{-4} \text{ mol})\left(0.0821 \frac{\text{L} \bullet \text{atm}}{\text{mol} \bullet \text{K}}\right)(295 \text{ K})}{1.01 \text{ atm}} = 0.013 \text{ L } O_2$$

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HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handout are provided below.

Handout 3.3: Candy That Pops – A Stoichiometry Lab

Pre-Lab Questions

1. (a) Citric acid: white crystalline solid with a lemon scent

   Baking soda: white powdery solid with no odor

   Mixture: homogeneous white solid with a lemon scent

   (b) The two ingredients are well distributed in a homogeneous mixture. Citric acid and baking soda cannot be distinguished from one another.

   (c) The two ingredients must be aqueous, so water is needed.

2. $\underline{1}\,H_3C_6H_5O_7(aq) + \underline{3}\,NaHCO_3(aq) \rightarrow \underline{1}\,Na_3C_6H_5O_7(aq) + \underline{3}\,H_2O(l) + \underline{3}\,CO_2(g)$

   citric acid *baking soda* *sodium citrate*

3. The mass will decrease because the carbon dioxide gas produced in the reaction will escape from the open container.

4. Students should circle the citrate ion in the reactant citric acid and the product sodium citrate. Students should draw a box around the bicarbonate ion in the reactant sodium bicarbonate.

5. The bicarbonate ion. The citrate ion itself remains unchanged from reactants to products, so none of the carbon in the CO_2 product could have resulted from a change in the citrate ion.

6. All the carbon in the carbon dioxide comes from the baking soda, so I can use the mass of the carbon dioxide produced to determine the number of moles of carbon dioxide produced. I can then use the mole ratio between carbon dioxide and baking soda to determine the number of moles of baking soda that reacted. Finally, the molar mass of baking soda can be used to determine the mass of baking soda that reacted.

Procedure

Sample procedure:

1. Measure the mass of the empty beaker.
2. Add the baking soda and citric acid mixture to the beaker and measure the total mass.
3. Add 25 mL of water to a graduated cylinder.

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4. Pour water in 5 mL increments into the beaker while stirring until bubbles stop forming.
5. Measure the mass of the container with the products.

Data and Observations

Student answers will vary. A sample response is provided.

Mass of empty container (g)	52.15
Mass of container with solid mixture (g)	72.15
Mass of solid mixture (g)	20.00
Volume of water added to mixture (mL)	15.00
Mass of container with products (g)	82.62
Mass of non-gaseous products (g)	30.47

- Bubbles were produced when water was added. Eventually, no more bubbles were produced.
- The lemon scent decreased as the reaction proceeded.

Post-Lab Questions

Student answers will vary. Answers are based on sample data.

1. 20.00 g solid mixture + 15.00 g water = 35.00 g starting material

   The products and excess water must also have a mass of 35.00 g since mass is conserved.

2. 35.00 g – 30.47 g non-gaseous product = 4.53 g CO_2 produced

3. $4.53 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} = 0.103 \text{ mol } CO_2$

   $PV = nRT$

   $$V = \frac{nRT}{P} = \frac{(0.103 \text{ mol})\left(0.0821 \frac{\text{L} \times \text{atm}}{\text{mol} \times \text{K}}\right)(295 \text{ K})}{1.00 \text{ atm}} = 2.49 \text{ L } CO_2$$

4. $0.103 \text{ mol } CO_2 \times \frac{3 \text{ mol } NaHCO_3}{3 \text{ mol } CO_2} = 0.103 \text{ mol } NaHCO_3$

5. $0.103 \text{ mol } NaHCO_3 \times \frac{84.01 \text{ g } NaHCO_3}{1 \text{ mol } NaHCO_3} = 8.65 \text{ g } NaHCO_3$

6. 20.00 g mixture – 8.65 g baking soda = 11.35 g citric acid

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7. $11.35 \text{ g } H_3C_6H_5O_7 \times \frac{1 \text{ mol } H_3C_6H_5O_7}{192.12 \text{ g } H_3C_6H_5O_7} = 0.05907 \text{ mol } C_6H_8O_7$

8. Sample response: The mole ratio of baking soda to citric acid in my mixture was 1.74:1. The mole ratio in the balanced equation is 3:1. The ratio in the balanced equation is the ratio in which the substances react, not the ratio of the exact amounts present at the beginning of any given experiment. We could have started the experiment with any number of reactants and they still would have reacted in a 1:3 ratio. There was some leftover powder, so not everything reacted.

9. (a) This value varies based on the mixture created. The sample data was collected using a mixture of 9.00 g of baking soda and 11.00 g of citric acid.

   (b) $9.00 \text{ g } NaHCO_3 \times \frac{1 \text{ mol } NaHCO_3}{84.01 \text{ g } NaHCO_3} \times \frac{3 \text{ mol } CO_2}{3 \text{ mol } NaHCO_3} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 4.71 \text{ g } CO_2$

   (c) $\frac{4.53 \text{ g } CO_2}{4.71 \text{ g } CO_2} \times 100 = 96.2\% \text{ yield}$

10. Student responses will vary.

11. Student responses will vary.

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LESSON 3.4

Limiting Reactants

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Limiting and Excess Reactants
Students use a physical model and a particle diagram of a mixture of hydrogen and oxygen to determine how many molecules of water can be formed from a given number of reactant atoms. From this brief activity, students are introduced to the concept and vocabulary of limiting and excess reactants.

Part 2: Modeling Limiting and Excess Reactants with Particle Diagrams
Students model several chemical reactions using particle diagrams in order to identify limiting and excess reactants.

Part 3: Modeling Limiting and Excess Reactants Through Graphing
Students model a chemical reaction using a graph to show the quantities of reactants and products present in a reaction mixture over time. By introducing graphing as another way to represent stoichiometric concepts, in addition to particle diagrams and reaction equations, this lesson deepens students' conceptual model of reaction stoichiometry.

CONTENT FOCUS

This lesson introduces students to the concepts of limiting and excess reactants through the analysis of particle diagrams and graphical representations. Students use their prior experiences of representing

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 3.4.A: Introduction to Limiting and Excess Reactants
- 3.4.B: Modeling Limiting and Excess Reactants with Particle Diagrams
- 3.4.C: Modeling Limiting and Excess Reactants Through Graphing

MATERIALS

- bingo chips or other small objects available in multiple colors
- colored pencils, pens, or markers
- LCD projector, electronic whiteboard, or other technology for showing an online video to students (optional)

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chemical reactions visually (with particle diagrams) and symbolically (with reaction equations) and extend their knowledge to situations involving reaction mixtures with non-stoichiometric ratios.

At the introductory level, treatment of these concepts is often restricted to calculations. In such instructional approaches, students often identify the limiting reactant as that which produces the fewest moles or grams of a particular product, but with little rationale as to why that reactant "ran out first." This lesson seeks to fill in a common gap in the instructional sequence by focusing on building conceptual understanding and proportional reasoning abilities.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction. ▪ In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.	
Learning Objectives	**Essential Knowledge**
3.2.C.1 Create and/or evaluate models of a reaction mixture before and/or after a reaction has occurred, including situations with a limiting reactant.	**3.2.C** The limiting reactant is the reactant that is completely consumed during a chemical reaction. The limiting reactant determines the amount of product formed.

SETUP AND PREPARATION NOTES

- You can use any appropriate substitute for different colors of bingo chips, such as pop beads, components of model sets, or cut-out pieces of construction paper.

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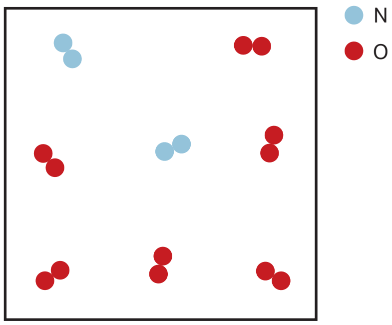
FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

1. The particle diagram below shows a mixture of N_2 and O_2 molecules before any reaction occurs.



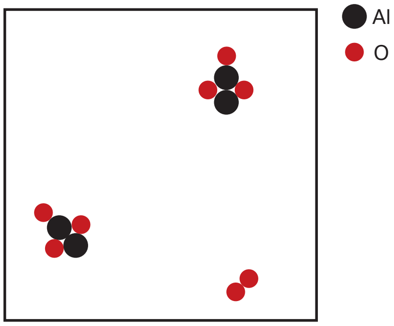
(a) The following reaction occurs: $N_2 + 2O_2 \rightarrow 2NO_2$. Draw a particle diagram of the mixture of products after the reaction.

(b) The limiting reactant is ______________.

The excess reactant is ______________.

(c) Justify your selection of limiting and excess reactant.

2. The particle diagram below shows the mixture of products after samples of aluminum and oxygen gas react according to the following equation: $4Al + 3O_2 \rightarrow 2Al_2O_3$.



Draw the reactant mixture that would produce the product mixture shown in the diagram.

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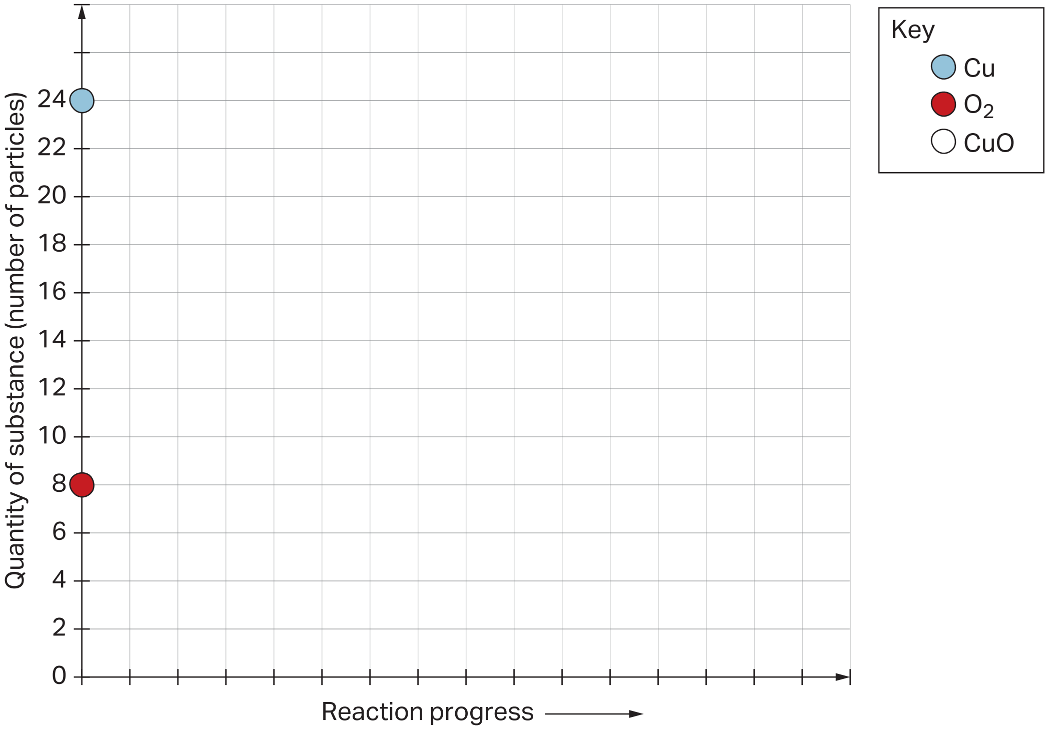
3. The graph below is set up to show the progress of a reaction that began with 24 atoms of Cu and 8 molecules of O_2. The initial quantities of reactants are already plotted on the graph.

(a) Complete each line of the graph, including a line for the product.



(b) Identify the reactant that corresponds to the line with the steeper slope and explain why the slope is steeper.

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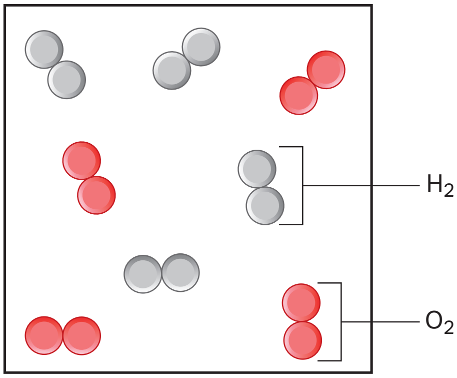
PART 1: INTRODUCTION TO LIMITING AND EXCESS REACTANTS

Students use a physical model and a particle diagram of a mixture of hydrogen and oxygen to determine how many molecules of water can be formed from the given number of reactant atoms. From this brief activity, students are introduced to the concept and vocabulary of limiting and excess reactants.

- To begin, remind students that they have learned a lot about chemical reactions and how to model them using particle diagrams and reaction equations. Tell them that you have a challenge for them that involves a situation they haven't encountered before, but have all the knowledge to figure out.
- Ask the students to work in small groups to make a model of four molecules of hydrogen gas and four molecules of oxygen gas using two different colors of bingo chips—preferably red for oxygen and white for hydrogen. Students should make a model that looks similar to the one shown at the right.



- Students will next create models of the reaction between hydrogen gas and oxygen gas that produces water vapor. It may be beneficial for students to see a macroscopic representation of the reaction before working with their models. You can show a video of someone igniting a hydrogen-filled balloon from a video sharing site.
- Present students with the following task:

Meeting Learners' Needs
Students may forget that hydrogen and oxygen occur as diatomic molecules. Remind them to consider which elements always exist as groups of two of the same type of atom.

> Consider the following chemical reaction:
>
> $$2H_2 + O_2 \rightarrow 2H_2O$$
>
> Modify your model to show the products of this reaction. How many molecules (or moles) of water would be made? Would any reactants be left over? If so, which ones?

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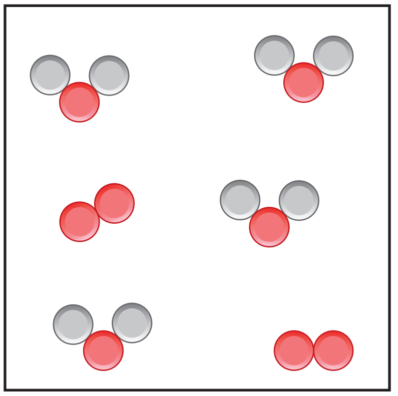

- Circulate among the groups to take note of how they are approaching the problem. Most groups will come up with the answers to the questions rather quickly, but possibly through different methods. Some students may break apart their existing models to create the products while others may make new models with additional bingo chips. Some groups may perform calculations before working with their models. Watch for groups that don't reference the given chemical equation and ask them how they could use the equation to help them. Students should produce a model similar to the one shown at the right.
- Once everyone has finished, have a few groups who approached the problem in different ways explain their methods to the rest of the class. Invite the rest of the class to ask questions about points that aren't clear and guide the student discussion toward the idea that a chemical equation gives us the "recipe" for how to make the products.
- Next, ask students to compare the reactants in the model: Which reactant would they say was "used up completely"? Which one was "left over"? Ask students to explain their choices. Then have them propose some other terms they could use instead of "used up" and "left over." Affirm their suggestions; you might want to record them on the board. Conclude by telling them that the agreed-upon name for the "used up" reactant is *limiting reactant* and for the "left over" reactant is *excess reactant*.

Instructional Rationale

Having students propose their own terminology before introducing the terms *limiting reactant* and *excess reactant* helps to promote authentic understanding of these concepts rather than rote memorization of vocabulary.

- To give students an opportunity to synthesize the information discussed so far, have them complete **Handout 3.4.A: Introduction to Limiting and Excess Reactants**. This handout instructs students to draw particle diagrams to represent the before and after states of this reaction and to write their own definitions of *limiting reactant* and *excess reactant*.

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- Next, to introduce the idea of stoichiometric ratios, point out to students that the excess O_2 molecule is not included in the reaction equation and that the coefficients of the substances in the reaction equation do not match the exact numbers of molecules they started with in the model. Ask them why they think this is, but refrain from validating their answers as correct or incorrect. Students may not have an accurate understanding of the meanings of the coefficients in a balanced equation yet. You can revisit this question later in the lesson to see if students' thinking has progressed.
- Ask students how many more molecules of hydrogen they would need to completely use up the excess oxygen and to model that using their bingo chips. Give them time to figure it out if necessary, and then tell students that when the quantities of both reactants would be completely used up in a reaction, they are said to be in a *stoichiometric ratio*. Note that while students should have a conceptual understanding of stoichiometric ratios, it's not critical for them to know this as a vocabulary term.
- Before moving on to the next part of the lesson, extend your students' thinking and help them develop their proportional reasoning with reactions by asking questions such as:
  - How many water molecules could be made from 8 hydrogen molecules and an unlimited supply of oxygen molecules?
  - How many oxygen molecules are needed to make 10 water molecules?

Meeting Learners' Needs

If your students are unfamiliar with the meanings of *limiting* and *excess*, it's worth spending a few minutes on these vocabulary words. You can point out the connection between *limiting* and the idea of speed limits, and the fact that *excess* shares the prefix *ex-* with *extra* and *exaggerate*.

Meeting Learners' Needs

For students who are struggling with proportional reasoning in the context of chemical reactions, ask some proportional reasoning questions about more familiar contexts, such as food recipes. Guide students to see that even when the context changes, the proportional reasoning strategies they have already developed can still be applied.

Guiding Student Thinking

When asking these initial questions involving proportional reasoning with reactions, the goal is to strengthen student confidence and understanding of the ratios involved, so use examples involving whole number multiples of the reaction coefficients.

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PART 2: MODELING LIMITING AND EXCESS REACTANTS WITH PARTICLE DIAGRAMS

Students model several chemical reactions using particle diagrams in order to identify limiting and excess reactants.

- Students should be prepared after Part 1 of the lesson to work with their group on **Handout 3.4.B: Modeling Limiting and Excess Reactants with Particle Diagrams**. The questions used in this part of the lesson are scaffolded so that students start with completing the products of a reaction and then work toward being able to determine the reactants based on the product mixture.
- While students are working, circulate around the room and ask guiding questions and extension questions like the ones in Part 1 to probe their understanding. Some additional tips for supporting students in this part of the lesson are:
  - Based on student responses to the question you posed earlier about the difference between the coefficients in the balanced equation and the actual numbers of particles reacting, you may want to focus your questioning on continuing that discussion.
  - You could have students pause after each reaction to compare their diagrams with those of another group and then revise them based on feedback.
  - Students can use multiple colors of bingo chips to support them in working through the questions, especially starting with question 4. Encourage students to make a key to indicate the bingo chip color used to represent specific elements.
- After students have completed their models of all five reactions, assign one reaction to each group and ask them to present their model and reasoning to the class.

Classroom Ideas
You might want to have students use whiteboards to share models with their peers so that they can more easily make revisions based on feedback.

Meeting Learners' Needs
If you find that students need more practice with the kinds of questions in this handout, have them complete the game section of PhET's Reactants, Products and Leftovers simulation as part of an in-class challenge: **https://phet.colorado.edu/en/simulation/reactants-products-and-leftovers**.

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PART 3: MODELING LIMITING AND EXCESS REACTANTS THROUGH GRAPHING

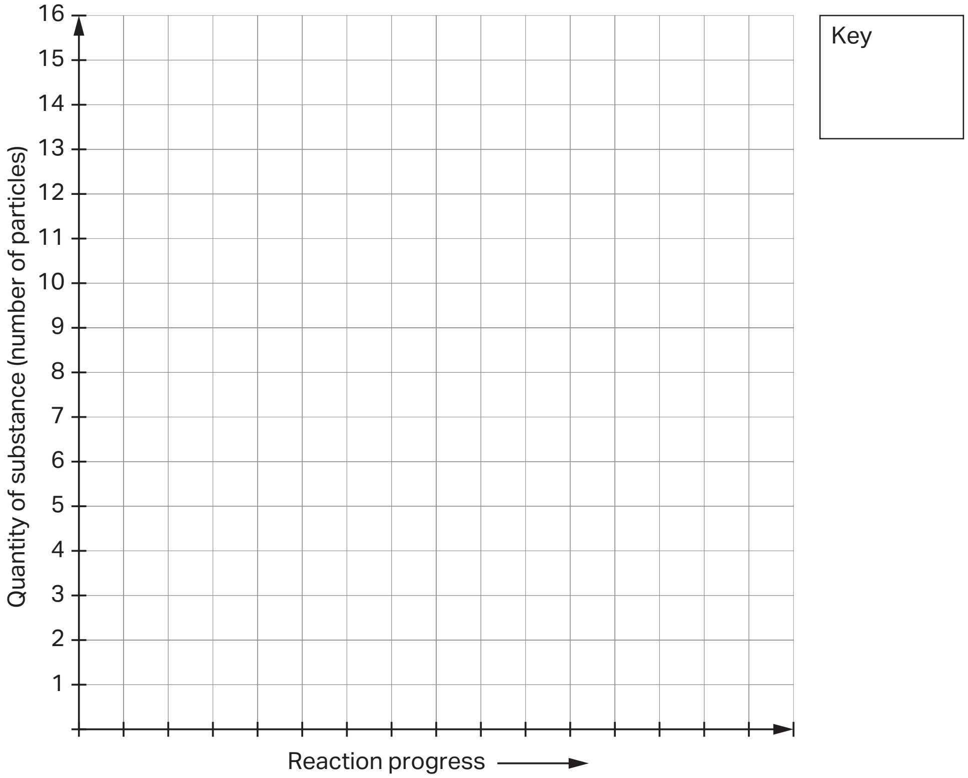
Students model a chemical reaction using a graph to show the quantity of reactants and products present in a reaction mixture over time. By introducing graphing as a way to represent stoichiometric concepts, in addition to particle diagrams and reaction equations, this lesson deepens students' conceptual model of reaction stoichiometry.

- Tell students they are going to look at one additional method of modeling a chemical reaction: graphing. Direct students to the question at the top of **Handout 3.4.C: Modeling Limiting and Excess Reactants Through Graphing** and have a volunteer read it aloud. The question involves the same kind of situation students have been working with in Parts 1 and 2, but this time, they will examine the reaction using graphing. The question and grid for graphing are shown below for reference.

Consider the following chemical equation:

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

Now suppose sodium and chlorine react in a mixture that has 16 atoms of sodium and 6 molecules of chlorine present. Graph the progress of the reaction on the provided grid.



Handout 3.4.C

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- Allow students time to study the question and the grid and share what they notice. They are likely to notice that the *x*-axis has no numbers while the *y*-axis does. They might wonder how to graph multiple reactants on the same grid. Use these observations to guide students toward figuring out what to plot on the graph. Here are some additional prompts you can use to guide students.
  - Ask students which grid line represents time zero on the graph and how many of each reactant and product exist at time zero. Plot the points for the students using different colors and have them plot the points on their own handouts. Students should add a key to the graph on their handout.
  - Next, solicit from students how many of each reactant are needed to make 1 unit of NaCl. What about 2 units of NaCl? As a class, plot answers to these questions on the graph. Ask students to describe what patterns emerge; they should see the amount of each reactant and product go up or down, but not at the same rate.
- Have the students complete the graph on their own or with their group. Once they have completed their graphs, ask them to add trend lines.

Guiding Student Thinking

Students may not realize that the reaction stops when the limiting reactant is used up. Be sure to monitor students as they work and be ready to ask them what would happen to the reaction if one reactant is gone. This is a good way to determine if students conceptually understand limiting reactants.

- Finally, ask students to add to their graph what would happen to each of the three lines if the graph were to continue after one reactant has been used up and have them complete the sentence stems below the graph.

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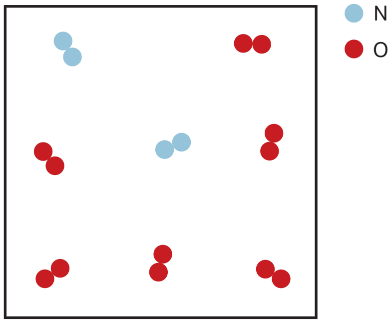
ASSESS AND REFLECT ON THE LESSON

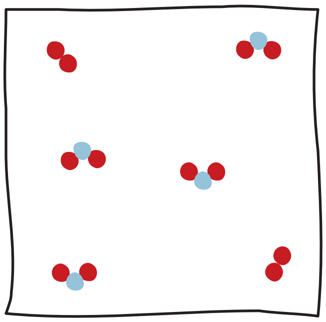
FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

1. The particle diagram below shows a mixture of N_2 and O_2 molecules before any reaction occurs.



(a) The following reaction occurs: $N_2 + 2O_2 \rightarrow 2NO_2$. Draw a particle diagram of the mixture of products after the reaction.



(b) The limiting reactant is N_2.

The excess reactant is O_2.

(c) Justify your selection of limiting and excess reactant.

O_2 is in excess because there is more of it present than is needed to react with the number of N_2 molecules that were present. The N_2 is completely used up in the reaction, meaning it is the limiting reactant.

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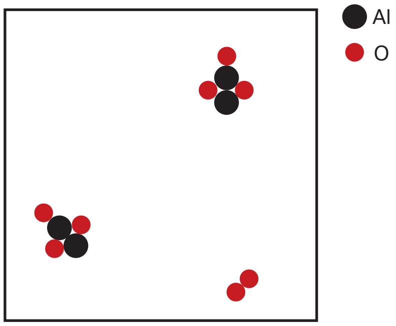
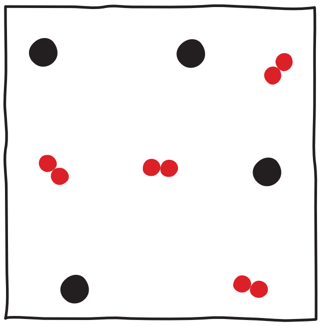
2. The particle diagram below shows a product mixture that follows the reaction $4Al + 3O_2 \rightarrow 2Al_2O_3$.



Draw the reactant mixture that would produce the product mixture shown in the diagram.



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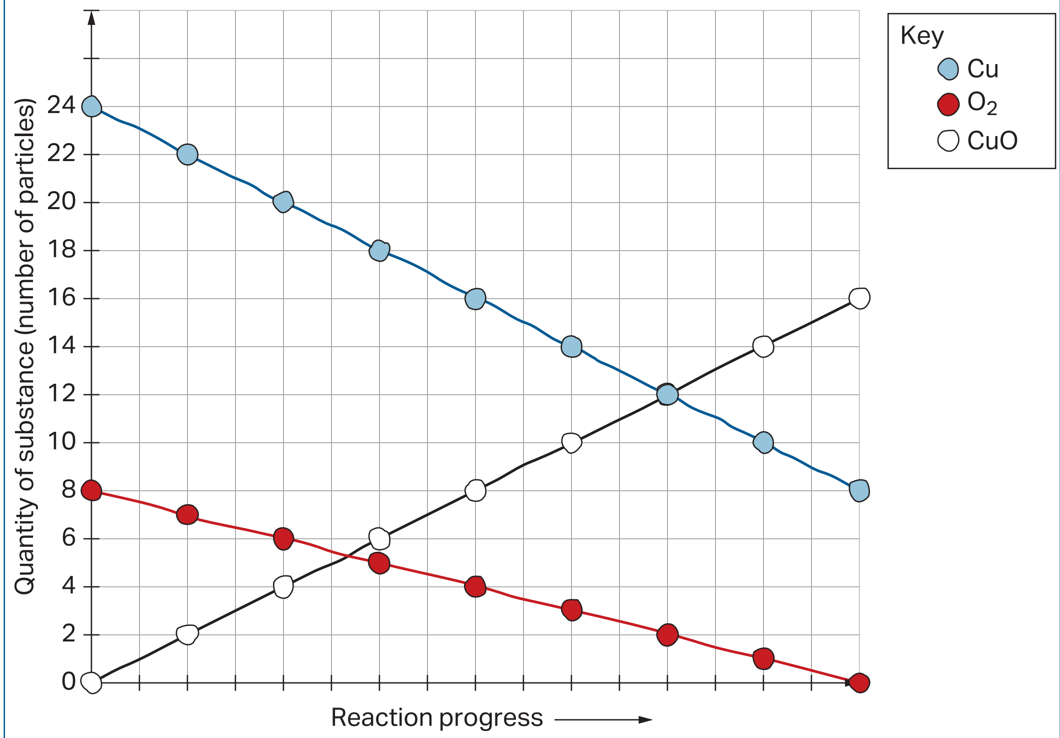
3. The graph below is set up to show the progress of a reaction that began with 24 atoms of Cu and 8 molecules of O_2. The initial quantities of reactants are already plotted on the graph.

(a) Complete each line of the graph, including a line for the product.



(b) Explain why the slope of the line representing the number of Cu atoms is steeper than the slope of the line representing the number of O_2 molecules.

As the reaction progresses, two atoms of Cu react for each molecule of O_2 because the product has the molecular formula CuO. So, for each unit of decrease in the number of O_2 molecules, the number of Cu atoms decreases by 2 and the number of CuO molecules increases by 2.

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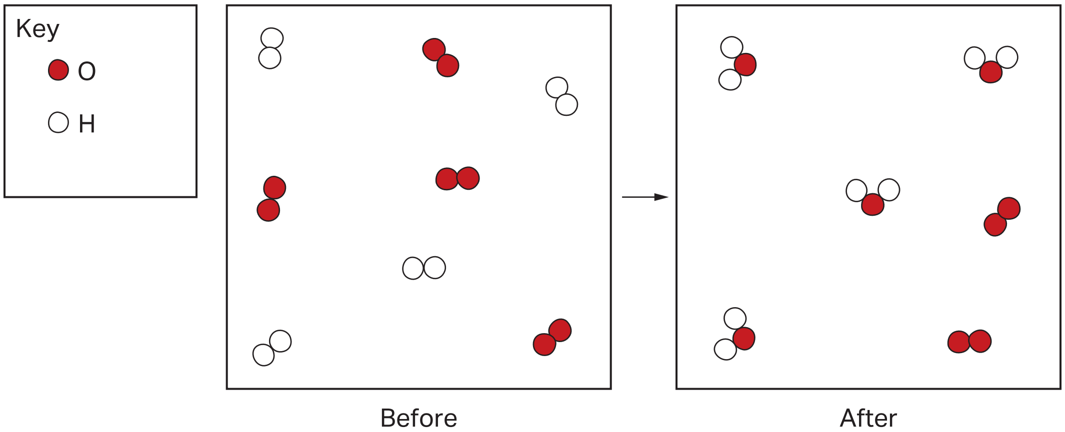
HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 3.4.A: Introduction to Limiting and Excess Reactants

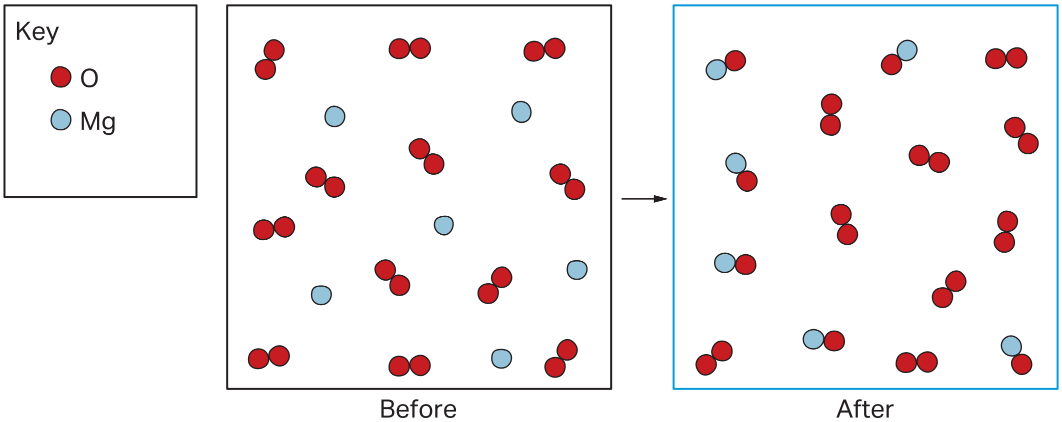
1.



2. Answers will vary but should reflect a correct understanding of the terms.

Handout 3.4.B: Modeling Limiting and Excess Reactants with Particle Diagrams

1.



Limiting reactant: Mg; Excess reactant: O_2

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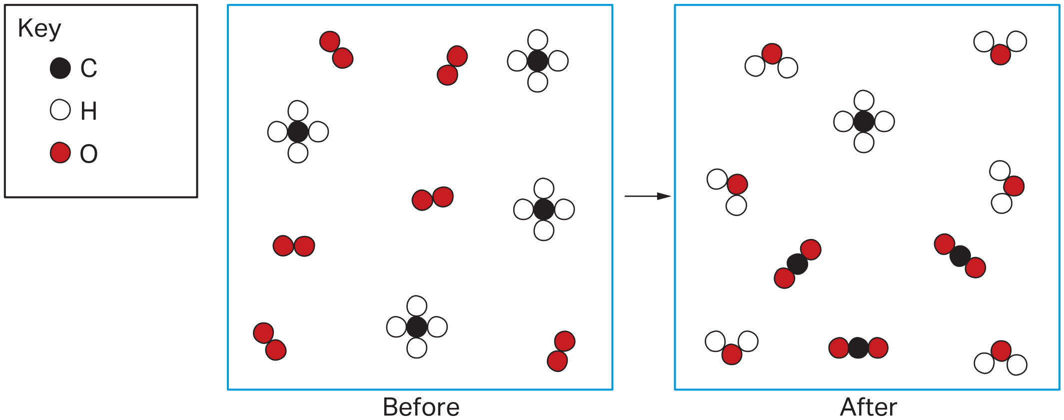
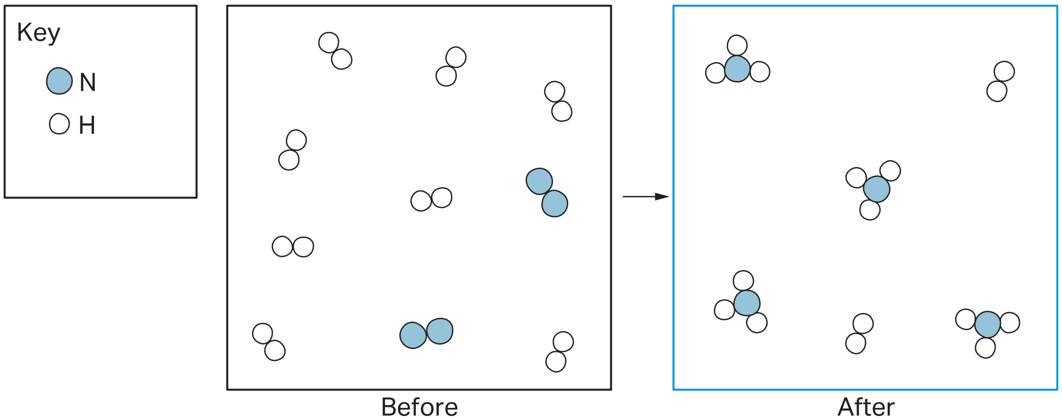
2. 1 CH_4 + 2 O_2 → 1 CO_2 + 2 H_2O



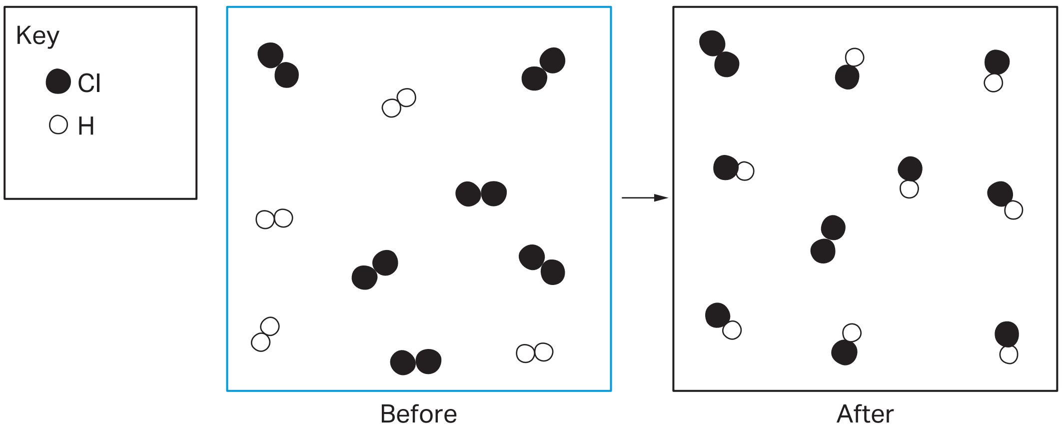
Limiting reactant: O_2; Excess reactant: CH_4

3. 1 N_2 + 3 H_2 → 2 NH_3



Limiting reactant: N_2; Excess reactant: H_2

4. 1 H_2 + 1 Cl_2 → 2 HCl



Limiting reactant: H_2; Excess reactant: Cl_2

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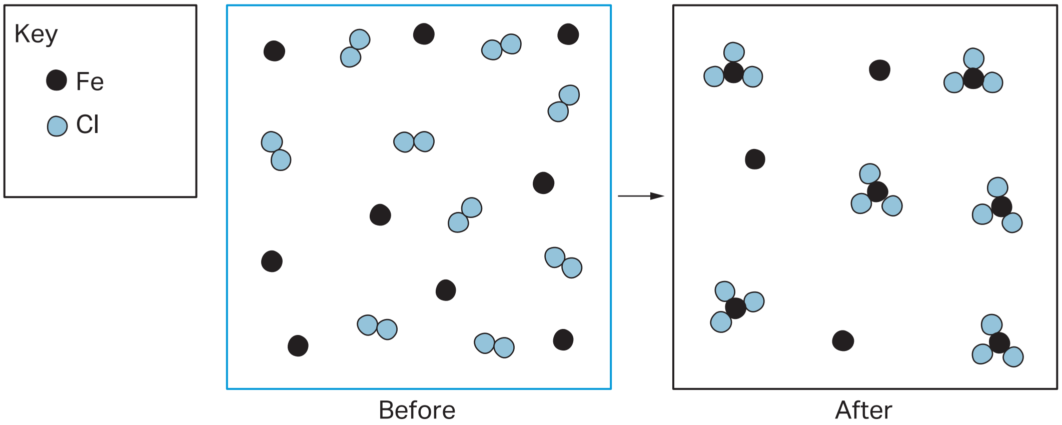
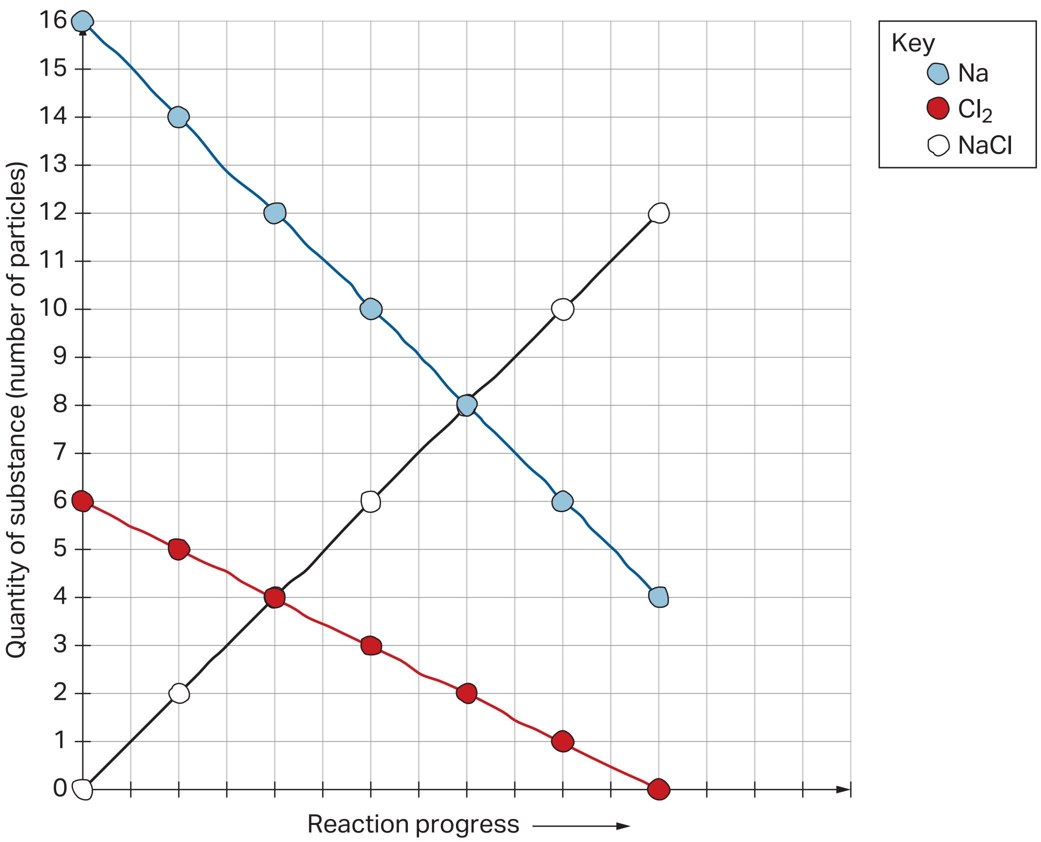
5. 2 Fe + 3 Cl_2 → 2 $FeCl_3$



Limiting reactant: Cl_2; Excess reactant: Fe

Handout 3.4.C: Modeling Limiting and Excess Reactants Through Graphing



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- The line representing Na would be horizontal because there is no more chlorine left for it to react with, so the reaction will stop.
- The line representing Cl_2 would be horizontal because chlorine is the limiting reactant, so there is no more of it left.
- The line representing NaCl would be horizontal because there is no more chlorine left to react, so the reaction stops and no more NaCl is produced.

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Unit 3

Performance Task

UNIT 3

PERFORMANCE TASK

The Chemistry of Respiration

OVERVIEW

DESCRIPTION

In this performance task, students are given information about similarities and differences in how humans and yeast acquire energy under aerobic and anaerobic conditions. In questions 1 and 2, students analyze the balanced equations for both aerobic and anaerobic respiration in order to make claims about the relative masses and numbers of moles of products of the two reactions given the same starting mass of glucose. In questions 3 and 4, students are asked to generate particle diagrams of the reactants that appropriately match the end products of one anaerobic and one aerobic respiration reaction. Question 5 assesses students' understanding of gas stoichiometry as they analyze an experimental setup investigating anaerobic respiration. Students also analyze experimental error.

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 3 Performance Task: The Chemistry of Respiration

MATERIALS

- calculator
- equation sheet
- periodic table

CONTENT FOCUS

This task asks students to apply stoichiometric concepts in a number of ways, including engaging their thinking through the use of multiple representations. Questions 1 and 2 assess students' ability to think about how the moles and masses of reactants and products in a reaction are related to each other and expressed in a balanced chemical equation. These questions require students to demonstrate their understanding by crafting claims and writing justifications to support those claims. Questions 3 and 4 ask students to demonstrate their understanding of limiting reactants and the conservation of mass on the particle scale by developing models. Question 5 assesses their ability to integrate concepts about gases with stoichiometric concepts. Students demonstrate their understanding as they analyze an experimental setup and are asked to conduct error analysis. All these applications and representations are important to the development of a coherent understanding of stoichiometry, which is fundamental to students' success in their further study of chemistry.

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UNIT 3

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction. ▪ In chemical reactions, bonding between atoms changes, leading to new compounds with different properties.	
Learning Objectives	**Essential Knowledge**
3.1.A.2 Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.
3.1.B.2 Perform calculations using the ideal gas law.	**3.1.B** The ideal gas law describes the mathematical relationship between pressure, volume, number of gas particles, and temperature. **a.** Two samples of gas with the same pressure, volume, and temperature have the same number of particles. **b.** The mass of the particles can be computed from atomic masses. **c.** Because macroscopic samples of a gas contain many particles, moles are useful units for counting particles.
3.2.A.1 Create and/or evaluate models of chemical transformations.	**3.2.A** All chemical transformations involve the rearrangement of atoms to form new combinations. **a.** Since the atoms are not created or destroyed, the total numbers of each atom must remain constant. **b.** Chemical transformations can be modeled by balanced chemical equations and particulate representations.

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3.2.B.1 Explain the relationship between the quantity of reactants consumed and the quantity of products formed in a chemical transformation. **3.2.B.2** Perform stoichiometric calculations involving the quantity of reactants and products in a chemical system.	**3.2.B** A balanced chemical reaction equation, combined with the mole concept, can be used to quantify the amounts of reactants consumed and products formed during a chemical transformation.
3.2.C.1 Create and/or evaluate models of a reaction mixture before and/or after a reaction has occurred, including situations with a limiting reactant.	**3.2.C** The limiting reactant is the reactant that is completely consumed during a chemical reaction. The limiting reactant determines the amount of product formed.

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SUPPORTING STUDENTS

BEFORE THE TASK

If you feel students need additional support before working on this performance task, you could do one or both of the following:

- Give students a balanced chemical equation and have them draw particle diagrams that represent various reactant mixtures.
- Give students practice problems that require the use of mole ratios and the ideal gas law.

DURING THE TASK

- Students could work in pairs. It is not recommended that students work in small groups. There is ample work and enough potential discussion areas for two students, but in larger groups, there may not be quite enough for everyone to meaningfully engage in the task.
- You could also divide the task into smaller parts and allow students to check their work after each part.
- Students could potentially confuse the types of respiration in each question. Consider having them highlight or underline the types so they are less likely to confuse them.

AFTER THE TASK

- If you feel your students need more practice with stoichiometric calculations, including limiting reactants, or representing reactions using particle diagrams, you could use the reactions given in this task with new scenarios. For example, you could ask students to determine the maximum mass of CO_2 that could be produced by the yeast in the flask.
- Similarly, if students need additional practice representing reactions, you could give them different starting quantities of reactants for both aerobic and anaerobic respiration and have them represent the products using particle diagrams.

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SCORING GUIDELINES

There are 17 possible points for this performance task.

Question 1

Sample Solutions	Points Possible
Greater than. From the stoichiometric coefficients in the balanced equations, 1 mole of glucose yields 6 moles of carbon dioxide in aerobic respiration but only 2 moles in anaerobic respiration. In aerobic respiration all the carbon in the glucose is converted to carbon dioxide, while in anaerobic respiration some of the carbon in the glucose is converted to ethanol and some to carbon dioxide.	**2 points maximum** 1 point for a correct choice 1 point for a correct explanation
Targeted Feedback for Student Responses	
Encourage students to use mole ratios to reason about the relationships between reactants and products. They can also use conservation of mass.	

TEACHER NOTES AND REFLECTIONS

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Question 2

Sample Solutions	Points Possible
Greater than. When glucose reacts in aerobic respiration, there is an additional reactant (oxygen), so the total mass of the reactants when 100 g of glucose reacts will be greater than 100 g. In anaerobic respiration, glucose is the sole reactant, so the total mass of reactants when 100 g of glucose reacts is exactly 100 g. Since the mass of products in a reaction is equal to the mass of reactants consumed (assuming a complete reaction), the mass of products in aerobic respiration is greater.	**2 points maximum** 1 point for a correct choice 1 point for a correct explanation
Targeted Feedback for Student Responses	
Remind students that mass is conserved in chemical reactions. Ask them if oxygen gas has mass and what that would mean about the total mass of reactants in aerobic respiration versus anaerobic respiration. Some students may try to use stoichiometric calculations to determine the answer. While this process will produce a correct answer, it is time consuming. If you see students using calculations, encourage them instead to try to reason through the scenario using their conceptual understanding.	

TEACHER NOTES AND REFLECTIONS

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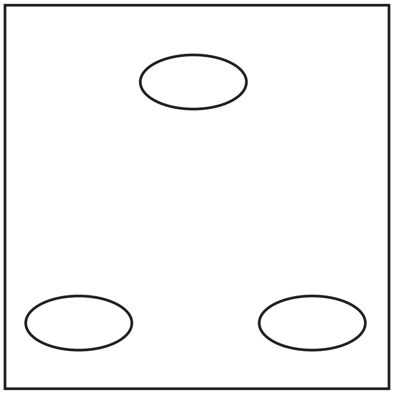
Question 3

Sample Solutions	Points Possible
A correct response will show 3 molecules of glucose. 	**2 points maximum** 1 point for showing at least one glucose molecule AND no other reactants 1 point for the correct number of glucose molecules

Targeted Feedback for Student Responses
Ask students to write out the mole ratios for the reactants and products and to use those ratios to reason about the quantities of reactants and products.

TEACHER NOTES AND REFLECTIONS

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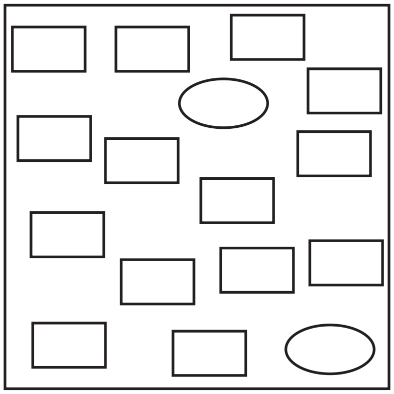
UNIT 3

Question 4

<table>
<tr><th>Sample Solutions</th><th>Points Possible</th></tr>
<tr><td>A correct response will show 2 molecules of glucose and 14 molecules of oxygen.
</td><td>3 points maximum
1 point for showing at least one glucose molecule AND one oxygen molecule AND no other reactants
1 point for the correct number of glucose molecules
1 point for the correct number of oxygen molecules</td></tr>
<tr><th colspan="2">Targeted Feedback for Student Responses</th></tr>
<tr><td colspan="2">Ask students to write out the mole ratios for the reactants and products and to use those ratios to reason about the quantities of reactants and products. Since the diagram shows 12 molecules of each product particle and 6 is the coefficient of each product in the equation, the number of glucose molecules that react must also be double its coefficient, which is 2. The product mixture shows 2 unreacted oxygen molecules, so there must have been 12 + 2, or 14, oxygen molecules present before the reaction.</td></tr>
</table>

TEACHER NOTES AND REFLECTIONS

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Question 5, part (a)

Sample Solutions	Points Possible
$PV = nRT$ $n = \frac{PV}{RT}$ $n = \frac{(1.0\text{ atm})(0.55\text{ L})}{\left(0.0821\frac{\text{L} \times \text{atm}}{\text{mol} \times \text{K}}\right)(318\text{ K})}$ $n = 0.021\text{ mol } CO_2$	**3 points maximum** 1 point for correctly converting volume to liters and temperature to Kelvin (can be implicit) 1 point for a correct setup 1 point for a correct answer *Scoring note:* No points are assigned for correct significant figures.
Targeted Feedback for Student Responses	
Volume must be in liters and temperature in Kelvin for the ideal gas law. Encourage students to underline or highlight relevant information in the question that can be used in a calculation.	

TEACHER NOTES AND REFLECTIONS

Question 5, part (b)

Sample Solutions	Points Possible
180.2 g/mol or 180.2 g	**1 point maximum** 1 point for a correct answer with units
Targeted Feedback for Student Responses	
Remind students to use the periodic table to determine molar masses of substances.	

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TEACHER NOTES AND REFLECTIONS

Question 5, part (c)

Sample Solutions	Points Possible
No. From part (a), 0.021 mol of CO_2 was produced. This means that 1.9 g of glucose reacted. $0.021\ \text{mol}\ CO_2 \times \frac{1\ \text{mol}\ C_6H_{12}O_6}{2\ \text{mol}\ CO_2} \times \frac{180.2\ \text{g}\ C_6H_{12}O_6}{1\ \text{mol}\ C_6H_{12}O_6}$ $= 1.9\ \text{g}\ C_6H_{12}O_6$ 10.0 g of glucose was present initially and 1.9 g reacted, so not all the glucose reacted.	**3 points maximum** 1 point for the correct mole ratio 1 point for the mass of glucose that reacted 1 point for comparing the amount consumed to the starting amount *Scoring notes*: ▪ If a student incorrectly calculated the molar mass in part (b) but uses that molar mass correctly in part (c), they should receive credit for their work in part (c). ▪ No points are assigned for correct significant figures.
Targeted Feedback for Student Responses	
Remind students to use mole ratios when determining the relationship between the amount of reactants consumed and the amount of products produced. The mass of glucose that reacted can be determined from the moles of carbon dioxide produced.	

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TEACHER NOTES AND REFLECTIONS

Question 5, part (d)

Sample Solutions	Points Possible
More than. Volume and number of moles of a gas are directly proportional if all other conditions remain the same. Therefore, a larger volume would mean a larger number of moles of carbon dioxide produced, which in turn would mean a larger mass of glucose reacted.	**1 point maximum** 1 point for a correct choice and explanation

Targeted Feedback for Student Responses
This question requires students to understand that the effect of an experimental error on a calculated value can be systematically analyzed by considering the algebraic relationship between the measured value and the calculated value. To help students get started, ask them what the relationship is between volume and moles. From math class, students may be familiar with the terms *vary directly* or *direct variation*, so they may use those terms in addition to or instead of *directly related* or *directly proportional.*

TEACHER NOTES AND REFLECTIONS

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The Chemistry of Respiration

Read the following text. Then answer the questions below based on the text and your knowledge of chemistry.

RESPIRATION IN YEAST

Yeast is a microscopic, single-celled fungus that we rely on for producing many types of food, including some breads. Yeast cells are remarkably similar to human cells in how they acquire energy to maintain their cellular functions. The cells of both yeast and humans, like those of most organisms, have the ability to metabolize glucose, $C_6H_{12}O_6$. If oxygen is present, glucose can be metabolized in a process known as *aerobic respiration*, which results in the production of carbon dioxide and water. Aerobic respiration is represented by the following balanced equation:

$$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$

Both yeast and humans also have processes to acquire energy when no oxygen is present. However, yeast cells have a unique *anaerobic respiration* process that human cells do not: this process still relies on glucose as a reactant, but produces carbon dioxide and ethanol. Anaerobic respiration is represented by the following balanced equation:

$$C_6H_{12}O_6(s) \rightarrow 2\ C_2H_5OH(l) + 2\ CO_2(g)$$

1. Examine the two scenarios below.

   - Scenario A: 1 mole of glucose in the presence of unlimited oxygen is metabolized through **aerobic** respiration.
   - Scenario B: 1 mole of glucose in the absence of oxygen is metabolized through **anaerobic** respiration.

   Would the number of moles of carbon dioxide produced in Scenario A be greater than, less than, or equal to the number of moles of carbon dioxide produced in Scenario B? Justify your answer.

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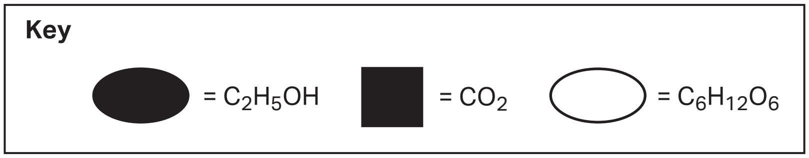
PERFORMANCE TASK

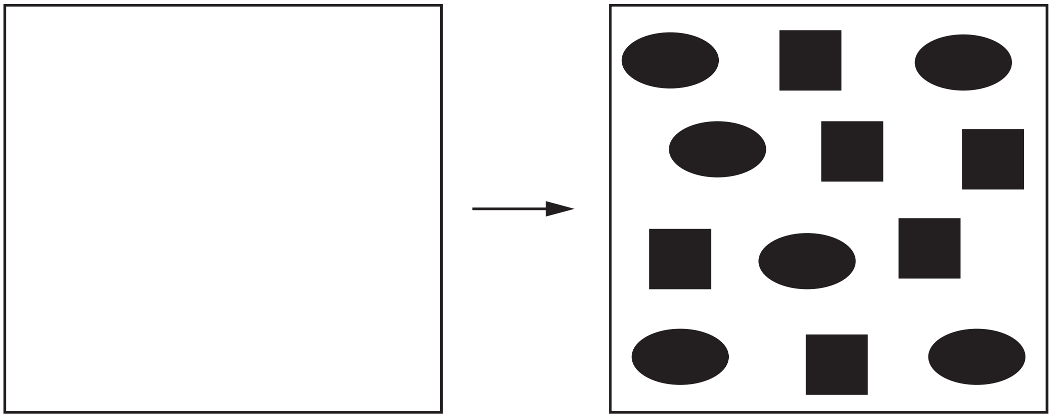
2. Examine the two scenarios below.
   - Scenario A: 100 g of glucose in the presence of unlimited oxygen is metabolized through **aerobic** respiration.
   - Scenario B: 100 g of glucose in the absence of oxygen is metabolized through **anaerobic** respiration.

   Would the mass of products produced in Scenario A be greater than, less than, or equal to the mass of products produced in Scenario B? Justify your answer.

3. A sample of glucose reacts in **anaerobic** respiration. The right-hand box below shows a particle diagram of the moles of substances present after the reaction is complete.

   In the left-hand box, draw a particle diagram of the reactant molecules that produced the mixture shown on the right.





Before

After

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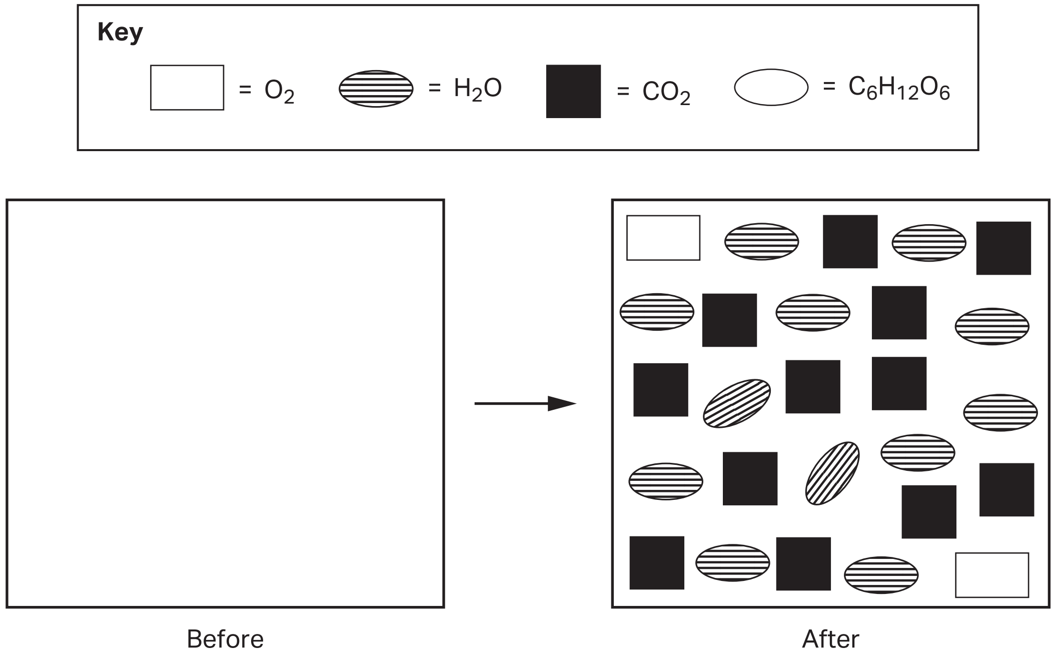
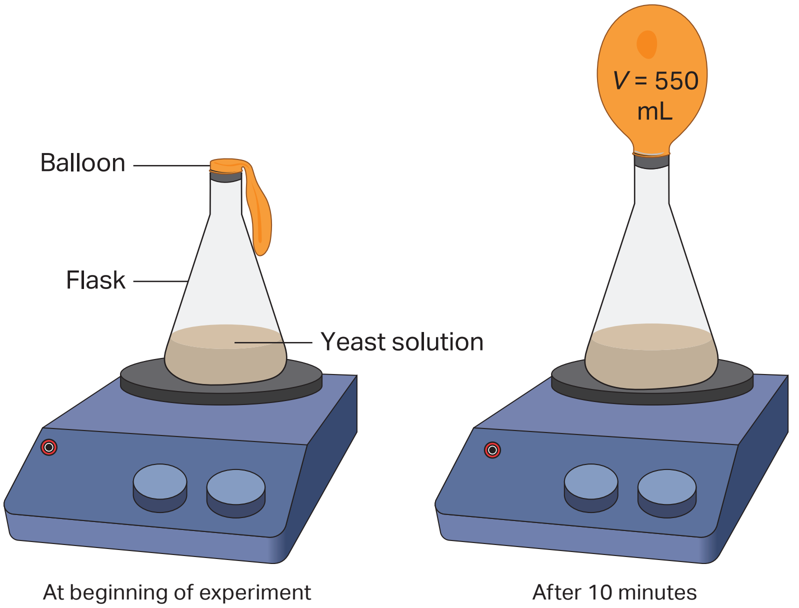
4. A mixture of glucose and oxygen reacts in **aerobic** respiration. The right-hand box below shows a particle diagram of the moles of substances present after the reaction is complete.

   In the left-hand box, draw a particle diagram of the reactant molecules that produced the mixture shown on the right.



PERFORMANCE TASK

5. A student conducts a laboratory investigation of **anaerobic** respiration. The student places 10.0 g of glucose in a yeast solution in a small flask with an uninflated balloon over the top of the flask as shown below. The experiment is conducted at a temperature of 45°C and a pressure of 1.0 atm. After 10 minutes, the student estimates the volume of the balloon to be 550 mL.



(a) Assuming that the volume of the balloon is equal to the volume of carbon dioxide gas produced in the reaction, calculate the number of moles of carbon dioxide produced.

(b) Calculate the molar mass of glucose.

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(c) Did all the glucose react during the experiment? Justify your answer with a calculation and an explanation.

(d) If the student's estimate of the balloon's volume was incorrect and the actual volume was 620 mL, would the amount of glucose that actually reacted be more than or less than the amount calculated in part (c)? Explain your response.

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Unit 4

Unit 4
Chemical Transformations

Overview

SUGGESTED TIMING: APPROXIMATELY 8 WEEKS

In this unit, students explore the primary driving forces in chemical reactions through symbolic, particulate, and mathematical representations. The study of precipitation reactions, oxidation–reduction reactions, and acid–base reactions allows students to apply what they have learned about bonding in Unit 2 and stoichiometric relationships in Unit 3 as they explore specific reaction types and predict products of reactions. An emphasis on net ionic equations allows students to focus on the substances that are directly involved in chemical reactions. Students also revisit and extend the concepts of energy from Unit 1 as they apply them to energy changes involved in chemical transformations, building to the fundamental understanding that breaking chemical bonds requires energy and that bond formation releases energy. Students also study the rates of chemical reactions and factors that influence the rates, using a particulate perspective.

ENDURING UNDERSTANDINGS

This unit focuses on the following enduring understandings:

- Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.
- All chemical reactions are accompanied by a transfer of energy.
- Chemical reactions occur at varying rates that are related to the frequency and success of collisions between reactants.

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KEY CONCEPTS

This unit focuses on the following key concepts:

- 4.1: Precipitation Chemistry
- 4.2: Oxidation–Reduction Chemistry
- 4.3: Acid–Base Chemistry
- 4.4: Thermochemistry
- 4.5: Reaction Rates

UNIT RESOURCES

The tables below outline the resources provided by Pre-AP for this unit.

Lessons for Key Concept 4.1: Precipitation Chemistry				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.1: Introduction to Precipitation Reactions	4.1.A.1, 4.1.B.1	4.1.A, 4.1.B	~90 minutes	Attention to Modeling
4.2: Molarity and Precipitation Reactions	4.1.B.1, 4.1.C.1, 4.1.C.2, 4.1.D.1, 4.1.D.2	4.1.B, 4.1.C, 4.1.D	~105 minutes	Attention to Modeling, Strategic Use of Mathematics
All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.				

Lessons for Key Concept 4.2: Oxidation–Reduction Chemistry				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.3: The Chemistry of Rusting – An Introduction to Redox Reactions	4.2.A.1, 4.2.A.2, 4.2.C.1	4.2.A.a, 4.2.A.b, 4.2.A.c, 4.2.C	~45 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling

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4.4: Redox Reactions – Rusting Nails and Tarnishing Silver	4.2.A.1, 4.2.A.2, 4.2.C.1	4.2.A.a, 4.2.A.b, 4.2.A.c, 4.2.C	~75 minutes	Attention to Modeling

The following Key Concept 4.2 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: 4.2.B.1, 4.2.B.2
- Essential Knowledge Statement: 4.2.B

Learning Checkpoint 1: Key Concepts 4.1 and 4.2 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements for Key Concepts 4.1 and 4.2. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Practice Performance Task for Unit 4 (~45 minutes)

This practice performance task assesses learning objectives and essential knowledge statements addressed up to this point in the unit.

Lessons for Key Concept 4.3: Acid–Base Chemistry

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
4.5: Acids, Bases, and pH	4.3.A.1, 4.3.A.2, 4.3.A.3, 4.3.B.1	4.3.A, 4.3.B	~90 minutes	Strategic Use of Mathematics, Attention to Modeling
4.6: Classifying Reactions	4.1.A.1, 4.1.B.1, 4.2.A.1, 4.2.C.1, 4.3.C.1, 4.3.D.1	4.1.A, 4.1.B, 4.2.A.a, 4.2.A.b, 4.2.A.c, 4.2.C, 4.3.C, 4.3.D	~45 minutes	Attention to Modeling

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The following Key Concept 4.3 learning objective is not addressed in Pre-AP lessons. Address this in teacher-developed materials.

- Learning Objective: 4.3.B.2

Lessons for Key Concept 4.4: Thermochemistry

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
4.7: Bond Energy and Fuel Reactions	4.4.B.1	4.4.B	~45 minutes	Strategic Use of Mathematics, Attention to Modeling

The following Key Concept 4.4 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address this in teacher-developed materials.

- Learning Objectives: 4.4.A.1, 4.4.A.2, 4.4.A.3
- Essential Knowledge Statements: 4.4.A.a, 4.4.A.b

Lessons for Key Concept 4.5: Reaction Rates

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
4.8: Antacid Rate of Reaction Lab	4.5.A.2	4.5.A.a, 4.5.A.b, 4.5.A.c	~105 minutes	Attention to Modeling, Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing

The following Key Concept 4.5 learning objective is not addressed in Pre-AP lessons. Address this in teacher-developed materials.

- Learning Objective: 4.5.A.1

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Learning Checkpoint 2: Key Concepts 4.3–4.5 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts 4.3, 4.4, and 4.5. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 4 (~45 minutes)

This performance task assesses learning objectives and essential knowledge statements from the entire unit.

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LESSON 4.1

Introduction to Precipitation Reactions

OVERVIEW

LESSON DESCRIPTION

Part 1: Observing and Modeling a Precipitation Reaction
Students observe a demonstration of a precipitation reaction and make particulate models of the reactants and products.

Part 2: Precipitation Dropper Lab
Students build on knowledge gained in Part 1 by performing several precipitation reactions using a reaction grid and dropper bottles, and then model the reactions using equations and particle diagrams.

Part 3: Deionized Water Versus Tap Water
Students address one last scenario as a class to learn about the difference between deionized water and tap water.

CONTENT FOCUS

This lesson introduces students to precipitation reactions, the first of three reaction types they will learn about in this unit (the other two being oxidation–reduction and acid–base reactions). After observing a demonstration of a precipitation reaction, students use their prior knowledge of solutions and ionic interactions in order to deduce what the yellow product is and then create particulate models and equations to support their claims. Through this exercise, students gain an understanding of the benefits and shortcomings of different reaction equations (molecular, complete ionic, and net ionic), learn how

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 4.1.A: Precipitation Reactions Lab
- 4.1.B: Precipitation Reactions Lab Mat

MATERIALS

For teacher demonstration:

- 0.1 *M* solutions of lead(II) nitrate and potassium iodide
- test tubes
- conductivity meter (optional)
- $AgNO_3$ solution (optional)
- deionized water (optional)
- tap water (optional)

For each group:

- whiteboards and markers or bingo chips to model reactions

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to identify a precipitation reaction, and predict possible products from the mixing of two aqueous solutions.

Some lessons on net ionic equations and precipitation reactions focus only on manipulation at the symbolic level of understanding (i.e., reaction equations), leaving students to memorize a set of steps in order to produce a net ionic equation. In this lesson, students interact with each system at the macroscopic, symbolic, and particle levels and draw on prior understanding so that the reaction equations are infused with more meaning.

- 0.1 *M* solutions of the following:
  - sodium carbonate
  - sodium hydroxide
  - ammonium nitrate
  - calcium chloride
- plastic page protector
- toothpicks
- paper towels
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.1.A.1 Predict the products of a precipitation reaction.	**4.1.A** Precipitation reactions may occur when two aqueous solutions are mixed, because some ionic compounds are insoluble in water and therefore precipitate out of solution.
4.1.B.1 Create and/or evaluate models of precipitation reactions.	**4.1.B** Precipitation reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

SETUP AND PREPARATION NOTES

- For the demonstration of the lead(II) iodide precipitate, have an additional test tube already prepared so that the precipitate has had time to settle to the bottom. This will allow students to see the solid product if it is difficult to see while suspended in solution.
- The use of these ions as a small-scale demonstration is recommended to minimize the waste produced.
- You may want to provide each lab group with dropper bottles or disposable pipettes filled with each solution.

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- If you do not have the chemicals indicated in the lab, you can use appropriate substitutes. Ideally, some reactions will produce a precipitate and some will not. It is also best if reactions have mole ratios that are not all 1:1.

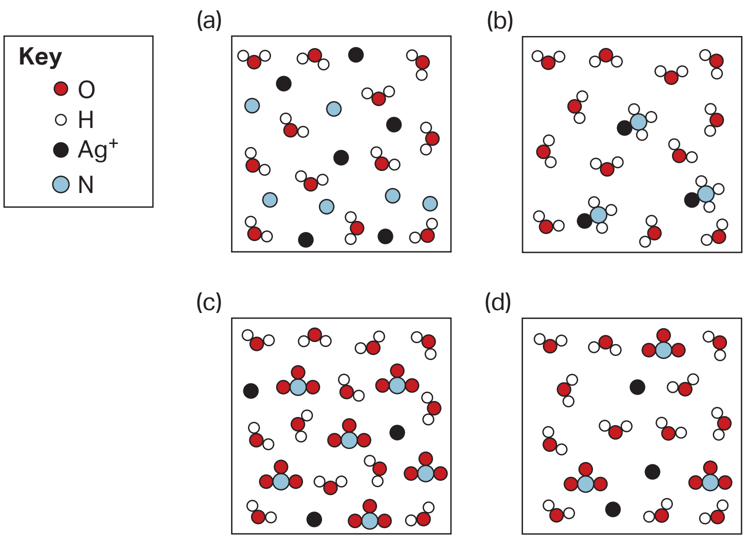
SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear chemical splash goggles.
- Dispose of waste products properly.

FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

1. A student mixes a solution of $Mg(NO_3)_2(aq)$ with a solution of $NaF(aq)$ and observes the formation of a white precipitate.
   (a) Write the net ionic equation that shows the formation of the precipitate.
   (b) Explain at least one benefit and one shortcoming of representing the reaction using a net ionic equation as opposed to a different type of equation.
2. Answer the following questions about mixing solutions of $AgNO_3(aq)$ and $NaCl(aq)$.
   (a) Which of the following particle diagrams best illustrates a solution of $AgNO_3(aq)$? Justify your answer.



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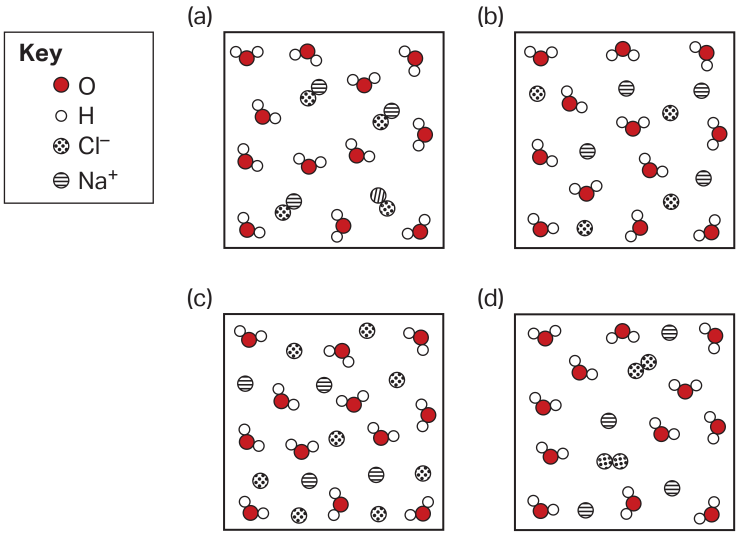
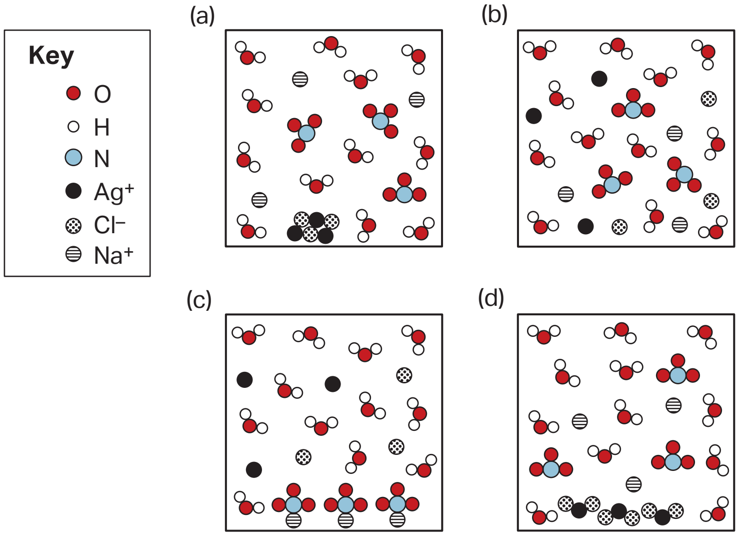
(b) Which of the following particle diagrams best illustrates a solution of NaCl(*aq*)? Justify your answer.



(c) Which of the following particle diagrams best represents the mixture of the two solutions? Justify your answer.



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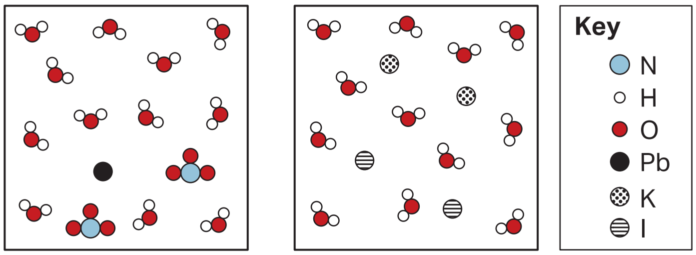
PART 1: OBSERVING AND MODELING A PRECIPITATION REACTION

In this part of the lesson, students observe a demonstration of a precipitation reaction and make particulate models of the reactants and products.

Instructional Rationale

This part of the lesson allows students to connect their macroscopic observations with particle diagrams and symbolic representations. The actual reaction studied is less important than the thinking the students are asked to do, but if you choose a different reaction, try to select something without all 1:1 mole ratios. Spending the time to deeply examine one reaction will enable students to transfer their understanding to other precipitation reactions in the future.

- First, ask students how they would define a *chemical reaction* at this point in their learning. After some discussion, tell them that, in this unit, they are going to build on the knowledge they've developed so far in the course to learn about three types of reactions.
- Show students aqueous solutions of 0.1 *M* KI and 0.1 *M* $Pb(NO_3)_2$ and give them the molecular formula of each. Ask students to make observations of each solution and record those observations on the board.
- Ask students if each compound is ionic or molecular in character. Guide them to see that both solutions are ionic because they contain metal cations and nonmetal anions. Also ask them what laboratory test they could perform to confirm their claims and, if possible, show them, using a conductivity meter, that both solutions conduct electricity.
- Next, have students work in small groups to create particulate models of the two solutions. Students could use bingo chips or draw on whiteboards. Circulate around the room to assist students if needed as they work. You can encourage them to leave out the water to make the diagrams simpler. Sample particulate models are shown below.



$Pb(NO_3)_2(aq)$ KI(*aq*)

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- Once students have created their models, bring the groups back together as a class. Ask several groups about different aspects of their models such as relative numbers of ions and dissociated/undissociated species.
- Next, show students the following two symbolic representations of each solution:
  - $KI(aq)$ and $K^+(aq) + I^-(aq)$
  - $Pb(NO_3)_2(aq)$ and $Pb^{2+}(aq) + 2NO_3^-(aq)$

  Ask them what they think the benefits and shortcomings of each representation are. Students are likely to point out that the first representation is more concise and easier to write, while the second takes more time but may be a more realistic representation. Expand on this observation by noting that both of these models are acceptable ways of representing the solutions and serve different purposes. The addition of (*aq*) in the first representation tells a chemist that the solution contains a dissociated ionic substance, which is what the second representation shows.
- Next, in a small test tube, mix the two solutions and show students the precipitate that forms. Then ask:
  - What do you think the product is made of?

    After hearing some ideas, make sure students understand that it must be made of things present in the two solutions that were the reactants.
  - Is the product soluble or insoluble?

    Insoluble.
- Now that students have seen the reaction and discussed the product, give them time to work in their groups on drawing or building a particulate model of the product mixture that identifies all species present in it, especially the solid product. Encourage them to use their models of the reactant mixture to help them. A sample particle diagram is shown on the next page.

Classroom Ideas

This reaction was chosen for the bright yellow precipitate that forms. If you are concerned with disposal of the lead(II) iodide, you can choose a different precipitation reaction to demonstrate. You could also find a video of the formation of a lead(II) iodide precipitate to show students.

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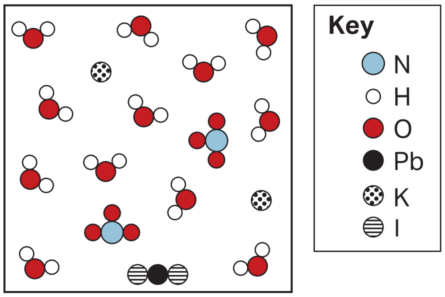

$KNO_3(aq)$ and $PbI_2(s)$

Guiding Student Thinking

Part of the goal of this task is to help students conclude on their own that they need to apply solubility rules and figure out how to do so. If possible, avoid telling students specifically what they need to do. If they need help, you can suggest they start by thinking about the solid product. Remind them that the solid product is an ionic compound made of a cation and an anion just like many other ionic compounds they have seen so far in the course.

- Once the groups have created their particulate models, challenge them to write a chemical reaction equation to represent the reaction.
- As students work, circulate around the room to help. Students may need support evaluating different possible combinations of ions and checking them against solubility rules. Below are the kinds of combinations a student could choose and a guiding question you could follow up with.
    - Ions with the same charge: "Can two positive (or negative) ions attract one another?"
    - Oppositely charged ions: "A positive and a negative ion would attract one another. How could you check to see if that combination would be soluble or insoluble?"
- When all groups have finished creating their particle diagrams and writing their equations, bring everyone back together as a class and have student groups take turns making and justifying claims about what the solid product is and what is still in the solution. After discussion, students should settle on PbI_2 as the solid product because those two ions form an insoluble combination. All other combinations produce either a soluble product or an impossible product. The other ions are still present in the solution (they remain unchanged).

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- Next, have students rejoin their groups to revise their equations, and then ask for a few groups to share their answers.
- You will likely get a variety of equations that differ from one another or from "standard" equations. Ask students if they see any patterns in what different groups wrote and guide the discussion toward a consensus as shown below.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

- To connect this symbolic representation to their macroscopic observations, ask students what is present in the test tube. Some students will likely say there is nothing but water there. Ask those students if they think the ions they drew before disappeared. They should respond "no" (and that there is no evidence of gas production), so those ions must still be in the solution but dissolved and dissociated.

Meeting Learners' Needs

Some students may be eager to try writing the equation using the alternative symbolic notation showing dissociated ions that we introduced earlier. You can encourage those students to continue that line of reasoning and to save their work for the next part of the discussion.

- Next, tell students that this type of reaction is called a *precipitation reaction* and the solid product is referred to as the *precipitate*. The ions that remain in the solution are called *spectator ions* because they do not participate in the reaction. Ask students to identify the precipitate and the spectator ions for the reaction you demonstrated.

Instructional Rationale

Introducing the vocabulary after students have experienced the phenomenon allows them to better associate the words with their conceptual understanding.

- Explain that chemists have a number of ways to represent reactions and that you are going to show them various equations based on what has been discussed so far. First, write the consensus molecular equation of the reaction on the board and ask students to list benefits and shortcomings of this representation. Students may say that it is concise and easy to read, but it does not represent the dissociated nature of the ions.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

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- Now tell students that you are going to write an equation that is as close to reality as possible. Begin by dissociating each of the reactants based on the earlier discussion. Then, for the products, ask students if they think each is best represented together as a single species, or apart as dissociated ions. Settle on this equation, and tell the students this equation is called the complete, or total, ionic equation:

$$Pb^{2+}(aq) + 2NO_3^-(aq) + 2K^+(aq) + 2I^-(aq) \rightarrow PbI_2(s) + 2K^+(aq) + 2NO_3^-(aq)$$

- Ask students to list benefits and shortcomings of this representation. They will likely say that it is a better representation of the reaction but that it is longer than the molecular equation. Explain that because the only change that occurred was the joining together of the lead(II) and iodide ions, we can simplify the complete ionic equation and represent the reaction this way:

$$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$$

- Ask students to list benefits and shortcomings of this representation. They will probably prefer this representation since it is shorter, but recognize that it is missing some ions. Help students realize that while this equation, called the net ionic equation, is a representation of the actual change that occurred, it is a simplified version because it does not show all the ions present in the system.
- Finally, ask each student to summarize in writing the purpose of each type of reaction representation. Once students have written their thoughts, ask them to share with a neighbor to see if they agree or disagree. Possible summaries are:
  - Molecular equation—shows the complete formulas of all reactants and products.
  - Total ionic equation—represents the actual forms of reactants and products, and substances that dissociate are shown as ions instead of compounds.
  - Net ionic equation—includes only the species that are involved in the reaction.

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PART 2: PRECIPITATION DROPPER LAB

Students build on the understanding gained in the first part of the lesson by performing several precipitation reactions using a reaction grid and dropper bottles, and then modeling the reactions using equations and particle diagrams.

- Begin by showing students the reaction grid, which they can find on **Handout 4.1.B: Precipitation Reactions Lab Mat**, and explaining that the reaction area is where they will mix the two solutions (with the handout inside a page protector). Make sure to tell them they only need to use 2–3 drops of each solution.
- Next, direct students to work together in groups through **Handout 4.1.A: Precipitation Reactions Lab**, which provides the procedure, data table, and reaction and particle diagram prompts for the lab. Circulate as groups work to help to clarify any misconceptions.

Classroom Ideas
Depending on your classroom setup and time frame, you can either have students perform all the reactions first, and then complete the particle diagrams and equations, or you can have students go through the handout one reaction at a time.

Guiding Student Thinking

Students may struggle with determining each precipitate. It may be simpler for them to complete the balanced equations before determining what the precipitate is. Once they have predicted what the products are for each reaction, they can compare the products to the solubility rules to determine the precipitate.

- Conclude this part of the lesson by pairing student groups and having them share their particle diagrams and net ionic equations. Students should discuss similarities and differences and then revise their diagrams and equations as needed.

Meeting Learners' Needs
If you feel your students need extra support, you can have pairs of groups stop and share their work for each reaction, rather than completing the entire handout first.

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PART 3: DEIONIZED WATER VERSUS TAP WATER

Students address one last scenario as a class to learn about the difference between deionized water and tap water.

- Ask students to discuss the following prompt with a small group.

> Think back to Unit 2 when we learned about the process of distillation. Suppose you add $AgNO_3$ to distilled water. Do you think you would get the same result if you added $AgNO_3$ to water directly from the tap? Why or why not? Explain your response.

Sample response: I think it's possible we would get a different result. I think there are substances dissolved in tap water because I know tap water tastes different in different places and also drinking water is tested for dangerous substances. Meanwhile, the distilled water should just be plain water. The $AgNO_3$ could possibly react with what's dissolved in tap water and create a precipitate.

Classroom Ideas
You could also do this as a closing demonstration if you have $AgNO_3$ available.

- Invite groups to share their responses and to challenge other groups' ideas, as appropriate. Support the class in arriving at a correct understanding through the discussion. Conclude by asking students why we often use distilled (or deionized) water in the labs rather than regular tap water.

We use distilled water so that we do not accidentally precipitate dissolved ions needed for the experiment being performed.

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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

1. A student mixes a solution of $Mg(NO_3)_2(aq)$ with a solution of $NaF(aq)$ and observes the formation of a white precipitate.

   (a) Write the net ionic equation that shows the formation of the precipitate.

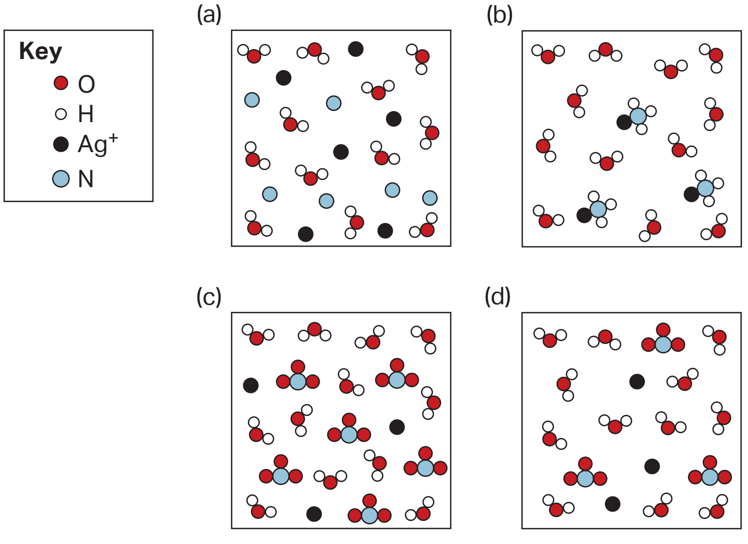
   $Mg^{2+}(aq) + 2F^{-}(aq) \rightarrow MgF_2(s)$

   (b) Explain at least one benefit and one shortcoming of representing the reaction using a net ionic equation as opposed to a different type of equation.

   One benefit is that net ionic equations only show the substances that are involved in the reaction, making it easier to focus on the changes that happen in the reaction. They are also shorter. One shortcoming is that net ionic equations do not show all the substances involved or what else is present in the solution of a precipitation reaction.

2. Answer the following questions about mixing solutions of $AgNO_3(aq)$ and $NaCl(aq)$.

   (a) Which of the following particle diagrams best illustrates a solution of $AgNO_3(aq)$? Justify your answer.



   Particle diagram (d). Silver nitrate dissociates when it dissolves, so the correct model has silver ions and nitrate ions in a 1:1 ratio, as well as water molecules.

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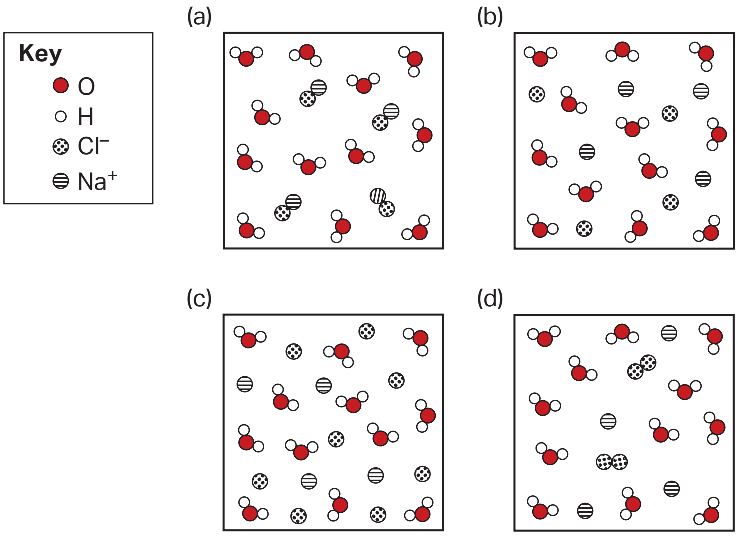
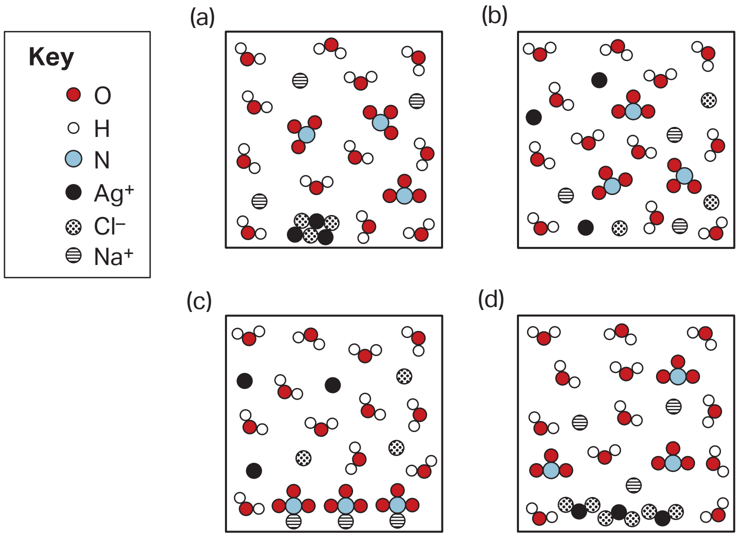
(b) Which of the following particle diagrams best illustrates a solution of NaCl(*aq*)? Justify your answer.



Particle diagram (b). Sodium chloride dissociates as it dissolves, so the correct model shows a 1:1 ratio of sodium ions and chloride ions.

(c) Which of the following particle diagrams best represents the mixture of the two solutions? Justify your answer.



Particle diagram (a). The reaction produces insoluble AgCl, which is shown as a solid in the correct model. The sodium ions and nitrate ions are unchanged during the reaction.

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HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

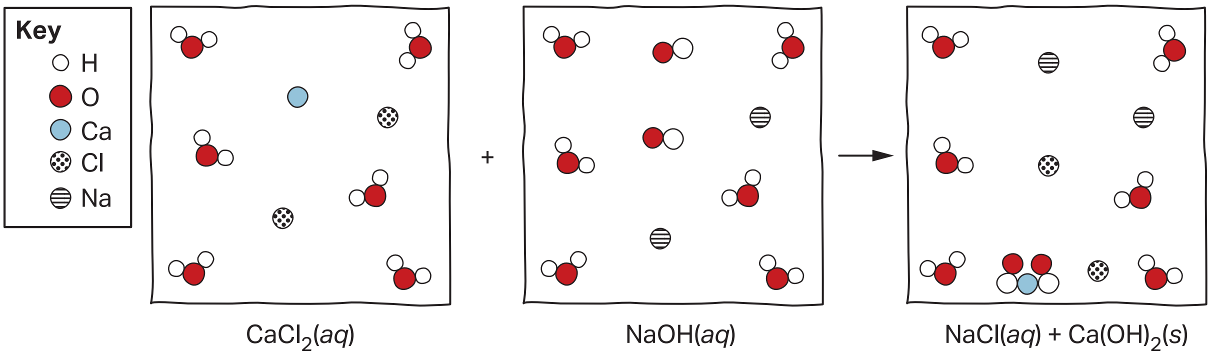
Handout 4.1.A: Precipitation Reactions Lab

Data

	Reactants	Precipitate?	Color of Precipitate	Chemical Formula of Precipitate
1	$NaOH(aq)$ and $CaCl_2(aq)$	Yes	White	$Ca(OH)_2$
2	$Na_2CO_3(aq)$ and $CaCl_2(aq)$	Yes	White	$CaCO_3$
3	$KI(aq)$ and $CaCl_2(aq)$	No	N/A	N/A
4	$NH_4NO_3(aq)$ and $CaCl_2(aq)$	No	N/A	N/A

Reactions and Particle Diagrams

Reaction 1



Molecular equation:

$CaCl_2(aq) + 2NaOH(aq) \rightarrow 2NaCl(aq) + Ca(OH)_2(s)$

Complete ionic equation:

$Ca^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + 2OH^-(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + Ca(OH)_2(s)$

Net ionic equation:

$Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(s)$

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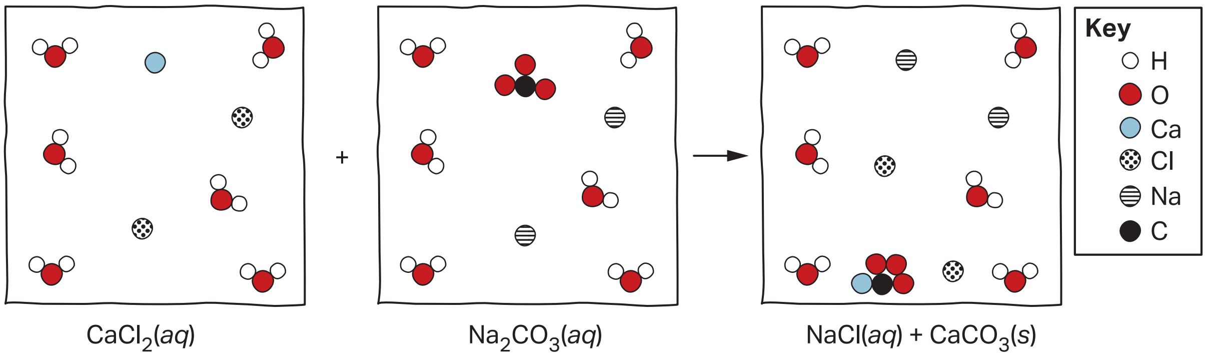
Reaction 2



Molecular equation:

$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow 2NaCl(aq) + CaCO_3(s)$

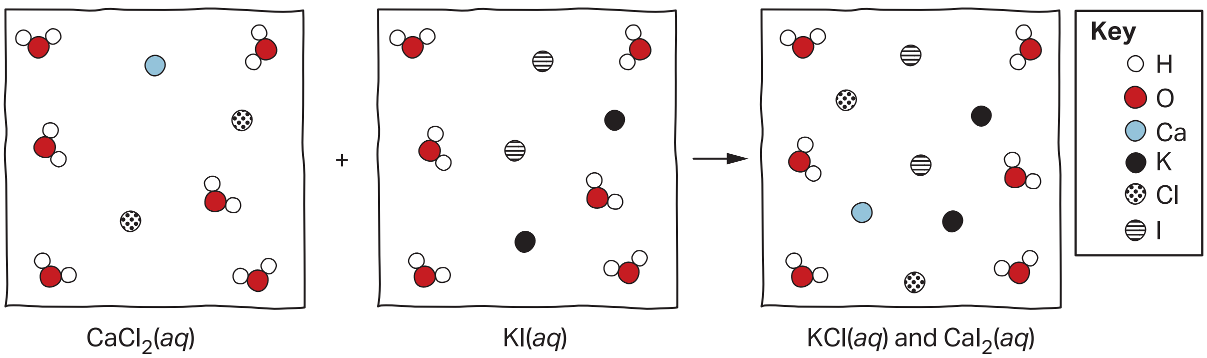
Complete ionic equation:

$2Na^{+}(aq) + CO_3^{2-}(aq) + Ca^{2+}(aq) + 2Cl^{-}(aq) \rightarrow 2Na^{+}(aq) + 2Cl^{-}(aq) + CaCO_3(s)$

Net ionic equation:

$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

Reaction 3



Molecular equation:

$2KI(aq) + CaCl_2(aq) \rightarrow 2KCl(aq) + CaI_2(aq)$

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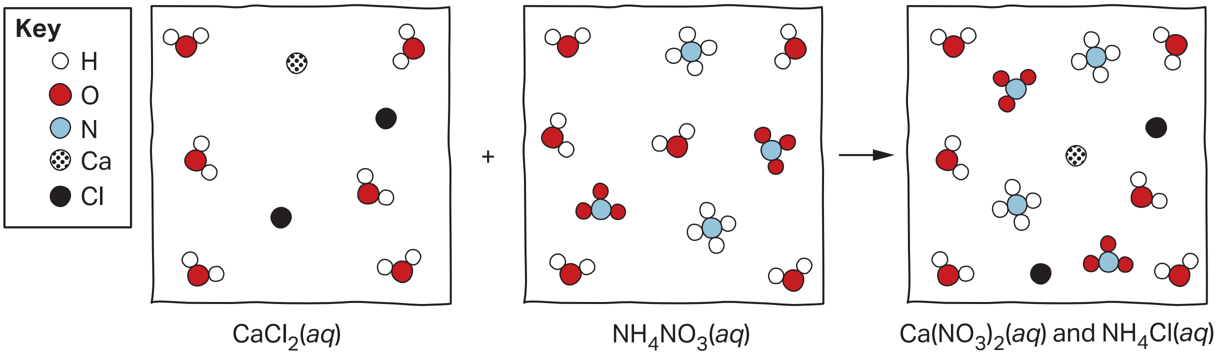
Complete ionic equation:

$2K^+(aq) + 2I^-(aq) + Ca^{2+}(aq) + 2Cl^-(aq) \rightarrow 2K^+(aq) + 2Cl^-(aq) + Ca^{2+}(aq) + 2I^-(aq)$

Net ionic equation:

No reaction

Reaction 4



Molecular equation:

$2NH_4NO_3(aq) + CaCl_2(aq) \rightarrow Ca(NO_3)_2(aq) + 2NH_4Cl(aq)$

Complete ionic equation:

$2NH_4^+(aq) + 2NO_3^-(aq) + Ca^{2+}(aq) + 2Cl^-(aq) \rightarrow$
$Ca^{2+}(aq) + 2NO_3^-(aq) + 2NH_4^+(aq) + 2Cl^-(aq)$

Net ionic equation:

No reaction

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LESSON 4.2

Molarity and Precipitation Reactions

OVERVIEW

LESSON DESCRIPTION

Part 1: The Molarity of Soda

Students are introduced to molarity using the concentration of sugar in an everyday solution: soda. They represent molarity through particle diagrams and mathematical calculations.

Part 2: Molarity and Aqueous Ionic Solutions

Students expand on their understanding from Part 1 by evaluating and drawing particulate representations of ionic solutions. They then apply their understanding of molarity to precipitation reactions.

CONTENT FOCUS

This lesson is designed to give students a particle-level view of the concept of molarity. Many students fail to understand that concentration is an intensive property, even when they can correctly perform calculations relating moles, volume, and molarity. Using soda to introduce solution concentration in Part 1 helps students connect chemical concepts to a familiar food item. Additionally, this part of the lesson provides the opportunity for students to become more fully aware of the large amount of sugar found in many sodas and similar beverages.

Part 2 allows students to quantitatively visualize what happens to ions as they form in an insoluble product, as well as predict the molarities of spectator ions in solution for their diagrams. It also requires students to make connections with what they learned about

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~105 minutes

HANDOUTS

- 4.2.A: Finding the Molarity of a Solution
- 4.2.B: Particulate Representations of Ionic Solutions

MATERIALS

- sugar
- water
- 12 oz can of regular soda
- 2 L bottle of regular soda
- 2 empty 20 oz plastic bottles
- graduated cylinder
- balance
- dropper or pipette
- funnel

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stoichiometry and limiting reactants in Unit 3 and precipitation reactions in Lesson 1 of this unit.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.1.B.1 Create and/or evaluate models of precipitation reactions.	**4.1.B** Precipitation reactions can be modeled by molecular equations, net ionic equations, and particulate representations.
4.1.C.1 Create and/or evaluate models that represent the concentration of a solution. **4.1.C.2** Perform calculations relating to the molarity of solutions.	**4.1.C** Molarity is one way to quantify the concentration of a solution. It describes the number of dissolved particles in a unit volume of that solution.
4.1.D.1 Predict the amount of solid produced in a precipitation reaction using gravimetric analysis based on the concentrations of the starting solutions. **4.1.D.2** Evaluate the results of a gravimetric analysis.	**4.1.D** Gravimetric analysis is a quantitative method for determining the amount of a substance by selectively precipitating the substance from an aqueous solution.

SETUP AND PREPARATION NOTES

- The amount of sugar and subsequent values and calculations were taken using Dr Pepper, which has 40 g of sugar in a 12 oz can. Different sodas have different sugar content.

SAFETY NOTES

All general safety guidelines should be followed.

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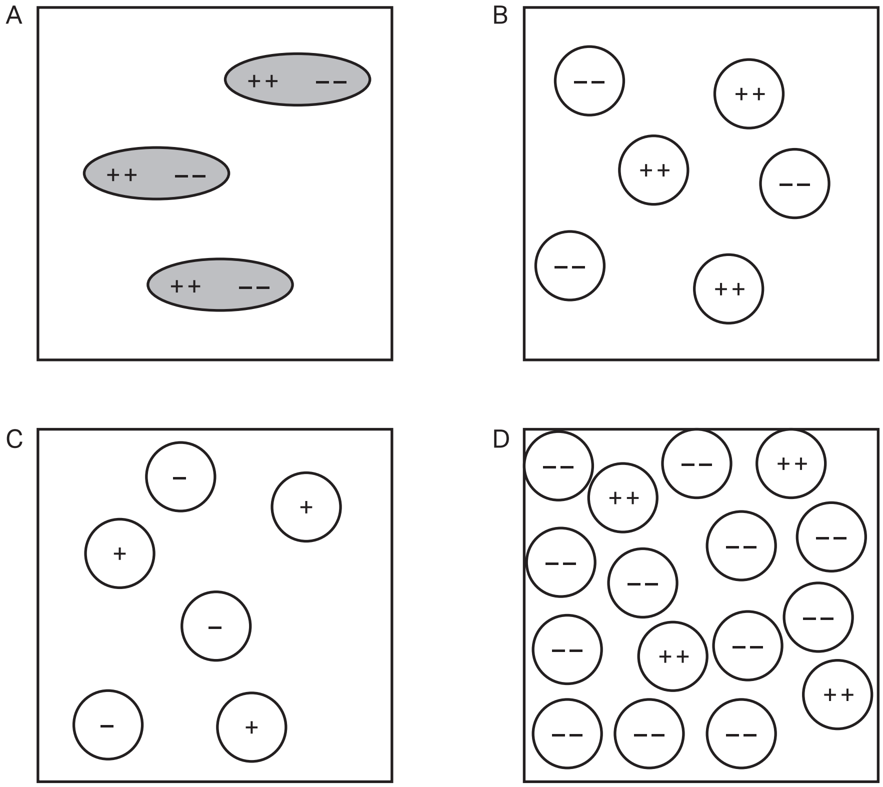
FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

1. A student dissolves 119 g of solid $CuSO_4$ in water to make 1.50 L of solution.
   (a) Calculate the molarity of the $CuSO_4$ solution.
   (b) Circle the particle diagram below that is the best representation of the $CuSO_4$ solution. Justify your selection.



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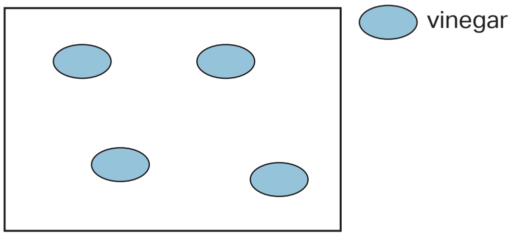
2. The student from question 1 then takes 1.50 L of a premade solution of 1.00 *M* $BaCl_2$, adds it to the $CuSO_4$ solution, and observes the formation of a white solid.

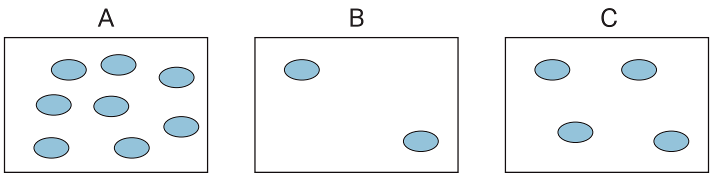
   (a) Write the net ionic equation for the formation of the precipitate.

   (b) In the box below, draw a particle diagram that represents the product mixture after the reaction has gone to completion.

3. Shown below is a particle diagram of a sample of liquid taken from 1.00 L of a 0.50 *M* solution of vinegar in water. Note that water is not shown in the particle diagram.



   (a) Which diagram below represents a drop of liquid taken from a 2.00 L solution of 0.50 *M* vinegar in water? Justify your choice.



   (b) Which diagram above represents a drop of liquid taken from a 1.00 L solution of 0.25 *M* vinegar in water? Justify your choice.

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UNIT 4

PART 1: THE MOLARITY OF SODA

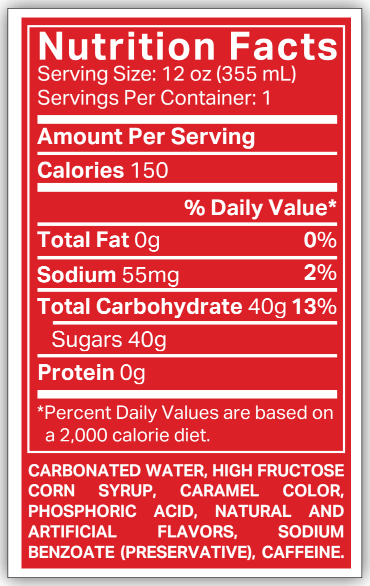
This part of the lesson serves as an introduction to the concept of molarity using the context of sugar content in an everyday solution: soda. Students are asked to represent their understanding of molarity through both particle diagrams and mathematical representations.

- Give students a few moments to examine a nutrition label from a can of soda, such as the one below and on their handout. Also have a can of soda to use as a visual reference.
- To help students begin to develop the idea of concentration as an intrinsic property, which will be explored in depth in this lesson, ask students a series of questions such as the following:
    - How much sugar is in the can?
    - How much is in half a can? What about two cans?
    - What if you poured out some soda into a cup, but you don't know how much? How could you quantify how much sugar is dissolved?

  Allow students to brainstorm and share ideas about the last question. Students may or may not arrive at the idea of concentration.

> **Meeting Learners' Needs**
> Before beginning this part of the lesson, you might want to review with students the definitions of *solvent* and *solute*.

Once you feel students have spent enough time with the question, have the class read the top of **Handout 4.2.A: Finding the Molarity of a Solution**, which introduces the concepts of concentration and molarity.



Handout 4.2.A

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- Explain to students that their goal is to calculate the molarity of the soda. To do this, they must mentally simplify the contents of the soda. They can approximate the soda as a solution of sucrose ($C_{12}H_{22}O_{11}$) in water. Since the label says "high fructose corn syrup," you may need to help students understand the relationship between sucrose and high fructose corn syrup.

Instructional Rationale

Soda was chosen as the introduction to molarity because some students have a misconception that the things they learn about in chemistry only apply to "chemicals" and not to everyday items or substances. Using a real-world example helps students see that chemistry is everywhere and can make the content less intimidating.

- Have students work with a partner on questions 1–9 on Handout 4.2.A (also shown below with answers). This set of questions asks students to calculate the molarity of soda and then represent their understanding of molarity through both particle diagrams and mathematical representations. You can provide the following specific guidance for each question:
  - **Questions 1 and 2:** These questions ask students to determine the molarity of the soda based on information from the nutrition label. Circulate around the room and check that students are correctly calculating the molar mass of sugar and converting the volume of the solution to liters. Based on what you observe, you may want to have each pair of students discuss their work with another group and then allow them to revise their calculations.

  Since this is the first time students are being asked to determine the molarity of a solution, you could ask questions such as the following to guide their thinking:
  - In the can of soda, what is the solute and what is the solvent?

    Sugar is the solute and water is the solvent.
  - What two values are needed to calculate molarity?

    Moles of the solute (sugar) and volume of the solution.
  - Are moles given on the label of the can? What unit is used on the label?

    No. The mass of sugar in the can is given in grams.
  - What relationship have you learned exists between grams and moles?

    Molar mass can be used to convert grams to moles.

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- What unit is the volume of the container given in? What unit do you need to calculate molarity?

  Ounces and milliliters. Liters.

1. How many moles of sugar are in the can of soda?

   $$40 \text{ g sugar} \times \frac{1 \text{ mol sugar}}{342.30 \text{ g}} = 0.117 \text{ mol sugar}$$

2. What is the molarity of the sugar in the can of soda?

   $$\frac{0.117 \text{ mol sugar}}{0.355 \text{ L solution}} = 0.330\ M$$

Handout 4.2.A

Instructional Rationale

The next series of questions on the handout are designed to get students thinking about the concentration of solutions in terms of a particulate model. Having students represent solution concentration both mathematically and by using particle diagrams can deepen their understanding.

- **Question 3:** This question asks students to draw particle diagrams representing one- and two-drop samples taken from the can. It may beneficial to actually take drops of soda from the can using a dropper or pipette to show students when they are constructing particulate representations of the sugar in the soda, so that they explicitly understand that the volumes of the drops in part (a)(i.) are equal and that the solutions must be the same on a fundamental level.

  Again, you may want each pair of students to share their diagrams with another group. Allow time for students to discuss the diagrams, get feedback, and revise their diagrams. Look for groups who incorrectly show the larger sample as more concentrated.

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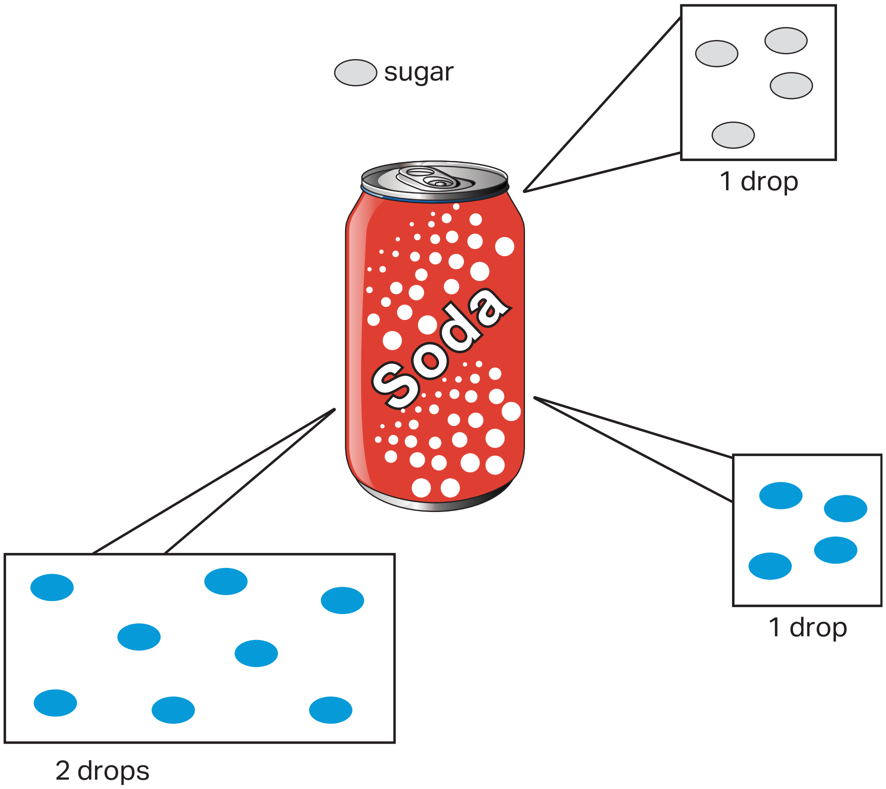
3. Shown below is a particulate representation of one drop of the soda taken from the 12 oz can. Note that water is not shown in the particle diagram.



(a) Draw a particulate representation for:

i. Another one-drop sample of soda from a different area of the can.

ii. A two-drop sample of soda from the can.

(b) Briefly explain why you have drawn the representations the way you have.

Since the soda tastes the same everywhere in the can, the amount of sugar per volume must always be the same. Therefore, any one drop will have the same number of molecules of sugar. Two drops will have twice the volume, and thus should have twice as many sugar molecules.

Handout 4.2.A

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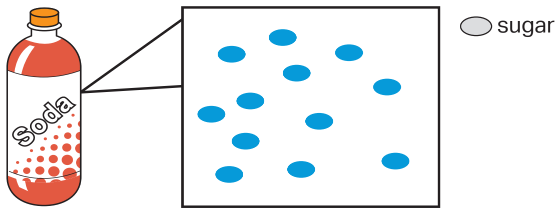
- **Questions 4 and 5:** Now that students have a basic understanding of molarity through both calculations and particulate representations, question 4 challenges them to extend their thinking by determining the mass of sugar in a 20 oz bottle of soda. Once they have calculated the mass of sugar, to help them visualize how much sugar this is, weigh out the amount of sugar in a 20 oz bottle (66.7 g) on a balance.

Classroom Ideas

Students may be surprised that this amount of sugar is in a bottle of soda. This observation can be extended into a discussion of healthy food choices and sugar consumption.

4. Suppose you have a 20 oz bottle of the same kind of soda discussed in questions 1–3. Draw a particulate diagram of three drops of soda from the bottle:



3 drops from 20 oz bottle

5. 20 oz is equivalent to 591 mL. Calculate the amount of sugar, in moles and grams, in a 20 oz bottle of soda.

$$0.591 \text{ L} \times \frac{0.330 \text{ mol sugar}}{1 \text{ L}} = 0.195 \text{ mol sugar}$$

$$0.195 \text{ mol sugar} \times \frac{342.30 \text{ g sugar}}{1 \text{ mol sugar}} = 66.7 \text{ g sugar}$$

Handout 4.2.A

Guiding Student Thinking

Many students will expect the 20 oz soda solution to be more concentrated since it contains more sugar. The handout specifically asks students to consider what must be the *same* in terms of flavor of the two solutions, helping to guide them to the conclusion that the molarities are the same.

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- **Question 6:** Before students work on this question, perform the following demonstration. This gives them a primer on how solutions are made, as well as a rationale for why molarity is measured per volume of solution as opposed to volume of solvent.
  1. Obtain two empty 20 oz bottles.
  2. Add about 10 oz (296 mL) of water to one bottle.
  3. Add 66.7 g of sugar to the water and then shake or stir the mixture to dissolve the solute.
  4. Add water to obtain a total volume of 20 oz (591 mL) to make the new "soda."
  5. In the second bottle, add 20 oz of water and then start to add 66.7 g of sugar. It will become immediately apparent the total volume will be significantly larger than 20 oz.

  Have students return to their handout to complete question 6, which asks them to describe why molarity is expressed in moles per liter of solution instead of moles per liter of solvent.

Classroom Ideas
You can use the sugar content of regular soda versus diet soda to connect back to concepts of density learned earlier in the course. A possible demonstration is to put cans of both regular and diet soda in a large container of water. The can of diet soda will float in water while the can of regular soda will sink in water, since the regular soda has many grams of sugar but the diet soda has a much smaller mass of artificial sweetener.

6. Now you will watch a demonstration of making a soda solution two different ways. After observing both methods, explain why molarity is moles per liter of solution as opposed to moles per liter of water (or solvent).

   If you dissolve the sugar in 591 mL of water, the final volume of the solution will be much greater than 591 mL. Using the total volume of the solution (rather than the volume of the solvent) makes it easier to have accurate and predictable measurements, which is critical for ensuring solutions are consistent.

Handout 4.2.A

- **Questions 7–9:** The last questions on Handout 4.2.A ask students to apply what they have learned about molarity and soda in 12 oz cans and 20 oz bottles to a 2 L bottle. For question 8, they are asked to determine what volume from the bottle must be poured out so 40 g of sugar is poured out. Students are consistently surprised to see that this volume is exactly the volume of the 12 oz can. Question 9 has students again connect a particulate representation to a mathematical representation of molarity, this time applied to a soda sample that was incorrectly prepared.

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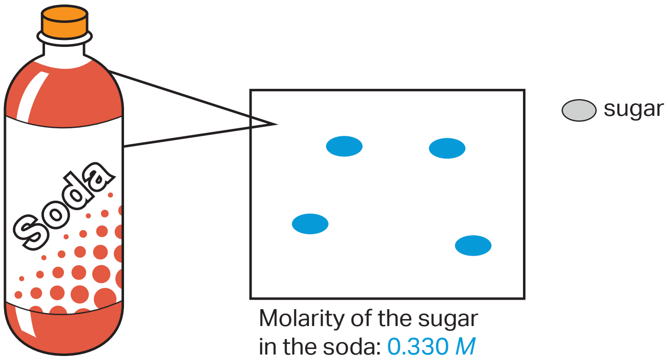
7. Molarity is a useful tool in chemistry because it allows us to measure out a certain number of moles of a substance, such as sugar, just by measuring a certain volume of a solution, such as sugar water. To illustrate this, consider a 2 L bottle of soda. The soda in 2 L bottles must be identical in every way to the soda in the 12 oz can or the 20 oz bottle. In the box to the right of the 2 L bottle shown below, draw a particulate representation of one drop of soda from the bottle and state what the molarity of the sugar in the bottle must be.



Particle view of 1 drop from 2 L bottle

Based on your answer to question 6, calculate the number of moles of sugar in the soda.

$$2\ \text{L} \times \frac{0.330\ \text{mol sugar}}{1\ \text{L}} = 0.660\ \text{mol sugar}$$

8. Calculate the volume of soda you would need to pour out of the 2 L bottle so that you were pouring out 40 g of sugar (the mass of sugar in a 12 oz can). Does this number surprise you? Explain.

$$40\ \text{g sugar} \times \frac{1\ \text{mol sugar}}{342.30\ \text{g}} \times \frac{1\ \text{L soda}}{0.330\ \text{mol sugar}} \times \frac{1000\ \text{mL}}{1\ \text{L}} = 354\ \text{mL soda}$$

Sample response: This number is not surprising because if you need to pour out the amount of sugar that is in the can, you would need to pour out a volume of liquid from the 2 L bottle that is equivalent to the volume of the can. The can is just a smaller amount of the same solution.

Handout 4.2.A

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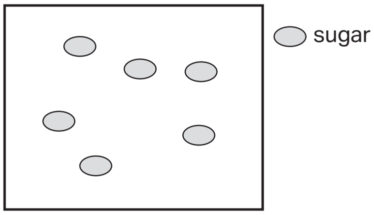
9. While doing some quality control on soda samples, an analytical chemist discovers a sample with an error. A particle view of a drop of the solution is shown below.

Particle view of 1 drop of solution



(a) Based on the diagram above, what is the molarity of this solution of soda?

Because there are 6 ovals in the box instead of 4, this solution is 1.5 times more concentrated. Thus the molarity of this solution is $1.5 \times 0.330\ M = 0.495\ M$.

(b) What would be the mass of the sugar dissolved in a 1.5 L bottle of this solution?

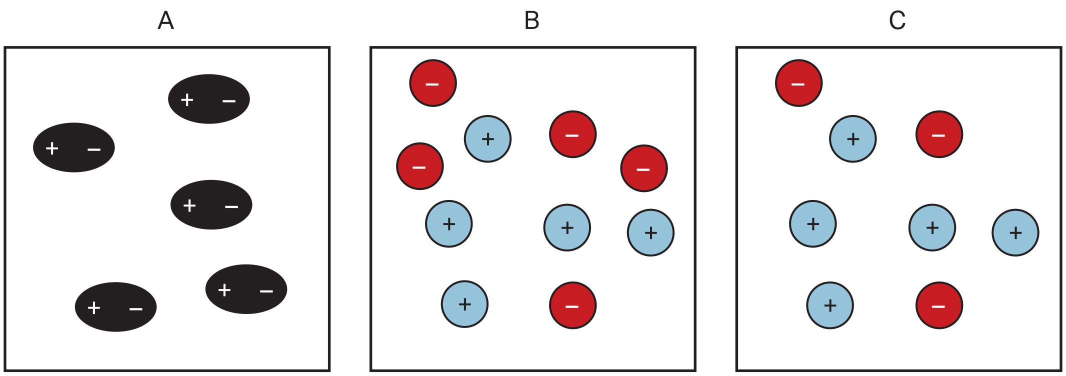
$$1.5\ \text{L} \times \frac{0.495\ \text{mol sugar}}{1\ \text{L}} \times \frac{342.30\ \text{g sugar}}{1\ \text{mol sugar}} = 254\ \text{g sugar}$$

Handout 4.2.A, *continued*

PART 2: MOLARITY AND AQUEOUS IONIC SOLUTIONS

In this part of the lesson, students expand on their understanding from Part 1 by evaluating and drawing particulate representations of ionic solutions. They then apply their understanding of molarity to precipitation reactions.

- As a refresher on the structure of ionic compounds learned in Unit 2 and reinforced in Lesson 4.1, show students the following particle diagrams.



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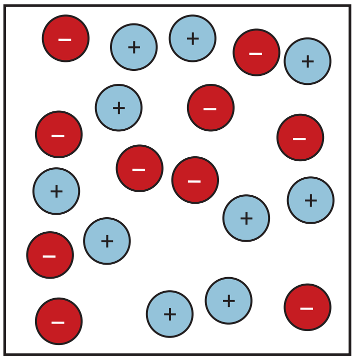
- Have students work with partners or in small groups to decide which diagram best represents a 1.0 *M* solution of NaCl. (You can point out that, to keep things simple, water molecules are purposefully not shown in any of the diagrams.) Ask each pair or group to write a brief statement explaining why they chose the representation they did and what is wrong with the other representations. Students could do this on large whiteboards.

  Ask a few groups to share their responses and then lead the class to the consensus that diagram B is the best representation because it shows the ions dissociated in a 1:1 ratio. Diagram A does not show the ions dissociated and diagram C does not show an equal number of cations and anions.

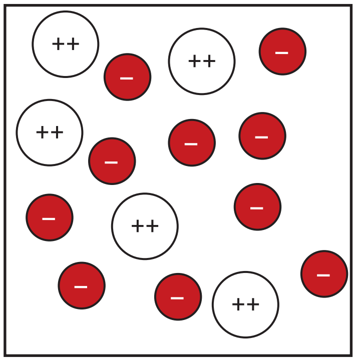
- Next, have each group draw a particle diagram of 2.0 *M* NaCl. Allow groups time to share and revise their representations. Again, students can draw these on large whiteboards for ease of sharing. Students should draw something similar to the diagram below, which shows twice as many ions as diagram B above, since the solution is twice as concentrated.

2.0 *M* NaCl



- Next, ask each group to draw a particle diagram of 1.0 *M* $MgCl_2$. Students should draw something similar to the diagram below.

1.0 *M* $MgCl_2$



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- The following questions can be used to guide students:
  - How many chloride ions need to be drawn for every magnesium ion?
    There should be two chloride ions for every magnesium ion.
  - How many sodium ions will be represented for every magnesium ion?
    There should be two sodium ions for every magnesium ion because the concentration of NaCl is twice that of $MgCl_2$.

  Allow groups time to share and revise their representations.

- Now that students have had some practice drawing diagrams to represent the concentration of solutions containing ions, they will revisit precipitation reactions, building on their experiences from Lesson 4.1. Ask students to read the equation at the top of **Handout 4.2.B: Particulate Representations of Ionic Solutions**, which describes a precipitation reaction.

Meeting Learners' Needs
For additional practice and review, consider having the students write the net ionic equation for the reaction.

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

Handout 4.2.B

- Once students have seen the equation, have them each work with a partner to draw the particle diagram for the 0.50 *M* $AgNO_3$ (question 1 on Handout 4.2.B).

Guiding Student Thinking

Students may notice or be concerned that the particle diagram for 0.50 *M* NaCl on their handout shows six particles each for Na^+ and Cl^-, while the diagram they looked at earlier for 1.0 *M* NaCl showed five of each type of ion. This was an intentional choice to highlight that the absolute number of particles is not important: only the relative number of particles matter. In this case, this means the students' particle diagram for 0.50 *M* $AgNO_3$ should have the same number of particles as the one given for the 0.50 *M* NaCl.

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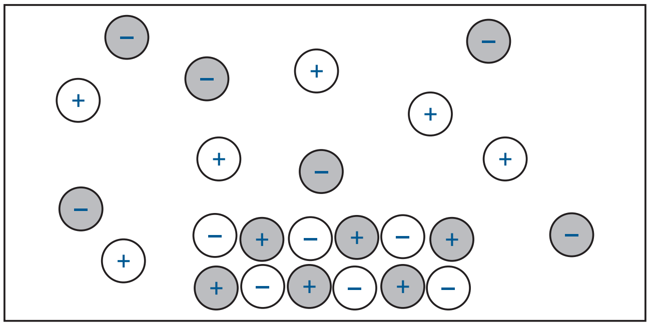
Instructional Rationale

The particle diagram uses a simplified representation of NO_3^- that does not show each of the four atoms in the polyatomic ion. The simplified representation was chosen for this diagram because the focus is on the relative numbers of particles, not their internal structure. This is intentionally different from how students drew the particle diagrams in Lesson 4.1. You could use the opportunity to talk about why different representations are used at different times and ask students to list some advantages and disadvantages of each.

- Next, have students draw the product mixture that will result when the two solutions are mixed (question 2 on Handout 4.2.B). This is similar to what students were asked to do in Lesson 4.1.
- Since there is much to consider when drawing this particle diagram, once students are finished, have groups pair up and discuss their models. Groups should then be given time to revise their diagrams. The question and its answer are also shown here for reference.

2. If the two drops are mixed, draw a particle diagram to show what would be observed on a particle level. Note that the volume of the mixture is now twice as large, as indicated by the larger box.



Handout 4.2.B

- Circulate around the room as students discuss their models, looking for the following features in the particle diagrams:
    - 1:1 ratio between all types of ions
    - Solid precipitate shown with alternating + and – charges
    - Unchanged sodium nitrate ions

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UNIT 4

- If groups found different ways to represent these features, ask a few groups to share their models.
- Now have students work with their partner on questions 3–5 on Handout 4.2.B. Question 3 asks them to again connect their particle-level understanding to mathematical and symbolic representations. The question and its answer are shown here for reference.

3. If the volume of each drop is 0.10 mL, use your diagram from question 2 to calculate:

(a) The number of moles of Ag^+ and Cl^- that reacted.

$$0.10 \text{ mL } AgNO_3 \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.50 \text{ mol } AgNO_3}{1 \text{ L}} \times \frac{1 \text{ mol } Ag^+}{1 \text{ mol } AgNO_3} = 5.0 \times 10^{-5} \text{ mol } Ag^+$$

$$0.10 \text{ mL NaCl} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.50 \text{ mol NaCl}}{1 \text{ L}} \times \frac{1 \text{ mol } Cl^-}{1 \text{ mol NaCl}} = 5.0 \times 10^{-5} \text{ mol } Cl^-$$

(b) The number of moles of AgCl(*s*) formed.

The moles of AgCl made must equal the moles of Ag^+ initially, since all the Ag^+ ions precipitated, forming 5.0×10^{-5} mol AgCl(*s*).

(c) The molarity of Ag^+ after the reaction.

There are no Ag^+ ions remaining. Thus, the moles of silver ions and the molarity are both 0.

(d) The molarity of NO_3^- after the reaction.

Nitrate is a spectator ion in the reaction. Therefore, the number of moles did not change. However, the volume increased by a factor of two and so the molarity is half of what it was before.

$$0.10 \text{ mL } AgNO_3 \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.50 \text{ mol } AgNO_3}{1 \text{ L}} \times \frac{1 \text{ mol } NO_3^-}{1 \text{ mol } AgNO_3} = 5.0 \times 10^{-5} \text{ mol } NO_3^-$$

$$\frac{5.0 \times 10^{-5} \text{ mol } NO_3^-}{0.0002 \text{ L}} = 0.25\ M\ NO_3^-$$

Handout 4.2.B

- Be available to support students, particularly with using the molarity of the solution as a conversion factor and with using mole ratios within a compound. Here is some specific feedback you can provide for question 3:

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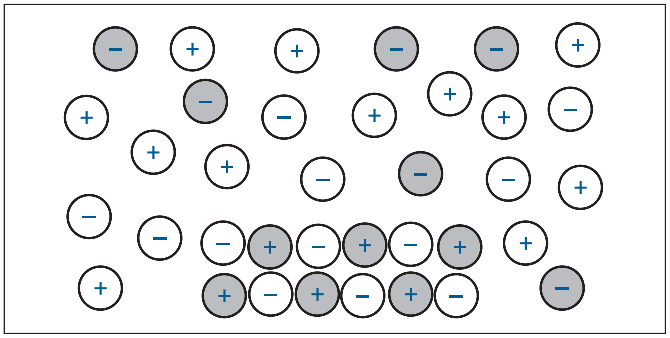
- If students struggle with part (a), have them revisit the definition of molarity and consider using it as a conversion factor to determine the number of moles.
- If students struggle with part (b), ask them to use conservation of matter to determine the source and amount of both the silver ions and chloride ions.
- For part (c), students may try to calculate the molarity of the precipitate since it is represented in the diagram. This is a good time to remind them that the precipitate is no longer "in the solution."
- For part (d), there are the same number of nitrate ions in the solution before and after the reaction. Consider asking students, "Did the number of nitrate ions change? Did the volume change? How would each of these affect the concentration?"

▪ Question 4, shown below with its answer, is designed to have students connect their particle representations and understanding of molarity to limiting reactants, which were introduced in Unit 3. This particle diagram should represent:

- The same amount of precipitate, since the Ag^+ will limit the amount produced.
- An excess of Na^+ ions and Cl^- ions.

4. How would the particle diagram you drew for question 2 change if a drop of 1.0 *M* NaCl is used instead of 0.50 *M* NaCl? Based on the particle diagrams in questions 1 and 2, draw a new particle diagram of this mixture.

If 1.0 *M* NaCl is used, there will be excess Na^+ and Cl^- ions, as shown in the diagram below. The amount of precipitate and NO_3^- ions are unchanged from the previous particle diagram.



Handout 4.2.B

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Guiding Student Thinking

Students will likely find question 4 challenging. This can give you good insight into student understanding of limiting reactants, precipitation reactions, and molarity. Some students may be able to draw the particle diagram from the description of the scenario, but others may need scaffolds or supports in order to be successful. Some students may benefit from writing a net ionic equation, while you could consider having students who are more mathematically oriented determine the number of moles of each reactant first, and then determine moles of each product. Other students may need a physical model to help them; consider bringing out the bingo chips used in Lesson 3.4. Students can build a physical model showing a 2:1 ratio of NaCl to $AgNO_3$ and then physically move the bingo pieces to make the products. This tangible model can help students see that the reaction will stop when they run out of the limiting reactant. You can also give students additional reaction scenarios for more practice.

- Since the particle diagrams are complex, students will benefit from having time to explain their thinking to each other. Consider asking each group to write a bulleted list or paragraph that describes their particle diagram. Groups can then compare diagrams and explanations. The act of trying to make their thinking apparent will likely help students identify flaws in their models, so allow time for revision.
- Question 5 has students return to using $MgCl_2$, which was introduced earlier in the lesson. Students are asked to write a balanced molecular equation for the reaction and draw a particle diagram for the reaction. As with question 4, there is much for students to consider and the same supports could also be beneficial here.

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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

1. A student dissolves 119 g of solid $CuSO_4$ in water to make 1.50 L of solution.

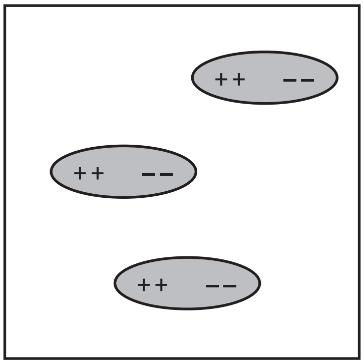
   (a) Calculate the molarity of the $CuSO_4$ solution.

   $$119 \text{ g } CuSO_4 \times \frac{1 \text{ mol } CuSO_4}{159.61 \text{ g } CuSO_4} = 0.746 \text{ mol } CuSO_4$$

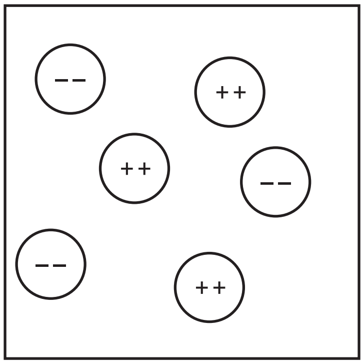
   $$\frac{0.746 \text{ mol } CuSO_4}{1.5 \text{ L}} = 0.50\ M$$

   (b) Circle the particle diagram below that is the best representation of the $CuSO_4$ solution. Justify your selection.

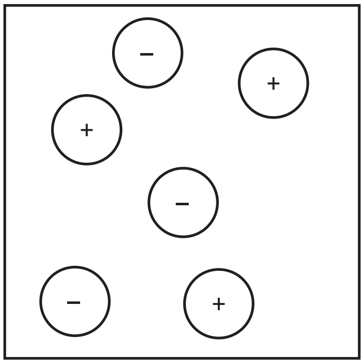
A



B



C



D

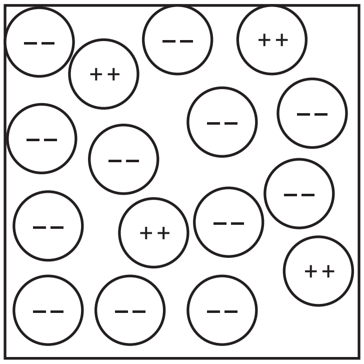


Diagram B is the best representation because it is electrically neutral and shows the dissociated Cu^{2+} and SO_4^{2-} ions.

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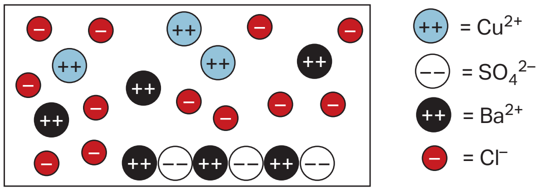
2. The student from question 1 then takes 1.50 L of a premade solution of 1.00 *M* $BaCl_2$, adds it to the $CuSO_4$ solution, and observes the formation of a white solid.

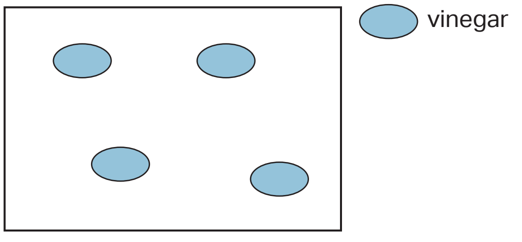
   (a) Write the net ionic equation for the formation of the precipitate.

   $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

   (b) In the box below, draw a particle diagram that represents the product mixture after the reaction has gone to completion.



3. Shown below is a particle diagram of a drop of liquid taken from 1.00 L of a 0.50 *M* solution of vinegar in water. Note that water is not shown in the particle diagram.



   (a) Which diagram below represents a drop of liquid taken from a 2.00 L solution of 0.50 *M* vinegar in water? Justify your choice.

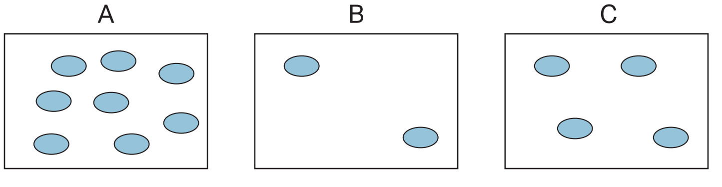


   Diagram C should be selected. As the molarity is the same, the number of particles in the drop is constant.

   (b) Which diagram above represents a drop of liquid taken from a 1.00 L solution of 0.25 *M* vinegar in water? Justify your choice.

   Diagram B should be selected. As the molarity is one half that of the previous solutions, the number of particles per drop should be halved.

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UNIT 4

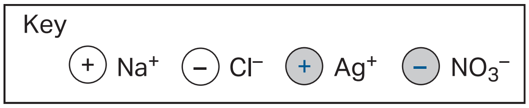
HANDOUT ANSWERS AND GUIDANCE

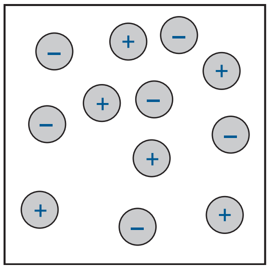
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 4.2.A: Finding the Molarity of a Solution

Answers are provided in the lesson.

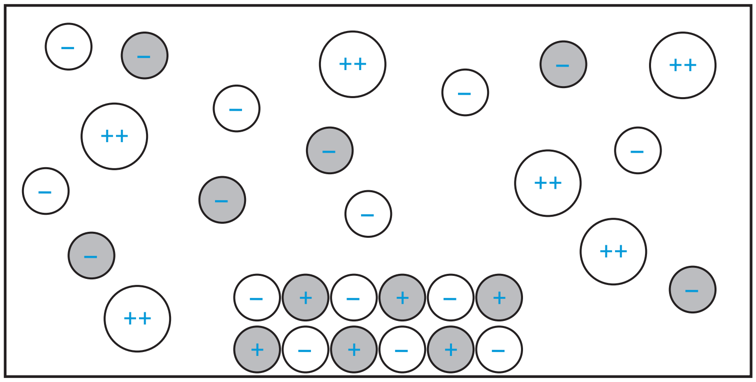
Handout 4.2.B: Particulate Representations of Ionic Solutions

1. 



2. Answer is provided in the lesson.
3. Answer is provided in the lesson.
4. Answer is provided in the lesson.
5. (a) $2AgNO_3(aq) + MgCl_2(aq) \rightarrow 2AgCl(s) + Mg(NO_3)_2(aq)$

   (b) Note that the same amount of product (AgCl) is made, since the number of silver ions available did not change. The number of charged particles in solution is different for the Mg^{2+} and Cl^- because of the different charges of each particle, but charge balance is maintained.



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UNIT 4

LESSON 4.3

The Chemistry of Rusting – An Introduction to Redox Reactions

OVERVIEW

LESSON DESCRIPTION

Part 1: Analytical Reading About the Phenomenon of Rust

Students are introduced to the vocabulary of oxidation–reduction reactions. They apply their analytical reading and writing skills to a text about a real-world context—the rusting and corrosion of cars—as an inroad to this fundamentally important topic in chemistry.

Part 2: Individual and Partner Questions About Redox Reactions

Students answer questions about the reading on their own, and then discuss their answers with a partner and revise them as necessary. The questions ask about redox reactions broadly and also ask students to apply a particle-level understanding to the reactions involved in cars rusting.

Part 3: Class Discussion to Synthesize Understanding of Redox Reactions

Students participate in a whole-class discussion to summarize the reading and review the answers to the questions.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 4.3.A: Flaking Away
- 4.3.B: Flaking Away – Check Your Understanding

CONTENT FOCUS

This lesson introduces students to oxidation–reduction (redox) reactions by explaining the common phenomenon of rusting. Through examining an article about factors that speed up rusting in cars, students become familiar with the vocabulary and notation of redox reactions, with special attention paid to electron transfer, its effect on atomic charge, and the differences between neutral metal atoms and their cations. Moreover,

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built into this lesson are multiple opportunities for students to grapple with this new information—independently, with a partner, and with the class as a whole. As redox can be a challenging topic for students, this approach allows students the necessary time and space to productively engage with these concepts.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.2.A.1 Identify a reaction as an oxidation–reduction reaction based on the change in oxidation numbers of reacting substances. **4.2.A.2** Create and/or evaluate a claim about which reacting species is oxidized or reduced in an oxidation–reduction reaction.	**4.2.A** Electrons are transferred between reactants in oxidation–reduction (redox) reactions. **a.** Substances lose electrons in the process of oxidation and gain electrons in the process of reduction. **b.** Oxidation numbers are useful for determining if electrons are transferred in a chemical reaction. **c.** Electrons are conserved in redox reactions.
4.2.C.1 Create and/or evaluate models of redox reactions.	**4.2.C** Redox reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

1. Does the conversion of S to S^{-2} represent oxidation or reduction? Explain.
2. Is the reaction $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$ best classified as an oxidation–reduction or a precipitation reaction? Explain.

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PART 1: ANALYTICAL READING ABOUT THE PHENOMENON OF RUST

In the first part of the lesson, students are introduced to the vocabulary of oxidation–reduction reactions. They apply their analytical reading and writing skills to a text about a real-world context—the rusting and corrosion of cars—as an inroad to this fundamentally important topic in chemistry.

- To begin, ask students what they know about the process of rusting. Students are likely to have a wide range of understanding about what rusting actually involves, especially depending on the kind of climate they live in. To support the introductory discussion, consider asking probing questions such as:
  - Does rusting take place quickly or slowly?
  - Do all things rust?
  - What factors contribute to items rusting?
  - Can you protect items from rusting?

Classroom Ideas
Consider having samples or pictures of items that have rusted for students to observe and reflect on in order to generate more responses.

- Then, have students read the passage on **Handout 4.3.A: Flaking Away**. By this point in the course, students have likely encountered several analytical reading and writing passages and tried out a variety of strategies for working through them. Before students start reading, ask them to take a moment to reflect on various strategies they have used in the course and then choose one to apply here. Options might include reading the text aloud in pairs (alternating reading and summarizing paragraphs), writing the key idea of every few sentences, and using metacognitive markers. Encourage students to focus on the half-reactions in the reading.
- Before students answer the Check Your Understanding questions in the next part of the lesson, it can be helpful to gauge what they understand to help you determine what additional supports they might need. You can use questions such as the following:
  - What is something new you learned by reading the text?
  - What is something you already knew that was reinforced in the text?
  - What is oxidation?
  - What is reduction?
  - If a neutral atom loses an electron, does it become positive or negative?

  Since this is likely the first time students have heard of oxidation and reduction, you may want to help them come up with their own definitions. You could have students record these definitions or create posters for your wall to return to during their study of redox reactions.

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Instructional Rationale

The lesson does not introduce mnemonics, such as OIL RIG and LEO says GER. The emphasis here is on helping students to develop a conceptual understanding, and students can apply those mnemonics without understanding what they mean. Once you are confident that students understand oxidation and reduction at a particle level, you can introduce mnemonics if you choose.

PART 2: INDIVIDUAL AND PARTNER QUESTIONS ABOUT REDOX REACTIONS

After students read, annotate, and take notes on the text, they process the information further by answering text-dependent questions on their own, and then with a partner. The questions ask about redox reactions broadly and also ask students to apply a particle-level understanding to the reactions involved in cars rusting.

Instructional Rationale

Students have likely seen, in earlier lessons, the question format used here, in which they answer a series of questions on their own and then revisit them with a partner and as a class. This strategy is useful for an introduction to redox, as the iterative and collaborative thinking help students internalize the complex topics addressed.

- Have students find **Handout 4.3.B Flaking Away – Check Your Understanding** and instruct them to answer each question on their own, in the "My first answer, thinking on my own" box on the handout.
- As students answer the questions, have them look back at Handout 4.3.A and highlight sections of text that are relevant to each question. Students can number each highlighted section so that they can refer to it in the discussion with their partner later.
- After students have had time to individually answer all the questions, have them work in pairs to discuss and revise their answers. If they do not agree on an answer, they should discuss as needed to attempt to come to a consensus. Each student should then record their revised answers in the "My revised answer after discussing it with my partner" box.

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Guiding Student Thinking

For this part of the lesson to be most successful, it's important not to jump in too soon to provide answers as students are working. Support students by asking questions and allow them to sit with the challenge.

- As you circulate, support students by asking probing questions and offering suggestions, such as the following:
  - Question 1: Where do you see those words in the passage? Underline or highlight the words.
  - Question 2: Recall our discussion earlier in class. What were some of the factors that affected whether an item rusted?
  - Questions 3, 4, 6, 7: What is the charge on specific ions, and does it change from the beginning to the end of the reaction?

Guiding Student Thinking

Students learned the process of determining the charge on ions when they learned to write formulas for ionic compounds in Unit 2. You can explain that the process is similar for determining oxidation states.

  - Question 5: Try drawing a model of the atom and the ion. Use your periodic table to help you.
  - Question 8: Why do only parts of a bicycle rust? Which parts rust? Which parts don't rust?

PART 3: CLASS DISCUSSION TO SYNTHESIZE UNDERSTANDING OF REDOX REACTIONS

The final part of this lesson involves a whole-class discussion to summarize the key concepts of the text and review the answers to the handout questions.

- Explain to students that you are going to discuss the answers as a class, and that as you do so, they should record their final answers in the "My final answer after the whole-class discussion" box.
- Ask for volunteers to share their answers question by question. If you noticed that certain groups had particularly strong responses or approached the questions in a different way, you might call on them to highlight their responses.

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- During the discussion, restate, clarify, or extend the students' responses as needed to ensure that all students hear a complete response.

Extending the Lesson

For another example of a redox reaction, you can ask students to recall the electrolysis of water lab from Lesson 2.5. You can ask students to write the half-reactions and identify what substance was oxidized and what substance was reduced. You can also address why twice as much hydrogen gas was produced in the lab now that students have an understanding of stoichiometry. If students do not recall the lab, there are many videos of the electrolysis of water on video sharing sites.

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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

1. Does the conversion of S to S^{-2} represent oxidation or reduction? Explain.

   Reduction. In order to have an oxidation state of −2, an S atom must gain 2 electrons.

2. Is the reaction $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$ best classified as an oxidation–reduction or a precipitation reaction? Explain.

   Oxidation–reduction reaction. Na and Cl_2 react to form the ionic compound NaCl. Both substances go from being neutral to having charges (Na^+ and Cl^-), indicating that electrons were transferred.

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 4.3.B: Flaking Away – Check Your Understanding

All answers provided here are the correct final answers after the whole-class discussion.

1. Oxidation is a reaction that involves an atom losing an electron. Reduction is a reaction that involves an atom gaining an electron. These two reactions happen together in a redox reaction. Oxidation occurs at the anode and reduction occurs at the cathode.
2. Water and salt both speed up the process of rusting. Water on an anode's surface allows electrons to flow between the anode and the cathode. Salt dissociates in water and the ions make the water a better conductor.
3. Each iron atom that is oxidized loses two electrons to become an Fe^{2+} ion.
4. Electrons are gained by oxygen atoms, which are reduced. The oxygen goes from an oxidation state of 0 to −2.
5. $Fe(s)$ and Fe^{3+} ions have the same number of protons and neutrons. An Fe^{3+} ion has lost three electrons.
6. This reaction is not a redox reaction. The oxidation states of the reactants do not change, so no electrons are transferred. This reaction is a precipitation reaction because two aqueous substances react to produce a solid.
7. Iron has an oxidation state of +2 in $Fe(OH)_2$ and an oxidation state of +3 in Fe_2O_3, indicating that it loses an electron in the process.
8. Possibilities include using a less reactive metal or coating the metal with paint to prevent the metal from making direct contact with water.

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LESSON 4.4

Redox Reactions – Rusting Nails and Tarnishing Silver

OVERVIEW

LESSON DESCRIPTION

Part 1: Iron Nails in Copper Solution – Day 1
Students observe iron nails and a copper solution before they are mixed, and then observe the setup and predict what will happen when the iron nails soak in the copper solution overnight.

Part 2: Iron Nails in Copper Solution – Day 2
Students observe the nails after they have soaked in the solution overnight. They then work through a guided activity that helps them track the subatomic particles to identify that the reaction is a chemical change that involves the transfer of electrons. They also identify the species being oxidized and reduced.

Part 3: Application of Redox Reactions – Cleaning Silver
Students apply their knowledge of redox reactions to a real-world scenario where silver tarnish is cleaned in an aluminum pan. They identify the substances that are oxidized and reduced by tracking the exchange of electrons.

CONTENT FOCUS

Students make observations about a redox reaction and, building on their knowledge of ionic compounds from Unit 2, determine what is oxidized and what is reduced in the reaction. They are introduced to the idea that in order for an equation to be balanced, the

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~75 minutes

HANDOUTS

- 4.4.A: A Rusty Nail – Iron and Copper Redox Reaction
- 4.4.B: Using Redox to Clean Silver

MATERIALS

- large test tube and stopper
- cotton rounds
- non-iodized salt
- copper(II) sulfate pentahydrate
- three iron nails
- sandpaper
- scoopula
- stirring rod
- water

For each group for optional Part 3 experiment:

- zip-top sandwich bag
- peeled hardboiled egg
- piece of silver wire
- water
- beaker
- hot plate or microwave
- baking soda
- spoon or scoopula

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overall charge must be balanced. Students also create and revise a model to describe a redox reaction. The last part of the lesson has them extend their knowledge of redox reactions to a new context—cleaning tarnished silver using a redox reaction.

- aluminum pan or container lined with aluminum foil
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.2.A.1 Identify a reaction as an oxidation–reduction reaction based on the change in oxidation numbers of reacting substances. **4.2.A.2** Create and/or evaluate a claim about which reacting species is oxidized or reduced in an oxidation–reduction reaction.	**4.2.A** Electrons are transferred between reactants in oxidation–reduction (redox) reactions. **a.** Substances lose electrons in the process of oxidation and gain electrons in the process of reduction. **b.** Oxidation numbers are useful for determining if electrons are transferred in a chemical reaction. **c.** Electrons are conserved in redox reactions.
4.2.C.1 Create and/or evaluate models of redox reactions.	**4.2.C** Redox reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

SETUP AND PREPARATION NOTES

- **The setup and observations of the reactions on day 1 will not take an entire class period.** Since the reaction in Part 1 is slow, you can use the rest of the period after this demonstration to teach about redox reactions. Return to the test tubes the next day (or later in the week). You might also consider doing this part of the lesson during the last 10–15 minutes of the class period.

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- You might want to remove any coating from the nails using sandpaper before class starts.
- For the optional silver experiment in Part 3, students can tarnish any silver object, such as a piece of wire (available at most craft/hobby stores) or jewelry. To remove the tarnish, you can use aluminum pans or a container with aluminum foil in it. You may need to use some sandpaper on the aluminum foil.

SAFETY NOTES

All general safety guidelines should be followed.

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UNIT 4

PART 1: IRON NAILS IN COPPER SOLUTION – DAY 1

Students observe iron nails and a copper solution before they are mixed, and then observe the setup and predict what will happen when the iron nails soak in the copper solution overnight.

- To begin the lesson, allow students to observe iron nails and a solution of copper(II) sulfate pentahydrate before they are mixed. Students should record their observations in the table for question 1 on **Handout 4.4.A: A Rusty Nail – Iron and Copper Redox Reaction**.
- Have students work in pairs to draw particle diagrams of both the nail and the copper(II) sulfate solution (questions 2 and 3 on the handout). To keep the diagrams simple, they do not need to represent the water molecules.

Guiding Student Thinking

Ask students to think about what they learned about the structure of matter in Unit 1 to accurately represent the solid iron. For the copper(II) sulfate solution, students should use what they learned about ionic compounds in Unit 2 (reinforced in Key Concept 4.1) to represent the ions in solution.

- Next, have students respond on their own to questions 4 and 5 on their handout, which ask them to determine the number of protons and electrons in both the iron atoms and the copper(II) ions. Students will be asked to repeat this process several times during the lesson to account for the transfer of electrons during various redox reactions.

  Students sometimes struggle with determining the number of electrons in an ion, so have them check their answers with a neighbor before moving on. You can also have a few groups report their answers and discuss them with the class to reach a consensus before moving on.
- Now you will set up the demonstration for students.
  1. Cut out two pieces of cotton the size of the test tube opening. Soak both in tap water.
  2. Using sandpaper, remove any rust or coating from three iron nails.
  3. Place 2 to 3 cm of solid copper(II) sulfate pentahydrate crystals in the bottom of the test tube.

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4. Add tap water to just cover the copper(II) sulfate pentahydrate. Place one of the water-soaked pieces of cotton on top of the copper(II) sulfate. Use a stirring rod to push it gently into place.
5. Place 1 to 2 cm of non-iodized salt into the test tube on top of the cotton.
6. Cover the salt layer with tap water. Pour slowly and carefully to avoid stirring or mixing the layers.
7. Add the second piece of wet cotton on top of the salt as a barrier layer.
8. Gently place three nails on top of the second piece of cotton.
9. Slowly and carefully add water to cover the nails.
10. Cap the test tube.
11. Label the test tube with the class period and place it in a test tube holder.

- Have students label the Before picture on their handout (question 6). You may want to take a picture of the setup for students to view after the reaction is complete.
- Next, have students individually answer question 7 on their handout, which asks them to make a prediction about what will happen as the nails soak in the test tube.

PART 2: IRON NAILS IN COPPER SOLUTION – DAY 2

Students observe the nails after they have soaked in the solution overnight. They then work through a guided activity that helps them track the subatomic particles to identify that the reaction is a chemical change that involves the transfer of electrons. They also identify the species being oxidized and reduced.

- To begin this part of the lesson, students should observe the test tube up close and record their observations in the table for question 1 in Part 2 on Handout 4.4.A.
- Next they will create an After representation of the test tube (question 2). If available, colored markers, crayons, or pencils can be used to show the changes that took place overnight.
- After students have drawn their representations, have them work in small groups on questions 3–7 on the handout, which walk them through determining what substance was oxidized and what substance was reduced in the reaction. Here is some support for these questions:
    - Question 3: Students may have learned in middle school that color change is evidence of a chemical reaction and therefore may pick up on the color change of the solution.

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- Questions 4 and 5: Students sometimes have difficulty recognizing the difference between an atom and an ion. You may need to help them realize that the copper in the solution is made of copper(II) ions, not copper atoms, while the nail is made of iron atoms and the rust contains iron(II) ions. For part (c) of question 4, have students refer to their answers from the previous day for the number of protons and electrons in the reactants.
- Questions 6 and 7: Students could make a table of the number of electrons in each substance before and after the reaction to help them track the changes to identify what has been oxidized and what has been reduced.

- Before moving on to the last two questions on the handout (8 and 9), you may want to do a quick check to confirm that all groups have correctly identified what was oxidized and reduced.
- Question 8 introduces the idea of balancing charge in redox reactions. Students are presented with an unbalanced net ionic equation and asked to identify what might be wrong with the reaction. To support this, students are asked to keep track of the number of electrons of each substance.

  This is a challenging question, but resist the urge to tell students the answer. Let them struggle a bit and discuss the question with another group if necessary. You can remind students of how they learned to balance equations using the law of conservation of mass and see if they can come up with a similar process for balancing the charge, or you can ask them to consider where the “extra” electrons go if each copper ion gains only two electrons while each iron atom loses three electrons. You can also prompt students to consider that not all reactions occur in 1:1 ratios.
- Once groups have balanced the net ionic equation, have them answer question 9 on the handout. This final question has students create their own model of the reaction that took place, including the reaction equation, changes in charge, changes in electrons, and changes in color. These models can take a variety of forms and there is no single correct answer.

Classroom Ideas

Use whiteboards and dry-erase markers for initial models so students can track color changes and amend their models quickly. Final models can be drawn on paper for submission, or on the whiteboards and submitted by taking pictures to send to you.

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Guiding Student Thinking

Encourage groups to use Before, During, and After representations to track the changes of the substances in the test tube over time. Remind students to "zoom in to the substances" and show representations at the particle level. Evaluate representations based on the transfer of electrons and whether students use chemical symbols to show substances that have been oxidized or reduced.

- When groups have finished their initial drafts, have them pair up to compare models. Each group should review the model from the other group, ask them questions, and offer feedback. Allow groups time to revise their models based on feedback.

Instructional Rationale

Students need to make connections between what they see macroscopically and what is happening on the particle level, and they need to practice using chemical symbols. Using the modeling method will increase connections made between these three ways of representing chemical reactions and help students build a stronger foundation for lessons to come. Allowing groups to receive feedback and then revise their models also serves multiple purposes. First, if students know they will be able to revise, they may be more likely to take a chance and draw something, even if it is incorrect. Second, this process models the process scientists follow when sharing their work.

- Ask a few (or all) groups to share their models. Based on what students created, lead a discussion about the advantages and disadvantages of the various models. You can also ask questions such as the following to deepen student understanding:
  - What are the differences between physical and chemical changes in terms of attractive forces and composition?
  - Has the iron from the nails gone anywhere? What does the law of conservation of mass mean?
  - Can electrons be created or destroyed? Why are we tracking how many there are?

PART 3: APPLICATION OF REDOX REACTIONS – CLEANING SILVER

Students apply their knowledge of redox reactions to a real-world scenario where silver tarnish is cleaned in an aluminum pan. They identify the substances that are oxidized and reduced by tracking the exchange of electrons. This part of the lesson is designed to give students an opportunity to apply their knowledge of redox reactions to a new situation. They may know about silver cleaners for jewelry and other household items.

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- Have students work with a partner on the questions on **Handout 4.4.B: Using Redox to Clean Silver**. They may then check their work with their group. Encourage students to use a periodic table to determine the charge on each ion. Here is some support for these questions:
  - If students struggle with question 4, consider breaking it into smaller tasks. For example, you could have students list what substances are oxidized and reduced, the charge on each, and then create a system to keep track of the electrons and balance the charges. You could also ask students to first balance the equation for mass and then for charge.
  - Question 5 requires students to create a model of this reaction. They should use their previous models to help create it, including the macroscopic materials used, the zoomed-in particle diagrams, and the chemical symbols. Depending on the models students drew in Part 2 and what you see here, you can decide if you want students to share their models and revise.
  - Question 7 introduces the idea that not all redox reactions occur at the same rate. Reaction rates will be explored further in Key Concept 4.5, and students can return to this scenario once they have learned more about reaction rates.
- If you have enough class time, you could have students do the following experiment so they can see the redox reaction firsthand:

  Tarnishing Silver

  1. Add a peeled hardboiled egg to a zip-top sandwich bag.
  2. Heat the bag in a microwave for 30 seconds.
  3. Place a piece of silver wire in the bag.
  4. Close the bag and gently knead it from the outside until the silver metal is coated with egg.
  5. Let the bag sit for a few minutes and make observations.
  6. Using gloves, take the pieces of silver out of the bag. Rinse in water briefly and wipe off excess egg.

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Cleaning Silver

1. Heat 100 mL of water in a beaker on a hot plate or in the microwave.
2. Place the water in an aluminum pan or a pan lined with aluminum foil.
3. Carefully add a spoonful of baking soda to the pan.
4. Add the oxidized silver.
5. Monitor the reaction for 5 minutes and make observations.
6. Using tongs, take out the silver and make more observations.

- You can close the lesson with a whole-class discussion, using questions such as the following as a guide:
  - If we added sugar or any covalent compound to the water instead of baking soda, do you think the reaction would work?
  - Why can't an oxidation reaction occur without a reduction reaction?
  - Can this reaction be done again and again, as silver tarnishes over and over again?

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ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

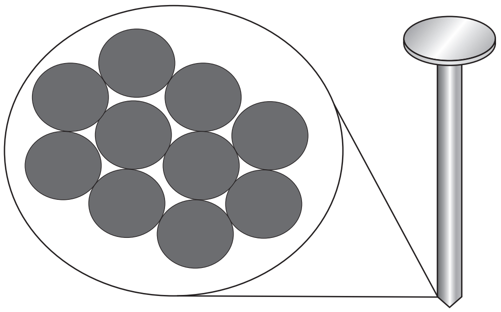
Handout 4.4.A: A Rusty Nail – Iron and Copper Redox Reaction

Part 1

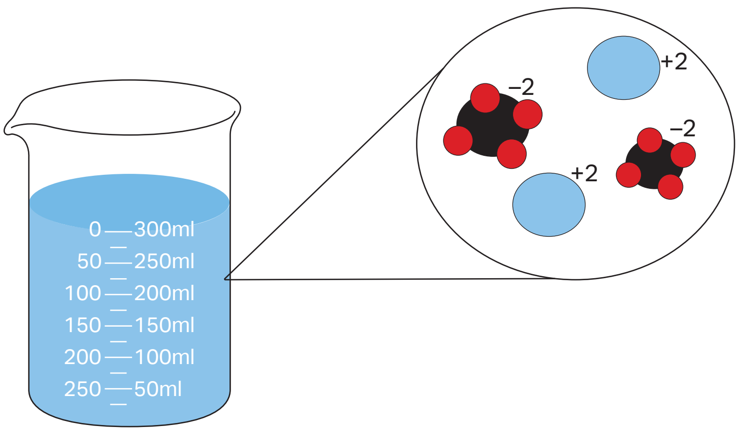
1.

Observations: Nail	Observations: Solution
shiny silver	clear, blue solution

2.



3.



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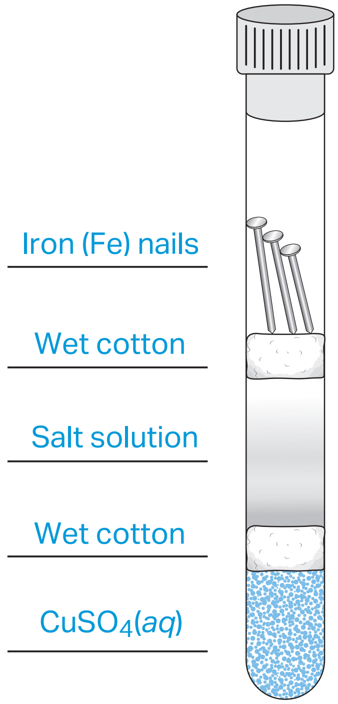
UNIT 4

4. Each iron atom has 26 protons and 26 electrons.

5. Each copper ion has 29 protons and 27 electrons.

6.

Before



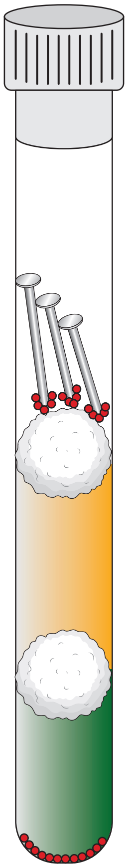
7. Answers will vary.

Part 2

1.

Observations: Nail	Observations: Solution
reddish/brown coating on nail	solution is green with a reddish precipitate at the bottom

2. After



3. Chemical: new substances formed.

4. (a) The copper ions in the solution.

   (b) An atom of copper has 29 protons and 29 electrons.

   (c) The number of electrons increased and the number of protons remained the same.

5. (a) i. The air above the nails in the test tube.

   ii. They will weigh more due to the addition of oxygen atoms.

   (b) An iron(III) ion has 26 protons and 23 electrons.

   (c) The number of electrons decreased and the number of protons remained the same.

6. Iron atoms transferred electrons to the copper ions in copper(II) sulfate.

7. Iron atoms were oxidized and copper ions were reduced.

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8. (a) 26, 27, 29, 23

   (b) The iron atom loses 3 electrons and the copper ion only gains 2 electrons. While the number of atoms is balanced in the equation above, charge is not balanced. The electrons that the iron atom loses must be gained by the copper ion. The equation can be balanced to show the transfer of 6 electrons.

$$2Fe(s) + 3Cu^{2+}(aq) \rightarrow 3Cu(s) + 2Fe^{3+}(aq)$$

9. Answers will vary.

Handout 4.4.B: Using Redox to Clean Silver

1. Ag has 47 electrons, Ag^{+} has 46 electrons. The silver lost electrons and oxidized.
2. Salt and baking soda are ionic compounds. When dissolved, their ions separate and the charges allow electricity to flow through the solution.
3. Aluminum will be reduced.
4. $3Ag^{+} + Al \rightarrow Al^{3+} + 3Ag$
5. Answers will vary.
6. The air and pollution.
7. Answers will vary. Factors include the amount of sulfur in the air, the temperature of the air, etc.

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UNIT 4

PRACTICE PERFORMANCE TASK

Reactions of Copper and Aluminum

OVERVIEW

DESCRIPTION

In this practice performance task, students demonstrate their ability to write molecular and net ionic equations for both redox and precipitation reactions involving solutions containing copper and aluminum cations. Students also determine if the reactions written are redox reactions by assigning oxidation numbers to various species. They then visualize these same reactions using particulate representations and use the representations to both predict the concentrations of ions in solution and develop a rudimentary activity series. Finally, students use stoichiometry to predict a theoretical yield of the product from one of their balanced equations.

CONTENT FOCUS

This task is designed to be used after students have completed their study of Key Concept 4.2: Oxidation–Reduction Chemistry. This task asks students to apply their understanding of concepts related to chemical reactions in a number of ways, including using multiple representations. The task begins with a short video showing a macroscopic representation of the vigorous reaction between aluminum metal and copper(II) chloride. Students are then asked to represent the reaction with both molecular and net ionic equations and to determine that the reaction is redox by assigning oxidation numbers to reactant and product species. Next, students are asked to change representations and visualize the reaction from a particle perspective. They are then given information about another experiment

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 4 Practice Performance Task: Reactions of Copper and Aluminum

MATERIALS

- calculator
- periodic table only (**not** the equation sheet)
- LCD projector, electronic whiteboard, or other technology for showing an online video to students
- internet access to a video showing the reaction between aluminum and copper(II) chloride, such as **youtu.be/OQPwPGDQqzs**
- aluminum foil (optional)
- copper(II) chloride (optional)
- water (optional)
- beaker (optional)

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in which potassium replaces copper and are asked to predict what would happen. In the final part of this task, students predict the products of a precipitation reaction between aluminum chloride and sodium hydroxide, then write molecular and net ionic equations for this reaction. The final part of the task also asks students to apply their understanding of stoichiometry to predict the maximum mass of product made.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings

- The mole concept is used to quantitatively relate the number of particles involved in a reaction to experimental data about that reaction.
- Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.

Learning Objectives	Essential Knowledge
3.1.A.2 Use the mole concept to calculate the mass, number of particles, or number of moles of a given substance.	**3.1.A** A large number of particles of a substance is needed to measure the physical properties of that substance. **b.** The molar mass of an element listed on the periodic table is the mass, in grams, of a mole of atoms of that element.
3.2.A.1 Create and/or evaluate models of chemical transformations.	**3.2.A** All chemical transformations involve the rearrangement of atoms to form new combinations. **a.** Since the atoms are not created or destroyed, the total numbers of each atom must remain constant. **b.** Chemical transformations can be modeled by balanced chemical equations and particulate representations.
3.2.B.2 Perform stoichiometric calculations involving the quantity of reactants and products in a chemical system.	**3.2.B** A balanced chemical reaction equation, combined with the mole concept, can be used to quantify the amounts of reactants consumed and products formed during a chemical transformation.
3.2.D.1 Calculate the theoretical yield and/or percent yield of a chemical reaction.	**3.2.D** A balanced chemical reaction equation, combined with the mole concept, can be used to calculate the theoretical and percent yield of a reaction.

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4.1.A.1 Predict the products of a precipitation reaction.	**4.1.A** Precipitation reactions may occur when two aqueous solutions are mixed, because some ionic compounds are insoluble in water and therefore precipitate out of solution.
4.1.B.1 Create and/or evaluate models of precipitation reactions.	**4.1.B** Precipitation reactions can be modeled by molecular equations, net ionic equations, and particulate representations.
4.1.C.1 Create and/or evaluate models that represent the concentration of a solution. **4.1.C.2** Perform calculations relating to the molarity of solutions.	**4.1.C** Molarity is one way to quantify the concentration of a solution. It describes the number of dissolved particles in a unit volume of that solution.
4.2.A.1 Identify a reaction as an oxidation–reduction reaction based on the change in oxidation numbers of reacting substances. **4.2.A.2** Create and/or evaluate a claim about which reacting species is oxidized or reduced in an oxidation–reduction reaction.	**4.2.A** Electrons are transferred between reactants in oxidation–reduction (redox) reactions. **a.** Substances lose electrons in the process of oxidation and gain electrons in the process of reduction. **b.** Oxidation numbers are useful for determining if electrons are transferred in a chemical reaction. **c.** Electrons are conserved in redox reactions.
4.2.B.1 Predict whether a redox reaction will occur between two reactants using an activity series. **4.2.B.2** Create and/or evaluate an activity series from experimental measurements.	**4.2.B** An activity series lists elements in order of decreasing ease of oxidation and can be used to determine whether a redox reaction will occur between two species.
4.2.C.1 Create and/or evaluate models of redox reactions.	**4.2.C** Redox reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

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SUPPORTING STUDENTS

BEFORE THE TASK

If you feel students need additional support before working on this practice performance task, you could do one or more of the following:

- Students may need a refresher on the assignment of oxidation numbers. In particular, it can be helpful to point out that assigning oxidation numbers to species in the net ionic equation is the most effective way of determining whether a reaction is redox or not.
- Consider giving the students practice problems that require them to use the molarity and volume of a solution to determine moles, since some students struggle with this.
- Give students example reactions and have them practice writing net ionic equations.
- To set students up for the task, you can show a video of the reaction between aluminum and copper(II) chloride, such as the one at **youtu.be/OQPwPGDQqzs**. Or, if you prefer, you can perform a demonstration of this reaction in class.

DURING THE TASK

Because this is a practice performance task, you could have students engage in the task differently from a conventional assessment.

- Students could work in pairs to complete the task. It is not recommended that students work in small groups. There is ample work and enough potential discussion areas for two students, but in larger groups there may not be quite enough for everyone to fully engage in the task.
- You could chunk the task into parts (oxidation–reduction and precipitation) and have students complete one part at a time. Students could check their solutions with you or the scoring guidelines before moving on to the next part. During the check, spend a few moments discussing the solutions with students, especially what changes, if any, they could make to their solution to craft a more complete response the next time they engage in a performance task.
- Students may be surprised to see that there is aluminum left over in their particulate representations. It may be necessary to remind them of what they saw in the video: although copper was clearly made, a significant amount of aluminum foil was left behind in the cupcake tin.

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- Circulate around the room, checking students' reactions for proper balancing. If they are stuck on how to produce the particulate representation, ask them if the balanced equations provide a "guide" for how to draw it. Students may also need guidance on how to tease out the molarity of the aluminum ion. In this case, ask them to think about the concept of concentration; it may be helpful to remind them that, as stated in the task, the volume of the liquid stays constant after the reaction.
- Some students may think they do not have enough information as nothing about potassium metal is explicitly discussed. This provides a great opportunity to hint at the fact that information about metallic ions not reacting can be just as useful as observations of metals oxidizing. **It is critical that in this task the equation sheet is not given, and students only have access to the periodic table.** The activity series given in the equation sheet would give away the answers to this task, preventing students from gathering information about activities of the metals from observation and close reading alone.
- **There is no need to have the solubility rules available, as enough information is given in the problem to predict the product.** If students question this, ask them what they remember about the solubility of sodium chloride. They have gained enough practical experience in the course up to this point to know that NaCl is soluble.
- Students may have difficulty coupling their knowledge of stoichiometry with their knowledge of precipitation reactions in the last part of the task, as some may believe that they need to know the amount of sodium hydroxide added. Remind students what the word *excess* implies and also be prepared to guide them to the idea of calculating moles of aluminum from the data given.

AFTER THE TASK

Whether you decide to have students score their own solutions, have students score a classmate's solution, or score the solutions yourself, the results of the practice performance task should be used to inform instruction. As this is the last practice performance task of the course, it incorporates knowledge and skills students have gained from all units. The last question in particular asks students to couple their knowledge of stoichiometry with reactions, and it should provide a good gauge of student skills in this area. If students find this part of the task particularly challenging, consider additional lab work that allows them to collect and measure products, comparing their actual yield to what stoichiometry would theoretically predict.

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SCORING GUIDELINES

There are 20 possible points for this practice performance task.

Question 1, part (a)

Sample Solutions	Points Possible
$3CuCl_2(aq) + 2Al(s) \rightarrow 2AlCl_3(aq) + 3Cu(s)$	**3 points maximum** 1 point for correctly writing the formula of each reactant 1 point for correctly writing the formula of each product 1 point for correctly balancing the equation *Scoring note:* Students do not need to include phases in their equation.

Targeted Feedback for Student Responses
Remind students to balance the equation for both charge and number of particles.

TEACHER NOTES AND REFLECTIONS

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Question 1, part (b)

Sample Solutions	Points Possible
$3Cu^{2+}(aq) + 2Al(s) \rightarrow 2Al^{3+}(aq) + 3Cu(s)$	**2 points maximum** 1 point for removal of all spectator ions 1 point for charge and mass balance of remaining species *Scoring notes:* ▪ Students do not need to include phases in their equation. ▪ Charges on ions are not needed to earn the first point. ▪ Students should receive full credit for consistency between the molecular equation in part (a) and the net ionic equation.

Targeted Feedback for Student Responses
Remind students to remove spectator ions and to balance the equation for both charge and number of particles.

TEACHER NOTES AND REFLECTIONS

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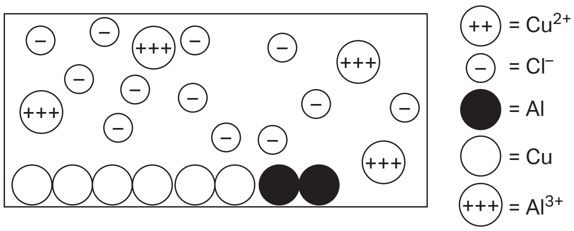
Question 1, part (c)

Sample Solutions	Points Possible
Yes, the reaction is redox because the oxidation number of copper changes from +2 to 0 *or* the oxidation number of aluminum changes from 0 to +3.	**1 point maximum** 1 point for recognition of redox with correct change of oxidation number in either copper or aluminum
Targeted Feedback for Student Responses	
Encourage students to identify the oxidation numbers of reactants and products and to discuss how the oxidation numbers change during the reaction.	

TEACHER NOTES AND REFLECTIONS

Question 2, part (a)

Sample Solutions	Points Possible
	**3 points maximum** 1 point for correct number of solid copper atoms formed 1 point for correct number of aluminum ions formed 1 point for no change in chloride (or for charge balance in solution) *Scoring note:* The excess solid aluminum reagent is not required for students to earn full credit for this part of the question.

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Targeted Feedback for Student Responses
Student responses must correctly show charge balance. Many students will inadvertently leave out the chloride ion as it is a spectator in the reaction, but the correct number of chloride ions is critical to maintain neutrality. Once students realize the chloride ions need to be shown, they can use charge balance to determine the number of aluminum ions to show in the diagram.

TEACHER NOTES AND REFLECTIONS

Question 2, part (b)

Sample Solutions	Points Possible
The final molarity of the aluminum ion should be $\frac{2.0 \text{ mol Cu}^{2+}}{1 \text{ L}} \times \frac{2 \text{ mol Al}^{3+}}{3 \text{ mol Cu}^{2+}} = 1.3\ M$.	**1 point maximum** 1 point for the correct answer *Scoring note*: If a student incorrectly balanced the equation, but used the information correctly, they should receive full credit for this part of the question.

Targeted Feedback for Student Responses
Instead of stoichiometric ratios, students can also determine the answer by using proportional reasoning between the concentration of the initial $CuCl_2$ solution and the number of particles shown in the reactant image. That same ratio can be used to determine the concentration of Al^{3+} ions from the number of particles shown.

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TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
Option (ii) (no reaction) should be circled. Since there was no reaction between the potassium ion and aluminum, potassium must be more active than aluminum. Since there was a reaction between Al and Cu^{2+}, aluminum is more active than copper. Therefore, potassium would also be more active than copper. Thus, the potassium ion could not remove electrons from solid copper and no reaction would occur.	**2 points maximum** 1 point for circling option (ii) 1 point for correct justification based on information that potassium is the most active metal of the three in the experiments
Targeted Feedback for Student Responses	
Emphasize to students that a complete response clearly explains the relationship between the relative activity of the metals and the experimental observations.	

TEACHER NOTES AND REFLECTIONS

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Question 4, part (a)

Sample Solutions	Points Possible
$AlCl_3(aq) + 3NaOH(aq) \rightarrow Al(OH)_3(s) + 3NaCl(aq)$	**3 points maximum** 1 point for correctly writing the formula of each product (2 points total) 1 point for correctly balancing the equation *Scoring note:* Students do not need to include phases in their equation.

Targeted Feedback for Student Responses
Students need to make sure they are balancing the equation for both charge and number of particles.

TEACHER NOTES AND REFLECTIONS

Question 4, part (b)

Sample Solutions	Points Possible
$Al^{3+}(aq) + 3OH^{-}(aq) \rightarrow Al(OH)_3(s)$	**2 points maximum** 1 point for removal of all spectator ions 1 point for charge and mass balance of remaining species *Scoring note:* Students do not need to include phases in their equation.

Targeted Feedback for Student Responses
Students should be careful to ensure balance of both charge and number of species.

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TEACHER NOTES AND REFLECTIONS

Question 4, part (c)

Sample Solutions	Points Possible
$0.125\text{ L} \times \frac{1\text{ mol AlCl}_3}{1\text{ L}} \times \frac{1\text{ mol Al}^{3+}}{1\text{ mol AlCl}_3} = 0.125\text{ mol Al}^{3+}$	**1 point maximum** 1 point for correct calculation of moles of $AlCl_3$ (or Al^{3+})
Targeted Feedback for Student Responses	
Remind students that they can use the volume and molarity of a solution to determine the number of moles.	

TEACHER NOTES AND REFLECTIONS

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Question 4, part (d)

Sample Solutions	Points Possible
Since the reaction is 1:1 in Al, there will be 0.125 moles of $Al(OH)_3$ made. $0.125 \text{ mol } Al(OH)_3 \times \frac{78.00 \text{ g } Al(OH)_3}{1 \text{ mol } Al(OH)_3} = 9.75 \text{ g } Al(OH)_3$	**2 points maximum** 1 point for correct calculation from stoichiometry of moles of product made (can be implicit) 1 point for correct molar mass of $Al(OH)_3$ and correct calculation of maximum mass of product that can be formed *Scoring note:* If a student incorrectly calculates the moles of aluminum ion, they can receive full credit for a correct mass of $Al(OH)_3$ based on this value.

Targeted Feedback for Student Responses
Remind students that the relationship of the moles of Al^{3+} to $AlCl_3$ can be obtained from the formula, which can also be used to predict the moles and mass of product.

TEACHER NOTES AND REFLECTIONS

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LESSON 4.5

Acids, Bases, and pH

OVERVIEW

LESSON DESCRIPTION

Part 1: Acid and Base Dissociation Reactions
Students are given cards that show various representations of acid–base dissociation reactions. They then group these cards by reaction type.

Part 2: Weak Versus Strong and Concentrated Versus Dilute
Students are given cards that show particulate representations of various acid–base solutions. They then sort these cards by the relative strength of the acid or base and by the concentration of the acid or base.

Part 3: pH of Acid and Base Solutions
Students sort the particulate representations from Part 2 by pH and develop explanations of how pH depends on both the concentration of the solution and the strength of the acid or base.

CONTENT FOCUS

This lesson introduces students to the difference between strong and weak acids and bases and how strength differs from concentration of a solution. Since students frequently misunderstand these terms, they are given multiple representations of each and construct their own definitions. The lesson begins with fairly simple representations and progresses to more complex representations. It culminates with students classifying acids and bases according to their pH and discovering the factors that determine the pH of a

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 4.5.A: Acids and Bases
- 4.5.B: Representations of Acid–Base Reactions
- 4.5.C: Particle Representations of Acids and Bases
- 4.5.D: Check Your Understanding

MATERIALS

- card sets from Handouts 4.5.B and 4.5.C (one of each card set per student group, with all cards cut out)
- small sticky notes
- document camera (optional)

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solution. To help students overcome the misconception that strong acids always have a lower pH than weak acids, they are given scenarios where that is not the case. After this lesson, students have the conceptual understanding necessary for calculations involving the pH of acids and bases to be more meaningful.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.3.A.1 Create and/or evaluate models of strong and weak acids and bases. **4.3.A.2** Distinguish between strong and weak acids in terms of degree of dissociation in aqueous solution. **4.3.A.3** Evaluate a claim about whether a compound is a strong or weak acid or base.	**4.3.A** Acids and bases are described as either strong or weak based on the degree to which they dissociate in aqueous solution.
4.3.B.1 Explain the relationship between the hydrogen ion concentration and the pH of a solution.	**4.3.B** The pH of a solution is a measure of the molarity of H_3O^+ (or H^+) in the solution.

SETUP AND PREPARATION NOTES

- Each student group will need a set of cards from Handouts 4.5.B and 4.5.C. Since there are many cards, you may want to make a laminated set of cards to reuse. Groups may also find scratch paper useful to create labels for the various ways they are asked to organize the cards.

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PART 1: ACID AND BASE DISSOCIATION REACTIONS

Students are given cards that contain various representations of acid–base dissociation reactions. They then group these cards by reaction type.

- To begin, have students brainstorm characteristics of acids and bases they have learned about or experienced previously. They should write the characteristics in the first row of the first table on **Handout 4.5.A: Acids and Bases**.
- Once they are finished, have a few students share characteristics they listed. Encourage them to add characteristics to their list that they did not originally include.
- Next, lead students through the following steps to help them refine the characteristics of acids and bases, since they may have incomplete ideas or misconceptions about them. This also introduces the concept of dissociation of acids and bases, which will help students develop their own definitions of them.

Instructional Rationale

When students are asked to identify patterns and construct their own definitions—rather than being given definitions and taking notes—they develop a deeper understanding because they have spent time thinking about and synthesizing the material.

- On the board, provide the following two lists of examples of acids and bases:
  - Acids: HCl, HBr, HNO_3, H_2SO_4, H_3PO_4, etc.
  - Bases: NaOH, LiOH, $Ca(OH)_2$, etc.

  Ask students to look at the lists and then write down the common ion that may be present in all acids and a common ion found in bases. They can do this on a sticky note or scratch paper.
- Have students discuss their response with a partner. Once pairs have reached a consensus, ask students to add these ions to their list of characteristics of acids and bases in the table on the handout.
- Next, ask each student pair to come up with an initial definition of an acid and a base. Again, they can do this on a sticky note or scratch paper.
- Ask a few volunteers to share their definitions and then lead the class to a consensus: *Acids* are compounds that contain hydrogen ions and *bases* are compounds that contain hydroxide ions. Once you have a class consensus definition, students should record it on their handout.

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Guiding Student Thinking

This is a simple definition of acids and bases, which is sufficient right now. The next part of the lesson will have students reconsider this definition, particularly for bases that do not contain hydroxide ions.

- Next, orient students to the four reactions in the second table on the handout, shown below.

ACID–BASE REACTIONS

Water Reaction $H_2O + H_2O \rightarrow H_3O^+ + OH^-$	
Acid Reaction $HA + H_2O \rightarrow A^- + H_3O^+$ Hydronium	**Base Reactions** (1) $NaOH \rightarrow Na^+ + OH^-$ (2) $B + H_2O \rightarrow BH^+ + OH^-$ Hydroxide
Acid–Base Reactions Summary Acid–base reactions involve transfer of a hydrogen ion between molecules.	

Handout 4.5.A

You can use the following tips and prompts to orient students to each reaction. It's also a good idea to display each reaction on the board and keep them visible for the rest of the lesson.

- Water Reaction: Point out that in liquid water, a very small number of molecules transfer a hydrogen ion between one another. Introduce the term *hydronium* ion (for H_3O^+).
- Acid Reaction: Identify this as the generic equation for the reaction of an acid with water. Ask students why they think HA is used as the formula for an acid and why one product is A^-. Have them label the hydronium ion in the reaction on their handout.
- Base Reaction 1: Show students the equation for the dissociation of sodium hydroxide in water, and explain that a common type of base is a salt where the anion is hydroxide. Have them label the hydroxide ion in the reaction.

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- Base Reaction 2: Explain to students that some bases don't contain hydroxide. Instead, they accept a proton from water, creating hydroxide. Take some time to make sure students understand why we're using B and BH^+ in the equation. Again, have them label the hydroxide ion in the reaction.

- Have students carefully consider all four reactions. Explain that they have at least one thing in common and challenge them to determine what it is. Allow a few minutes for students to reflect and share answers. Guide them to identify the transfer of a hydrogen ion as a common element in each reaction. To help students better visualize this, you can circle the hydrogen ion in each reactant and draw an arrow showing where it is moving to.
- Based on the previous discussion, have students come to a consensus definition for an acid–base reaction. This should be something like "Acid–base reactions involve transfer of a hydrogen ion between molecules."
- Emphasize the difference between a hydrogen atom and ion, noting that a hydrogen atom includes both a proton and an electron, and so takes up a lot of space, while a hydrogen ion is just a bare nuclear particle (proton) and so always attaches itself to water or some other molecule. Also emphasize that the terms *hydrogen ion* and *proton* are synonymous. Students should record the consensus definition on their handout.

- Give each pair or small group a set of cut-out cards from **Handout 4.5.B: Representations of Acid–Base Reactions**. Ask them to separate the cards into four groups, with each corresponding to one of the four acid–base reactions that were just discussed. As you circulate around the room, consider the following ways to guide students:
  - If students don't know where to start, encourage them to begin with cards 1–8, which show the symbolic representations of the reactions, because these are similar to what you wrote on the board.

Classroom Ideas

You may want to make a laminated set of the cards for durability. Colored representations are important to help students track the changes that happen in each model. Black and white photocopies will be hard to read.

Instructional Rationale

The different ordering of reactants and products provides an opportunity to emphasize that this order does not matter, and it is only important which chemical species are written as reactants versus products. It also helps students focus on the movement of the hydrogen ion. You can also emphasize that "A," "B," and "M" are not elements on the periodic table, and instead represent various types of acids and bases.

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- Next, have students consider the placement of cards 9–12, in which the chemical formulas of the reactions are replaced with particulate representations of the individual molecules.

Guiding Student Thinking

Use these cards to help students connect the symbolic (H_2O, HA, etc.) representations to their particulate representations. Draw students' attention to the charges present on the chemical species and the fact that these charges are balanced on both sides of the reaction. Connect this charge balance to the exchange of a proton between the species, with the proton carrying a positive charge.

- Finally, have students categorize cards 13–16, which illustrate collections of particles.
- Ensure that all groups have the cards arranged by reaction types so that they can easily refer back to these reactions for the remainder of the lesson. Correct arrangements are shown on the next page.

Meeting Learners' Needs

Some students may find it challenging to connect the chemical reactions on the first two sets of cards (1–8 and 9–12) to the collections of particles on the third set of cards (13–16). It may be helpful to describe the reaction equation as a rule regarding the way in which the molecules react; e.g., $HA + H_2O \rightarrow A^- + H_3O^+$ indicates that when one HA and one H_2O molecule react, they are replaced with one A^- and H_3O^+ species. In water, there are many different H_2O molecules that the HA could have reacted with. These diagrams show what happens after the reaction occurs and the reacting species have had time to diffuse away from one another.

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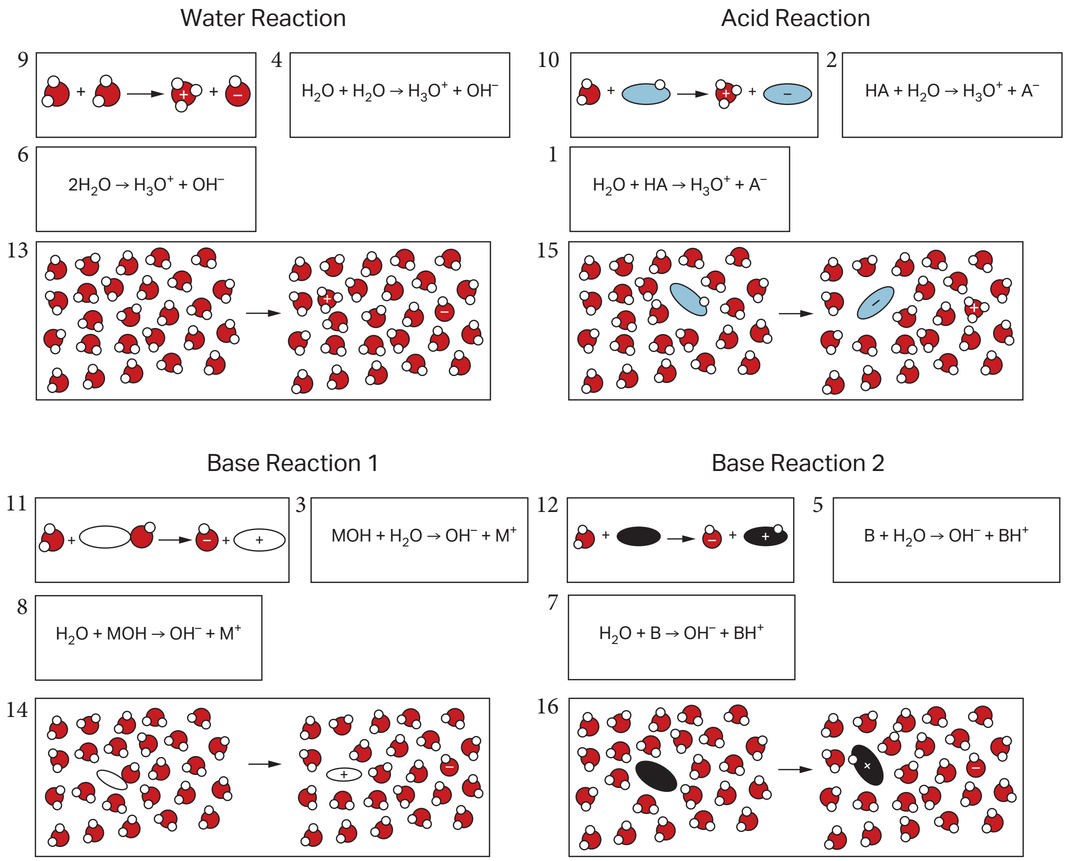
UNIT 4



PART 2: WEAK VERSUS STRONG AND CONCENTRATED VERSUS DILUTE

Students are given cards that contain particulate representations of various acid–base solutions. They then sort these cards by the relative strength of the acid or base and by the concentration of the acid or base.

- Have students keep their cards from Part 1 arranged in the four groups, corresponding to the four reactions they have been studying. Give each group of students a set of cards 1–10 from **Handout 4.5.C: Particle Representations of Acids and Bases** and allow them a few moments to carefully consider the cards. Help students see that each card shows a particulate representation of a small volume of a solution and that the volume shown is the same on all cards. The water in the solution is faded out so that students can focus on the other species (solutes) present in the solution. Be sure students understand that the species are drawn in the same way they were in the cards they used in Part 1.

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- Review the meaning of *concentration* and what it means for a solution to be concentrated versus dilute. You can use questions such as the following:
    - Which is more concentrated: dark-colored iced tea or nearly translucent iced tea?

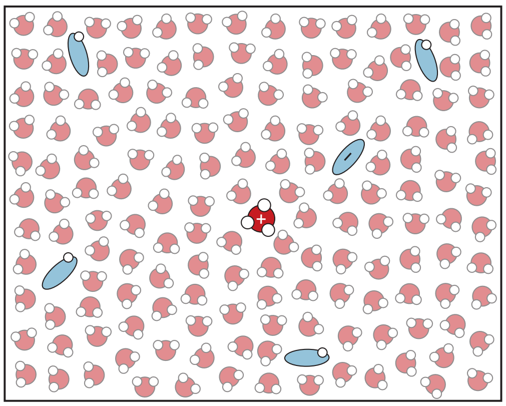
      The dark tea is more concentrated.
    - How do we quantify concentration of solutions?

      Molarity, which is the number of moles of solute per liter of solution.
    - If one solution has a concentration of 2.0 *M* and another has a concentration of 1.0 *M,* what does that mean about the number of solute particles in each solution?

      The 2.0 *M* solution has twice as many dissolved solute particles as the 1.0 *M* solution.
- Ask students to sort the cards from the most dilute to the most concentrated solution. Give them ample time to get familiar with the cards and to compare the particulate drawings on these cards to those from Part 1. As you circulate around the room, ensure that students understand that, because each card shows the same volume of solution, the concentration of a species is proportional to the number of particles of that species present on the card.
- Pay special attention to how students sort cards 8 and 6, shown below. Because there are more particles (excluding the water particles) present on the card on the right, students may reasonably choose to sort these cards as shown below.

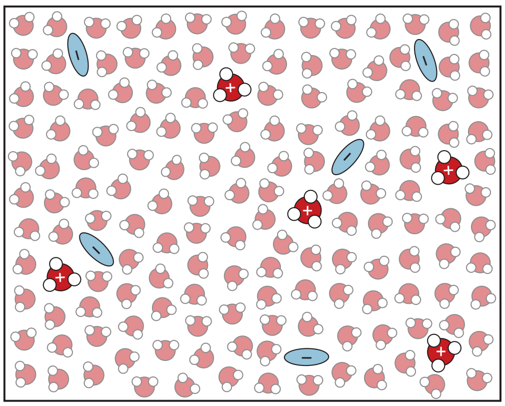
Most Dilute → Most Concentrated

8



weak acid with medium concentration

6



strong acid with medium concentration

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- Use the sorting of the above two cards as an opportunity to explain that the concentration of an acid in a solution refers to the number of HA molecules that were added to the water. Explain that, for both of these cards, 5 molecules of HA were added to the solution. The difference is that for the card on the left, most of the HA molecules remained HA, while for the card on the right, most of the HA molecules reacted with H_2O to form A^- and H_3O^+. During your explanation, try to avoid using the terms *weak* and *strong* since these terms haven't been introduced yet, and instead explain the sorting of the two cards using the counted number of particles.

Instructional Rationale

This instructional sequence is intended to give students time to work with the ideas of strong versus weak acids and bases by carrying out the sorting task before you introduce the terms *strong* and *weak*. Purposely not using these terms until the end of this card sort will help students discover the concept for themselves, leading to better long-term retention.

- Have students complete Check Your Understanding 1 on **Handout 4.5.D: Check Your Understanding**. This allows you to gauge how well students understand the dissociation of acids and bases at the particle level.
- Next, ask students to return to the above task of sorting the cards from most dilute to most concentrated, with the additional refinement that the sorting should be done by the concentration of acid or base added to the solution, i.e., the concentration of HA, NaOH, or B added to water to create the solution. As you circulate around the room, help students come to the sorting shown on the next page:

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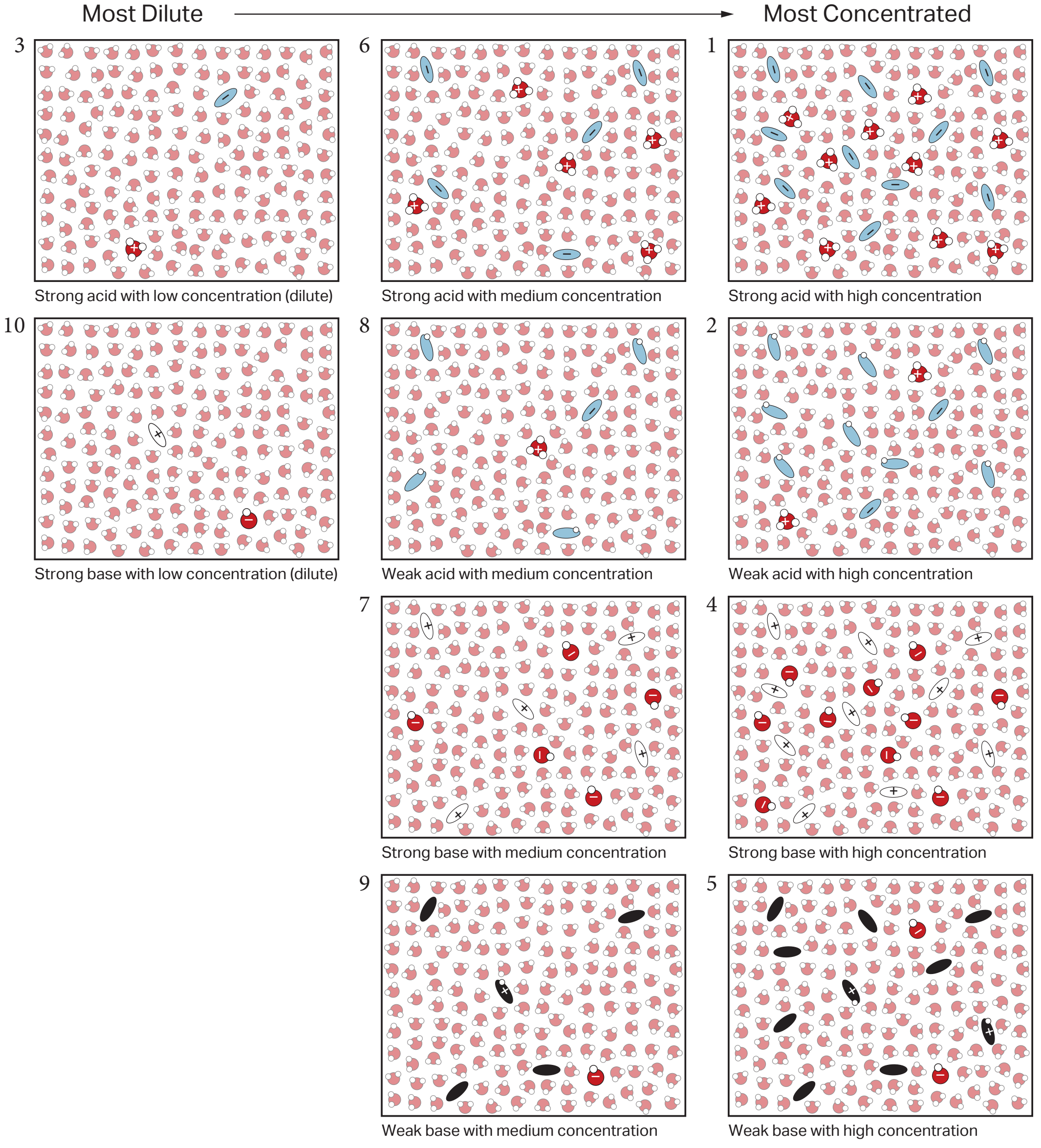

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UNIT 4

- Before confirming the correct answers, you may choose to have one student stay with their cards and one student check with other groups to see if they might want to rearrange their cards.
- Once groups have finalized their arrangements, ask each group to write a couple of sentences explaining why the cards in the middle column are classified as equally concentrated. Then ask a few groups to share their responses and identify any themes that emerge.
- Finally, provide the terms and definitions of *strong* and *weak* acids and bases. Many students have a hard time with these terms because they have the misconception that a strong acid has strong bonds and will stay together as HA. To help dispel the misconception, ask students to try to explain why the strong acids represented in the models above are stronger electrolytes than the weak acids in terms of number of ions and forces being broken.
- Have students complete Check Your Understanding 2 on Handout 4.5.D. This allows you to gauge how well they understand how strong and weak acids dissociate.

Instructional Rationale

The distinction between weak/strong and concentrated/dilute may be difficult for some students because it requires understanding and integrating a number of complex ideas. The instructional sequence of this part of the lesson is intended to gradually introduce these ideas and give students time to work with each idea before moving on to the next. To sort cards by the number of HA, NaOH, or B molecules added to the solution, students must understand both the nature of the experimental situation (the addition of HA, NaOH, or B to the solutions) and the way that reactions alter the nature of what was added; e.g., HA may transform to A^- and H_3O^+, and the degree to which this occurs is not under the control of the person carrying out the experiment. Part 3 takes this even further by connecting weak/strong and dilute/concentrated to the pH values of the resulting solutions.

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PART 3: PH OF ACID AND BASE SOLUTIONS

Students sort the particulate representations from Part 2 by pH and develop explanations of how pH depends on both the concentration of the solution and the strength of the acid or base.

- Students likely learned about pH in a middle school science course. To begin this part of the lesson, gauge what they remember about pH. Follow up with the information below, if students do not already know it.
  - Pure water has a pH of 7, which we refer to as neutral pH.
  - Because water autoionizes by the reaction introduced in Part 1 ($H_2O + H_2O \rightarrow H_3O^+ + OH^-$), both H_3O^+ and OH^- are present in water. But this is a very small amount, and H_3O^+ and OH^- are present in equal amounts.
  - An acidic solution has a substantial amount of H_3O^+. This causes the pH to be less than 7.
  - A basic solution has a substantial amount of OH^-. This causes the pH to be greater than 7.
- Students will again use cards 1–10 from Handout 4.5.C. Ask them to sort the cards based on whether they represent an acidic solution or a basic solution. As you circulate around the room, help students correctly place the cards in the appropriate category.
- Extend your explanation above to include the points that:
  - The solutions with higher concentrations of H_3O^+ and OH^- deviate more from the neutral pH of 7.
  - Acidic solutions with more H_3O^+ have a lower pH because that is the direction away from 7.
  - Basic solutions with more OH^- have a higher pH because that is the direction away from 7.
- Ask students to refine their sorting to include the relative pH values among the acids and the bases, ranking the cards from most acidic to most basic. As you circulate around the room, help students come to the sorting shown on the next page:

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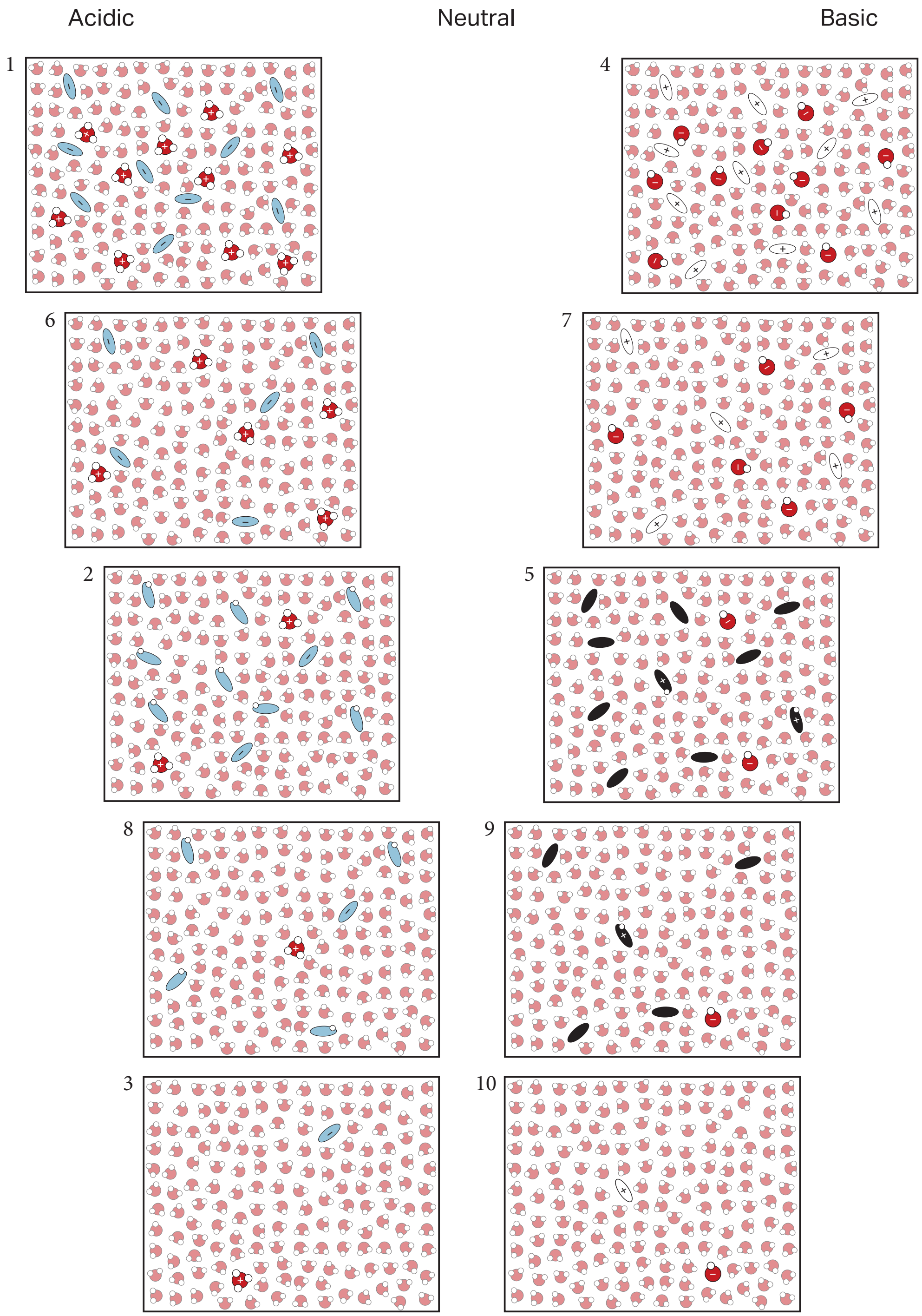

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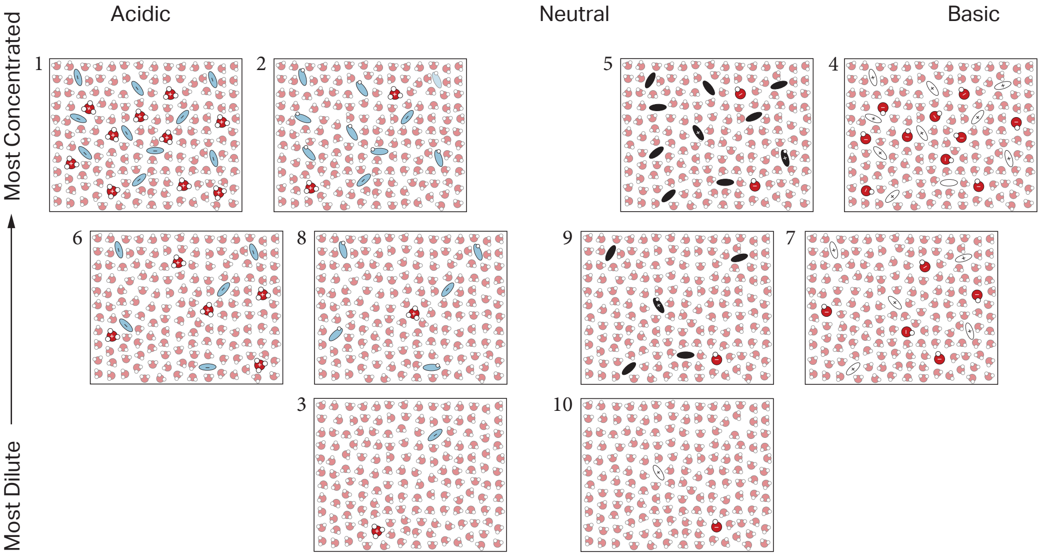
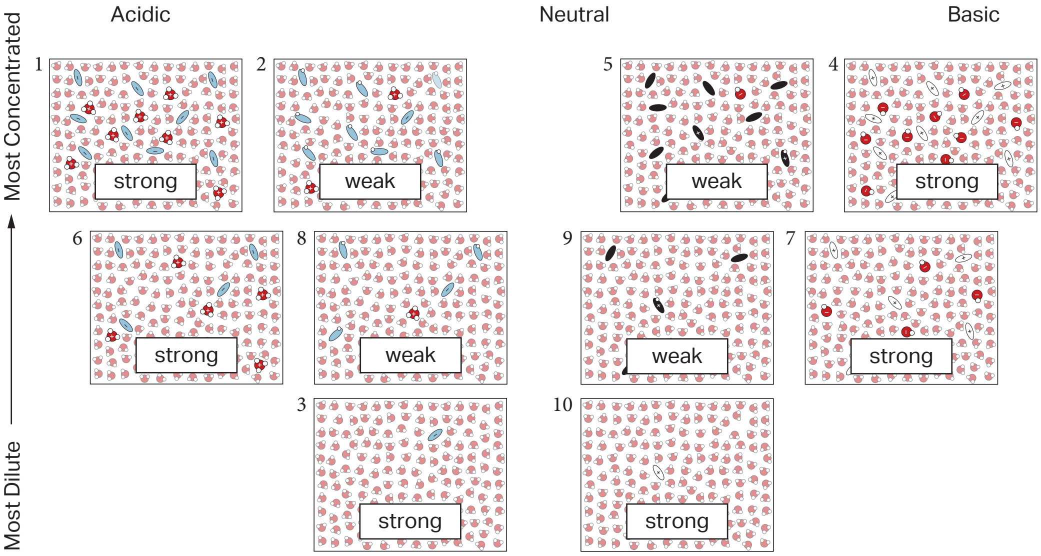
UNIT 4

- Next, have students sort for both pH and concentration. To do this, they can arrange the cards horizontally based on pH and vertically based on concentration, with the cards representing the most dilute solutions lower on the scale. You may want to draw an example of the horizontal and vertical scales on the board for students to replicate.
- Students should arrive at a solution similar to what is shown here:



- Once students have correctly sorted the cards as above, ask each group to write the words *strong* and *weak* on several small sticky notes and then use these sticky notes to label each card as a representation of a strong or weak acid or base.



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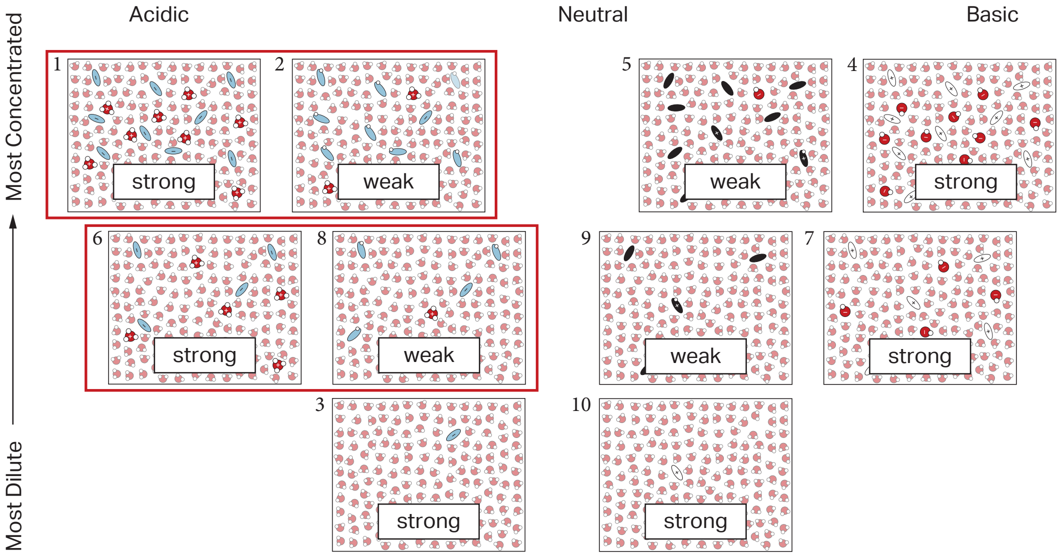
- Lead a discussion about the difference between acid–base concentration and acid–base strength. To help students think through the questions below, it will be useful to display a set of cards as arranged on the previous page. You can do this using a document camera or simply project the image on the previous page. Be sure to allow students plenty of time to think deeply about each question. You can facilitate the discussion by first giving students time to think individually, then discuss with a partner, and then in small groups. Each group could then share their answer with the class. Use the following questions to guide the discussion:
  - Do two acid solutions with the same concentration always have the same pH?



No. The red boxes above show cases where the concentration of the acid is the same, but the pH is not. This is because weak acids dissociate less than strong acids and so produce less H_3O^+.

  - What is true about the pH of two acid solutions with the same concentration but different strengths?

As seen for the solutions in the red boxes above, if the concentration is the same, the pH is of the strong acid is always more acidic than the pH of the weak acid.

  - What is true about the pH of two acid solutions with the same strength (i.e., the strong acid or weak acid in these solutions) but different concentrations?

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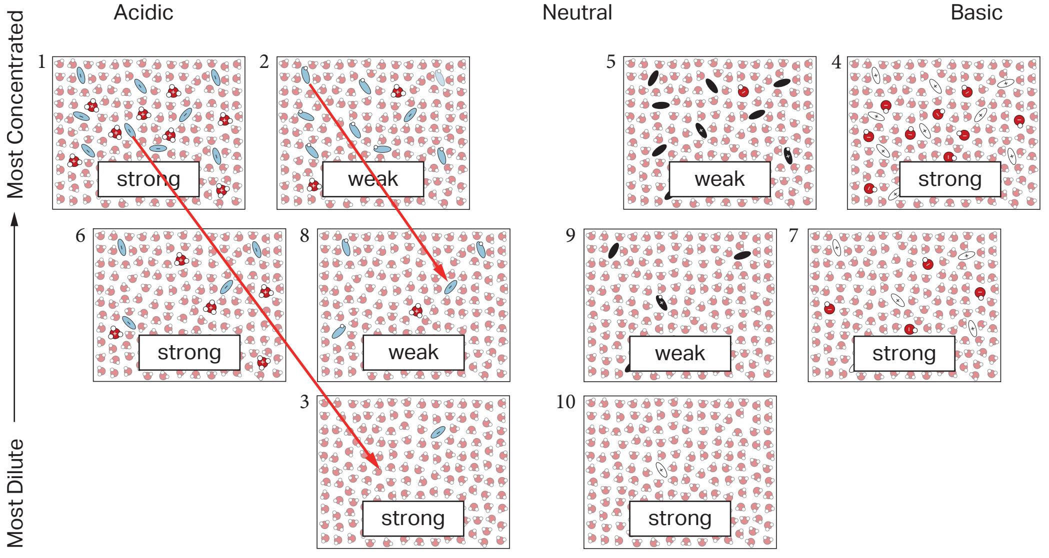
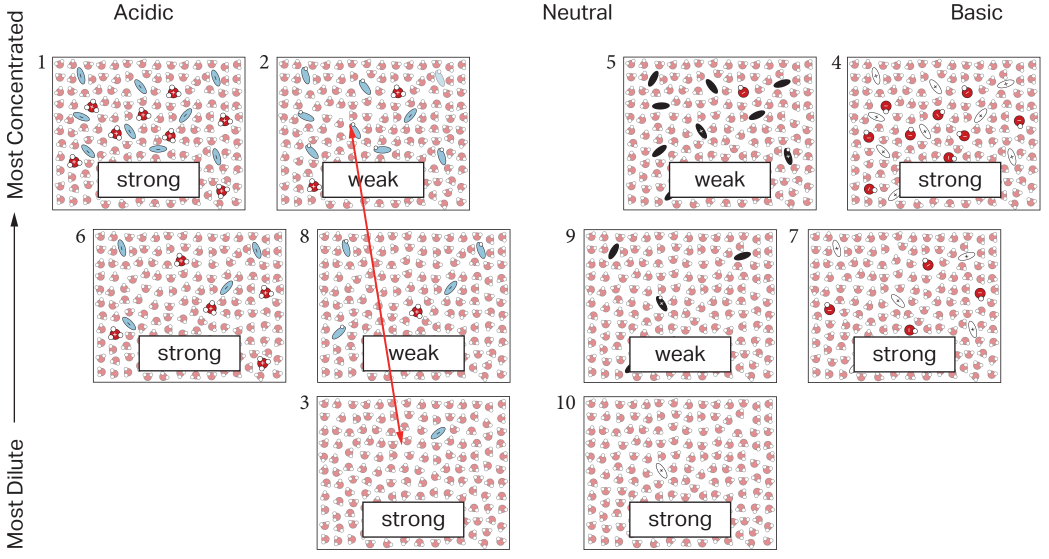


As seen for the solutions under the arrows above, the pH becomes less acidic as the concentration drops.

- What two factors contribute to the acidic pH of a solution?

Higher concentration and acid strength lead to a more acidic pH.

- Can a solution of a weak acid have a more acidic pH than a solution of a strong acid?



Yes, if, as shown above, the weak acid is much more concentrated than the strong acid. Emphasize that because there are two factors that contribute to an acidic pH, a concentrated weak acid can be more acidic than a dilute strong acid.

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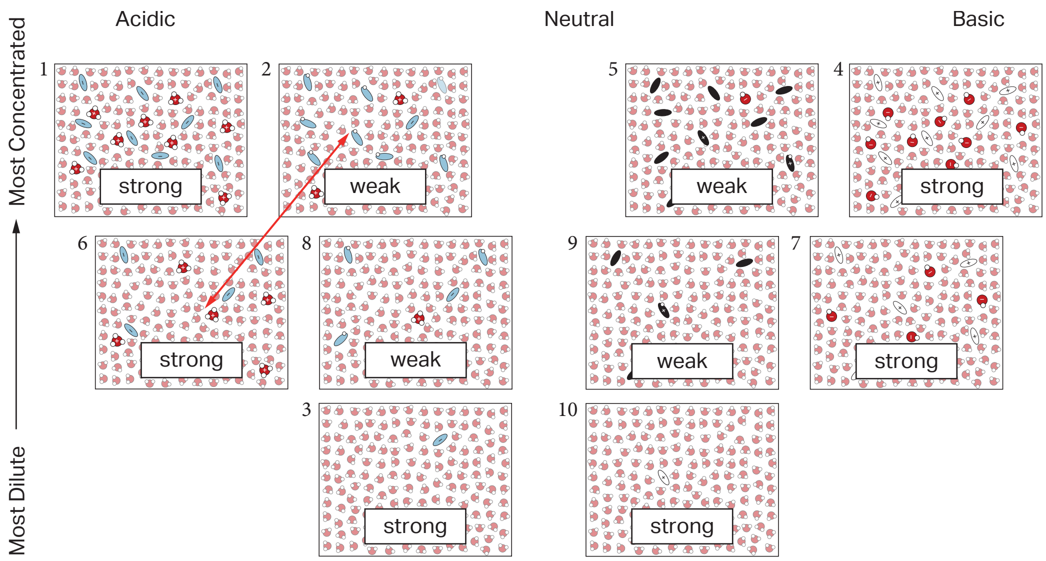
- Can a dilute solution of an acid have a more acidic pH than a concentrated solution of an acid?



Yes, if, as shown above, the dilute solution contains a strong acid and the concentrated solution contains a weak acid. Again, emphasize that because there are two factors that contribute to an acidic pH, a dilute strong acid can be less acidic than a concentrated weak acid.

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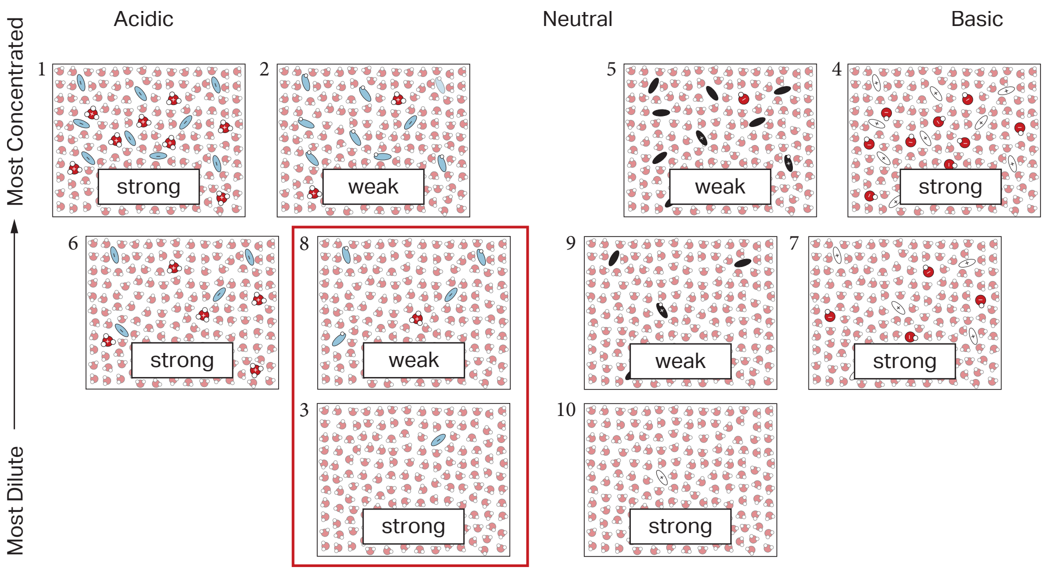
- Do two acid solutions with the same pH always have the same concentration of acid?



No. The red box above shows two solutions that have the same concentration of H_3O^+ and so the same pH. However, the solution of the weak acid is more concentrated than the solution of the strong acid.

- Have students complete Check Your Understanding 3 on Handout 4.5.D.

Extending the Lesson

You can use a line of questioning similar to the one above, this time focusing on the bases and the hydroxide ion concentration.

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ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 4.5.A: Acids and Bases

CHARACTERISTICS AND DEFINITIONS

Acid Characteristics	**Base Characteristics**
taste sour turn litmus red harmful/corrosive have a pH of less than 7	taste bitter slippery texture turn litmus blue have a pH of greater than 7
Acid Definition A compound that contains hydrogen ions.	**Base Definition** A compound that contains hydroxide ions.

ACID–BASE REACTIONS

Water Reaction	
$H_2O + H_2O \rightarrow H_3O^+ + OH^-$	
Acid Reaction $HA + H_2O \rightarrow A^- + H_3O^+$ Hydronium (H_3O^+)	**Base Reactions** (1) $NaOH \rightarrow Na^+ + OH^-$ (2) $B + H_2O \rightarrow BH^+ + OH^-$ Hydroxide (OH^-)
Acid–Base Reactions Summary Acid–base reactions involve transfer of a hydrogen ion between molecules.	

Handout 4.5.B: Representations of Acid–Base Reactions

Answers are provided in the lesson.

Handout 4.5.C: Particle Representations of Acids and Bases

Answers are provided in the lesson.

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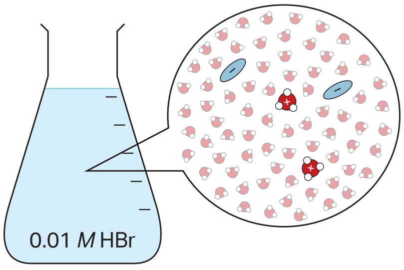
UNIT 4

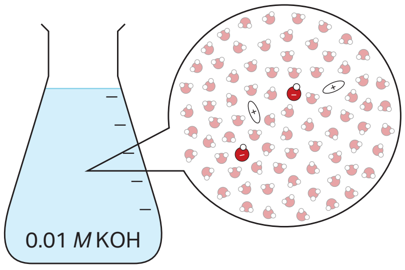
Handout 4.5.D: Check Your Understanding

Check Your Understanding 1

1.

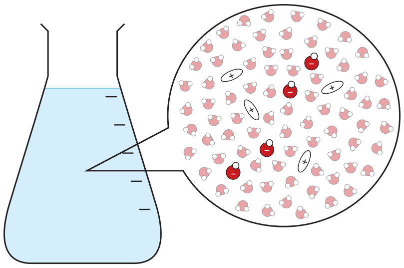


acid



base

2.



Sample response: Solution is 0.02 *M* KOH.

Check Your Understanding 2

1. HF is a weak acid because it only partially dissociates. The solution contains a mixture of HF molecules and H^+ and F^- ions. If HF were a strong acid, the solution would only contain H^+ and F^- ions.
2. CHOOH is a stronger acid because it dissociates more than CH_3COOH. There are more H^+ ions in the CHOOH solution than in the CH_3COOH solution.
3. d, a, b, c

Check Your Understanding 3

1. They would not have the same pH. HA completely dissociates, meaning it is a strong acid. HNO_2 only partially dissociates, meaning it is a weak acid. This means there will be more H^+ ions in the HA solution, which means it will have a lower pH.

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LESSON 4.6

Classifying Reactions

OVERVIEW

LESSON DESCRIPTION

Students explore the unique characteristics that can help identify each of the three types of chemical reactions—precipitation, oxidation–reduction, or acid–base—they've learned about so far. They then practice classifying reactions as one of the three types and justifying their choices.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 4.6.A: Classifying Chemical Reactions
- 4.6.B: Additional Practice Classifying Reactions

CONTENT FOCUS

Students learned about three types of reactions in Key Concepts 4.1, 4.2, and 4.3, and they may be comfortable predicting products or writing net ionic equations when they know the type of reaction. However, some students struggle with these skills when they do not know the reaction type. The focus of this lesson is on helping students identify what makes each type of reaction unique and justify their classification of a reaction in terms of the underlying mechanism: precipitation of ions, electron transfer, or hydrogen ion (i.e., proton) transfer.

Often, students' understanding of chemical reactions is limited to articulating how element symbols are rearranged in a reaction equation. For example, in the reaction $Fe(s) + CuCl_2(aq) \rightarrow Cu(s) + FeCl_2(aq)$, students may try to memorize a specific pattern such as A + BC → B + AC. This makes it difficult for students to develop an understanding of the differences in the types of reactions and what truly drives chemical reactions. This lesson helps students articulate their identification of reactions in terms of what is actually occurring at the particle level.

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COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions.	
Learning Objectives	**Essential Knowledge**
4.1.A.1 Predict the products of a precipitation reaction.	**4.1.A** Precipitation reactions may occur when two aqueous solutions are mixed, because some ionic compounds are insoluble in water and therefore precipitate out of solution.
4.1.B.1 Create and/or evaluate models of precipitation reactions.	**4.1.B** Precipitation reactions can be modeled by molecular equations, net ionic equations, and particulate representations.
4.2.A.1 Identify a reaction as an oxidation–reduction reaction based on the change in oxidation numbers of reacting substances.	**4.2.A** Electrons are transferred between reactants in oxidation–reduction (redox) reactions. **a.** Substances lose electrons in the process of oxidation and gain electrons in the process of reduction. **b.** Oxidation numbers are useful for determining if electrons are transferred in a chemical reaction. **c.** Electrons are conserved in redox reactions.
4.2.C.1 Create and/or evaluate models of redox reactions.	**4.2.C** Redox reactions can be modeled by molecular equations, net ionic equations, and particulate representations.
4.3.C.1 Predict the products of a reaction between a strong acid and a strong base.	**4.3.C** Acid–base reactions involve the transfer of a hydrogen ion from the acid to the base. Strong acid–base reactions produce water and an aqueous ionic compound.
4.3.D.1 Create and/or evaluate models of a reaction between a strong acid and a strong base.	**4.3.D** Acid–base reactions can be modeled by molecular equations, net ionic equations, and particulate representations.

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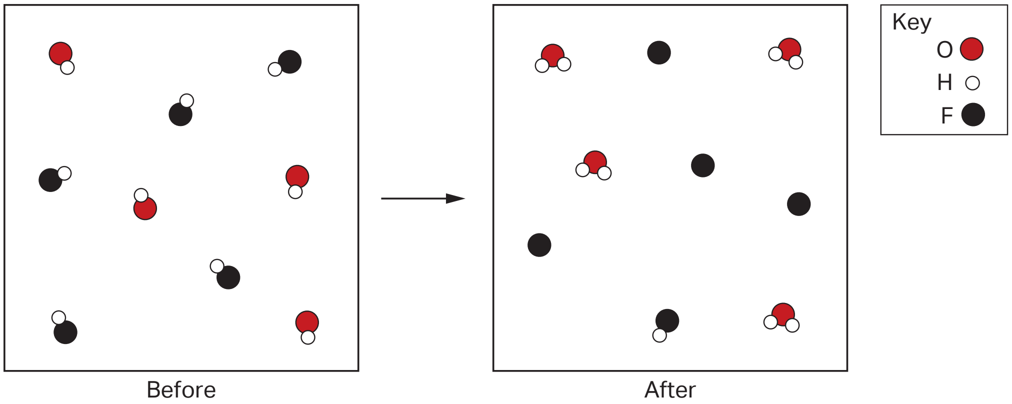
UNIT 4

FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

1. The net ionic equation of the reaction of zinc and hydrochloric acid is represented above. A student claims this is an acid–base reaction because the reactants contain H^+ ions. Do you agree or disagree with the student's claim? Explain.
2. Use the particle diagram below to answer the following questions.



   (a) Write the net ionic equation for the reaction.

   (b) Is the reaction an oxidation–reduction reaction, precipitation reaction, or acid–base reaction? Justify your selection.

   (c) In the particle diagram of the products, one of the reactants remains unreacted. Explain why, using stoichiometry principles.

3. For each of the following sets of reactants, predict the products of the reaction that will occur. Then write the net ionic equation, identify the type of reaction, and justify your selection.

   (a) $CaCl_2(aq) + Na_2CO_3(aq) \rightarrow$

   (b) $HBr(aq) + KOH(aq) \rightarrow$

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CLASSIFYING REACTIONS PRACTICE

Students explore the unique characteristics that can help identify each of the three types of chemical reactions—precipitation, oxidation–reduction, or acid–base—they've learned about so far. They then practice classifying reactions as one of the three types and justifying their choices.

- Begin the lesson by asking students to individually list what they remember about each type of reaction studied during this unit. Once students have had a chance to create their lists, ask them to work with a partner or small group to refine their lists. Ask for a few groups to share what they have written.
- Ask students to find **Handout 4.6.A: Classifying Chemical Reactions**. Have them work with a partner or small group on question 1, which asks them to match particle diagrams with molecular equations of chemical reactions.
- Once groups finish question 1, have them share their answers and explain how they came to their conclusions. These conclusions will help them answer the next question.
- Students should then work in their groups on question 2 to classify each reaction and provide their justification. Circulate around the room to assist students as they work.
- Once groups finish question 2, have them share their answers and how they came to their conclusions. Lead students through a discussion as you listen for student misconceptions. Ideal responses for each reaction will include the following characteristics:
  - For a precipitation reaction: Two aqueous solutions react to make an insoluble product.
  - For an acid–base reaction: The reactants include an acid and a base, the products contain water and a soluble ionic salt, and a hydrogen ion is transferred.
  - For an oxidation–reduction reaction: Oxidation numbers of more than one element change.

Classroom Ideas

Have students write their responses on whiteboards during the class discussion so others can see them.

Meeting Learners' Needs

For oxidation–reduction reactions, you may build on the lesson by having students write the oxidation–reduction half-reactions to show electrons were transferred.

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Guiding Student Thinking

If students struggle, encourage them to write the net ionic equation for a reaction first, as that will make the underlying mechanism easier to see. Next, model for them how to walk through the process step by step. You can do this with a question sequence like the following: Does this reaction contain an acid and a base? No? Then it cannot be an acid–base reaction. What happens in a redox reaction? Electrons are transferred. Let's check the oxidation numbers to see if they change.

- Finally, have students work in their groups to answer questions 3 and 4 about net ionic equations. This will serve as a good review of writing net ionic equations and their usefulness as a model.
- **Handout 4.6.B: Additional Practice Classifying Reactions** has additional questions that ask students to predict products of reactions, write net ionic equations, and classify reactions as either precipitation, redox, or acid–base. Have students work on the problems individually or in small groups.
- If you feel that students need additional practice with particle diagrams, you can ask them to draw diagrams for some or all of the reactions. You could also give them partial diagrams to complete.
- Once students have completed the additional practice questions, lead a whole-class debrief of the questions by asking students to defend their claims.

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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

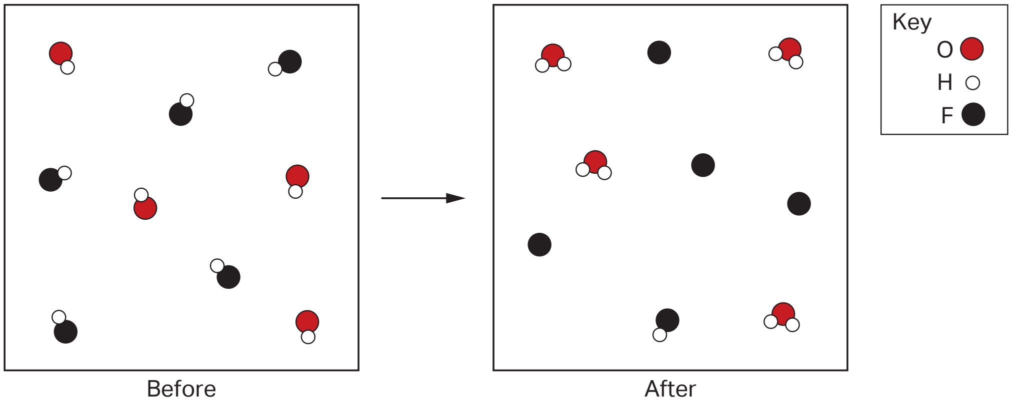
When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

1. The net ionic equation of the reaction of zinc and hydrochloric acid is represented above. A student claims this is an acid–base reaction because the reactants contain H^+ ions. Do you agree or disagree with the student's claim? Explain.

   Disagree. Although the reaction involves an acid, $HCl(aq)$, it is not an acid–base reaction. The reaction is an oxidation–reduction reaction. The oxidation number of zinc changes from 0 to +2, indicating it has lost electrons and was oxidized. The oxidation number of hydrogen changes from +1 to 0, indicating is has gained electrons and was reduced.

2. Use the particle diagram below to answer the following questions.



   (a) Write the net ionic equation for the reaction.

   $HF(aq) + OH^-(aq) \rightarrow F^-(aq) + H_2O(l)$

   (b) Is the reaction an oxidation–reduction reaction, precipitation reaction, or acid–base reaction? Justify your selection.

   The reaction is an acid–base reaction because a proton is transferred from HF to OH^-.

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(c) In the particle diagram of the products, one of the reactants remains unreacted. Explain why, using stoichiometric principles.

One HF molecule is unreacted because there were not enough OH^- ions to react with all the HF molecules. OH^- is the limiting reactant and HF is the excess reactant in this reaction.

3. For each of the following sets of reactants, predict the products of the reaction that will occur. Then write the net ionic equation, identify the type of reaction, and justify your selection.

(a) $CaCl_2(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + CaCO_3(s)$

$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

The reaction is a precipitation reaction because two aqueous solutions combine to form an insoluble ionic salt.

(b) $HBr(aq) + KOH(aq) \rightarrow KBr(aq) + H_2O(l)$

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ or $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$

The reaction is an acid–base reaction because

(i) a strong acid and a strong base react to form water, or

(ii) a hydrogen ion is transferred from the acid.

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 4.6.A: Classifying Chemical Reactions

1. Particle Diagram A matches with Reaction 2.

   Particle Diagram B matches with Reaction 3.

   Particle Diagram C matches with Reaction 1.

2. Reaction 1

   Reaction type: Acid–base

   Justification: The reactants contain both an acid and a base. In the reaction, a hydrogen ion is transferred from the acid (CH_3COOH) to the base (OH^-).

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Reaction 2

Reaction type: Precipitation

Justification: Two aqueous solutions produce an insoluble ionic salt, AgCl.

Reaction 3

Reaction type: Oxidation–reduction

Justification: The oxidation number of Fe changes from 0 to +2 and the oxidation number of Cu changes from +2 to 0. This shows that iron is oxidized, and each iron atom gives two electrons to each Cu ion, which are reduced.

3. Reaction 1: $CH_3COOH(aq) + OH^-(aq) \rightarrow CH_3COO^-(aq) + H_2O(l)$

   Reaction 2: $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

   Reaction 3: $Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$

4. The net ionic equation removes spectator ions and allows the driving force of the reaction to be easily seen. For acid–base, the driving force is the transfer of a hydrogen ion. For precipitation, it's the formation of the insoluble salt. For oxidation–reduction, it's the change in oxidation numbers of the reacting atoms and ions.

Handout 4.6.B: Additional Practice Classifying Reactions

1. (a) $HCOOH(aq) + OH^-(aq) \rightarrow COOH^-(aq) + H_2O(l)$

   (b) Acid–base

   (c) A hydrogen ion (proton) is transferred from HCOOH to OH^-.

2. (a) $Pb^{2+}(aq) + CrO_4^{2-}(aq) \rightarrow PbCrO_4(s)$

   (b) Precipitation

   (c) Two aqueous solutions combine to form an insoluble ionic salt.

3. (a) $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

   (b) Oxidation–reduction

   (c) The oxidation number of Mg changes from 0 to +2, indicating it has lost electrons and been oxidized. The oxidation number of H changes from +1 to 0, indicating it has gained electrons and been reduced.

4. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow NaCl(aq) + BaSO_4(s)$

   (a) $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

   (b) Precipitation

   (c) Two aqueous solutions combine to form an insoluble ionic salt.

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5. $NaOH(aq) + HBr(aq) \rightarrow NaBr(aq) + H_2O(l)$
   (a) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$, or $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$
   (b) Acid–base
   (c) The reaction is an acid–base reaction because
      (i) a strong acid and a strong base react to form water, or
      (ii) a hydrogen ion is transferred from the acid to the base.
6. $Zn(s) + NiCl_2(aq) \rightarrow ZnCl_2(aq) + Ni(s)$
   (a) $Zn(s) + Ni^{2+}(aq) \rightarrow Zn^{2+}(aq) + Ni(s)$
   (b) Oxidation–reduction
   (c) The oxidation number of Zn changes from 0 to +2, indicating it has lost electrons and been oxidized. The oxidation number of Ni changes from +2 to 0, indicating it has gained electrons and been reduced.

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UNIT 4

LESSON 4.7

Bond Energy and Fuel Reactions

OVERVIEW

LESSON DESCRIPTION

Part 1: Magnets as a Model of Bonds Breaking and Forming
Students engage in some simple experiments with magnets, allowing them to stick together and then pulling them apart. They relate their observations to what happens between atoms as a bond is broken or formed.

Part 2: Connecting Bond Strengths to Reaction Energies
This part of the lesson introduces a representation and a set of classroom materials that connect the energy released or absorbed by a chemical reaction to the energies of the bonds broken and formed in that reaction.

Part 3: How Chemical Fuels Store Energy
Students use the representations from Part 2 to model the energy involved in endothermic versus exothermic chemical reactions, and connect them to the relative strengths of the bonds broken and formed in the reactions.

CONTENT FOCUS

Students have been working with the idea of energy flow between substances—in both physical and chemical processes—throughout the course. This lesson extends this by connecting the energy generated or absorbed by a chemical reaction to the energy involved in breaking and forming chemical bonds. To help students make this connection, the lesson uses a model involving magnets, followed by a representation

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 4.7.A: Modeling Reactions Using Magnets
- 4.7.B: Reaction Components
- 4.7.C: Modeling Bond Energy

MATERIALS

- magnetic disks, four per student pair
- cut-out set of calorimeter components from Handout 4.7.B for teacher demo and for each student
- red and blue bingo chips
- document camera (optional)

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that relates the breaking and forming of bonds to the temperature of the solution in which the reaction takes place. A common misconception among students is that energy is released when a chemical bond is broken. This stems from the language, common in biology and other domains, that energy is "stored in chemical bonds." This misconception is addressed here by asking students to choose whether fuels should have strong or weak bonds. They then use the provided representation to model reactions corresponding to each choice. This provides an opportunity to discuss how fuels store chemical energy.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ All chemical reactions are accompanied by a transfer of energy.	
Learning Objectives	**Essential Knowledge**
4.4.B.1 Create and/or evaluate a claim about the energy transferred as a result of a chemical reaction based on bond energies.	**4.4.B** The relative strength of bonds in reactants and products determines the energy change in a reaction. Bond energy tables and Lewis diagrams provide a way to estimate these changes quantitatively for a wide variety of chemical reactions.

SETUP AND PREPARATION NOTES

- You can use magnets of any strength for this lesson. There is no need for very strong or expensive magnets.
- You will need a cut-out set of calorimeter components from Handout 4.7.B for a teacher demonstration.
- Each student group will also need a set of calorimeter components from Handout 4.7.B and bingo chips.

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FORMATIVE ASSESSMENT GOAL

This lesson should prepare students to complete the following formative assessment activity.

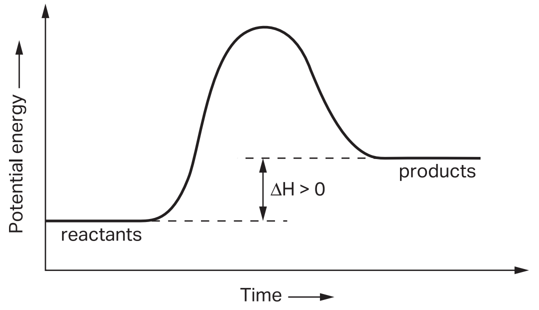
1. When a candle burns, paraffin wax reacts with oxygen in the air to produce a combustion reaction. The unbalanced equation for this reaction is:

   $C_{25}H_{52}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l) + \text{heat}$

   (a) Is the reaction shown endothermic or exothermic? How do you know?

   (b) Which are stronger: the bonds in the products or the bonds in the reactants? Justify your answer in terms of the direction of heat flow in the reaction.

2. In the following diagram, is the energy required to break the bonds in the reactants greater or less than the energy released when the bonds in the products are formed?



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PART 1: MAGNETS AS A MODEL OF BONDS BREAKING AND FORMING

Students engage in some simple experiments with magnets, allowing them to stick together and then pulling them back apart. They relate their observations to what happens between atoms as a bond is broken or formed. The modeling supports students in thinking about the effects of distance on the strength of attractive forces between atoms and about the energy changes that occur when bonds are broken or formed.

- Direct students to work in pairs, and give each pair a set of four magnetic disks. Explain that since we can't actually see bonds breaking and forming between atoms, we will use magnets to model the process. Have students work with their partners to answer questions 1–5 on **Handout 4.7.A: Modeling Reactions Using Magnets**.

Guiding Student Thinking

The connection between force and energy may be difficult for some students to understand. Most students will realize that it takes energy to pull the magnets apart, but it is more challenging to realize that when magnets draw together, energy is released. It may help to have students consider what would happen if one of the magnets were fixed and the other were attached to an elastic band. You could use the attraction between the magnets to stretch the elastic band, which means that the energy from the attraction is being stored in the elastic band.

- Next, lead a whole-class discussion that helps students see the connections between what they did with the magnets and the bonds between atoms. You can use questions such as the following to guide the discussion:
  - Why do the magnets stick together?

    The magnets stick together because they are attracted to each other.
  - If the magnets are analogous to bonds between atoms, why do you think atoms form bonds?

    Atoms form bonds when they are strongly attracted to one another.
  - Do you think it takes energy to separate atoms once they are bonded? Or do you think energy is released when bonded atoms are separated?

    Yes, it takes energy to separate atoms, because energy is required to overcome their attraction to each other. We call this "breaking the bond."

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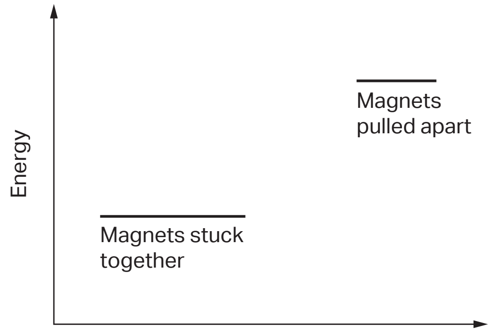
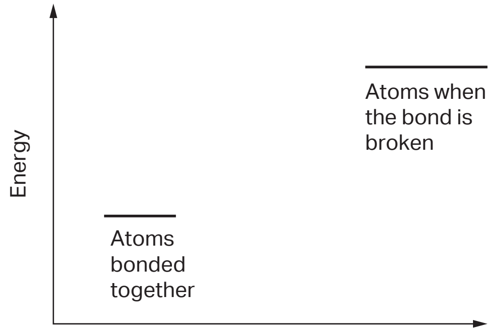
- To support the analogy between the magnets and atoms forming bonds, have students guide you in drawing an energy diagram like the one shown below, where objects placed higher on the diagram correspond to a higher total energy of the system. Ask students to refer back to questions 1–5 on their handout to decide which should be at higher energy—the magnets when they are stuck together or the magnets when they are pulled apart. From question 5, students should see that it takes energy to pull the magnets apart, which corresponds to an increase in energy.

Meeting Learners' Needs

To help students visualize the analogy between what they experience with the magnets and how it relates to bonds, they could make a graphic organizer comparing their work with magnets to bonds between atoms.



- Now repeat the process and let students guide you in creating a similar diagram, but for separating atoms. A sample diagram is shown below.



- Ask students if they think this change in energy happens all at once or if it is gradual. Have them think about their answer to question 2 before answering this question. Students should realize that when the magnets were farther apart they didn't have to pull as hard to keep them apart, indicating that the change in energy is gradual.

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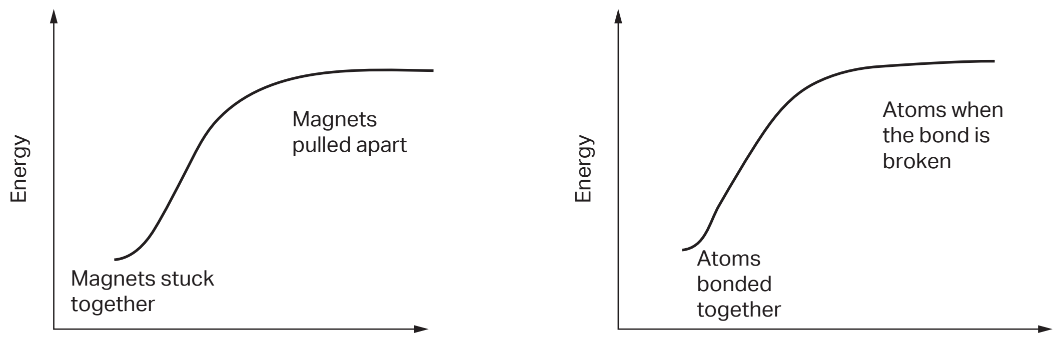
- You can extend this analogy to atoms by explaining to students that bonds don't break like a piece of glass. Rather, as atoms are pulled apart, the attractive force between them becomes weaker until, at a long distance, the attraction drops to zero.
- Next, refine your diagrams to show a gradual increase in energy as the magnets are pulled apart or as a bond is broken.



- To help students connect these diagrams to the forces they felt between the magnets, ask them to think about the curve of the graphs above as a hill they are walking down with a loaded cart. As you bring the magnets together, you have to pull on them to prevent them from snapping together. This is similar to how you would need to pull on the cart while walking down the hill to prevent it from rolling away from you. Emphasize that this kind of tension between different forces—between the magnets' attraction to each other and you pulling them apart—is similar to the interaction between different competing forces at the atomic level.
- To extend the analogy between magnets and atoms, ask students the following question:
  - Refer to question 3 on your handout. Do magnets always draw together? How is this consistent with using magnets to model the behavior of atoms?

    No, they only draw together when there is a strong attractive force between them, as is the case with atoms.
- Now you want to help students realize that not all bonds are of equal strength.
  - Describe what you experienced in question 4, when you used four magnets instead of two.

    Students should describe that they had to pull harder to separate the magnets. It took more energy.

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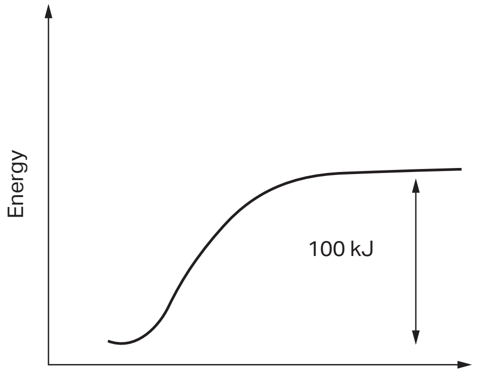
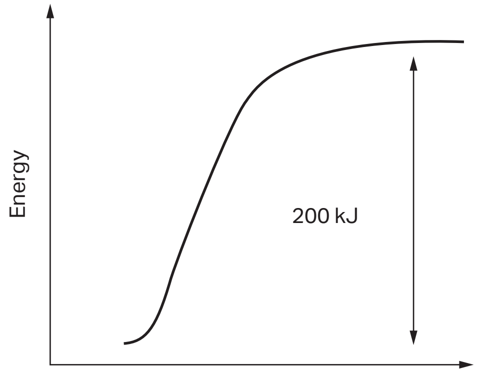
Continue the analogy by asking students what this could mean for atoms. Help them realize that bonds can have different strengths, and that it takes more energy to break a strong bond than it does to break a weak bond. When a bond is formed, energy is released. The energy released when a bond forms is equal to the energy required to break the bond. Both of these energies are the *bond strength* of that bond.

- Draw new energy diagrams to include bond strength for both a strong bond and a weak bond, and make analogies between these and the magnets they pulled apart in question 4. Put actual numbers, 100 kJ and 200 kJ, on the diagrams to help connect this part of the lesson to the table of bond strengths used in Part 2.



Weaker bond: requires less energy to separate atoms



Stronger bond: requires more energy to separate atoms

- Finally, have students return to their handout and discuss question 6 with their partner from the beginning of the lesson. Ask them to come to a consensus about the bonds in fuel reactions. You could have a few groups share their reasoning, but do not tell students the correct answer at this point. The goal is to get them to think about this question and commit to an answer. They will refer back to their answer in Part 3 of the lesson.

Instructional Rationale

The energy stored in chemical fuels is sometimes referred to as being "stored in the chemical bonds." This reinforces a common misconception that bonds contain energy and that this energy is released when the bond is broken. The magnets help address this misconception by emphasizing that bonds form because of attractions and energy is always required to break these interactions. However, even after emphasizing that it takes energy to break a bond, many students will still assume that stronger bonds "store" more energy and so fuels must have stronger bonds. The final question in Part 1 asks them to make a prediction that they later test in Part 3. The goal is to get students to realize that, in a fuel reaction, weak bonds are broken and strong bonds are formed.

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PART 2: CONNECTING BOND STRENGTHS TO REACTION ENERGIES

This part of the lesson introduces a representation and a set of classroom materials that connect the energy released or absorbed by a chemical reaction to the energies of the bonds broken and formed in that reaction. Students observe how these materials are used and begin to explore how they highlight important understandings about bond breaking and formation, in preparation for carrying out similar modeling tasks in Part 3.

- In this part of the lesson you will perform a demonstration for the class on breaking and forming a bond between molecules, using the components illustrated in **Handout 4.7.B: Reaction Components**. The components include:
  - A drawing of a calorimeter showing the following:
    - A cup containing water.
    - A particle-level view of the contents of the solution. This is represented as a magnified view of a very small volume of the solution.
    - A thermometer in the water. The alcohol level in the thermometer is depicted by squares that each represent 100 kJ of thermal energy in the solution.
  - Markers for initial and final temperature. This is to help students keep track of how the numerous steps involved in a chemical reaction lead to an overall change in the temperature of the solution.
  - Squares to indicate energy in the solution and how this compares to temperature.
  - Bingo chips to represent reacting molecules.
- **Handout 4.7.C: Modeling Bond Energy** includes the diagram of bond strengths shown on the next page. This shows the energy required to break a bond, which, for the materials listed above, corresponds to pulling apart the components used to represent atoms. Be sure to highlight the bond energy of the various reactions with students before conducting the demonstration.

Classroom Ideas

You may want to make a laminated set of the components for durability.

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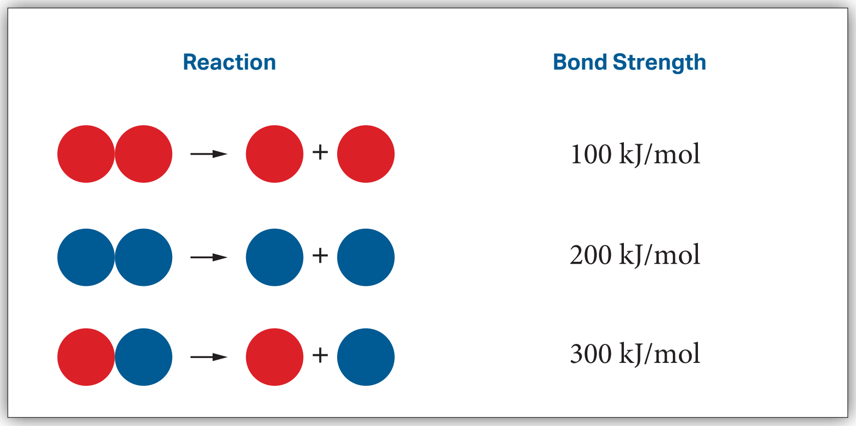

Handout 4.7.C

Instructional Rationale

This part of the lesson is designed to give students a strong conceptual understanding of the energetics of the breaking and forming of bonds before they do mathematical calculations.

- Begin the demonstration for the class by using the following steps to model breaking a bond in the red-red diatomic molecule shown in Handout 4.7.C. As you work through the demonstration, be sure to highlight for students how to use the various components since they will use them in Part 3 of the lesson. A diagram of the setup is shown on the next page.

Classroom Ideas

You can show your manipulations using a document camera so all students can see the demonstration.

1. Use four red bingo chips and the "+" and "→" cutouts to represent breaking a bond in the "Reaction being modeled" area.
2. Place four red bingo chips, arranged as two diatomic molecules, in the "Molecular-level view" box.
3. Place 100 kJ markers on the thermometer up to 25°C.
4. Put the initial temperature marker next to the thermometer at 25°C.

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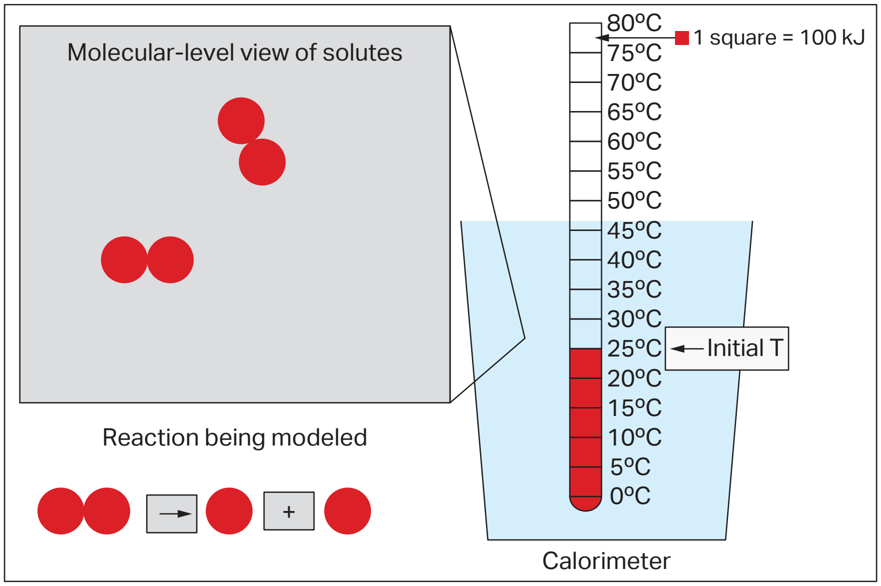
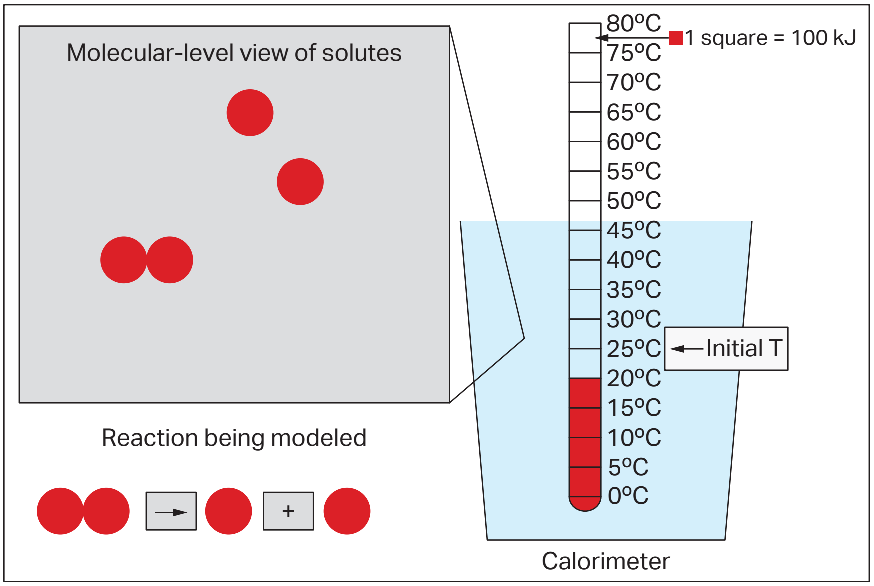


5. Break the bond in one of the diatomic molecules, and take away a 100 kJ marker, because the bond strength between two red particles in this scenario is 100 kJ/mol. (Note: In the expanded view of the solution, a single particle corresponds to a mole of particles in the solution. So breaking a single bond with a strength of 100 kJ/mol requires 100 kJ of energy.) Draw analogies to the magnets in Part 1, emphasizing that it took energy to pull the magnets apart, and because the energy in this scenario comes from the solution, the solution cools down. Your model should now look like this:



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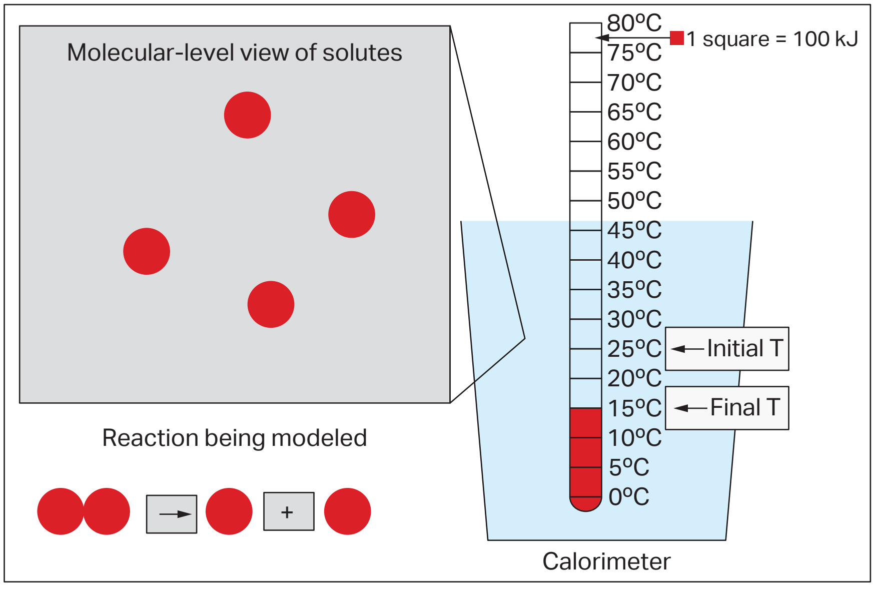
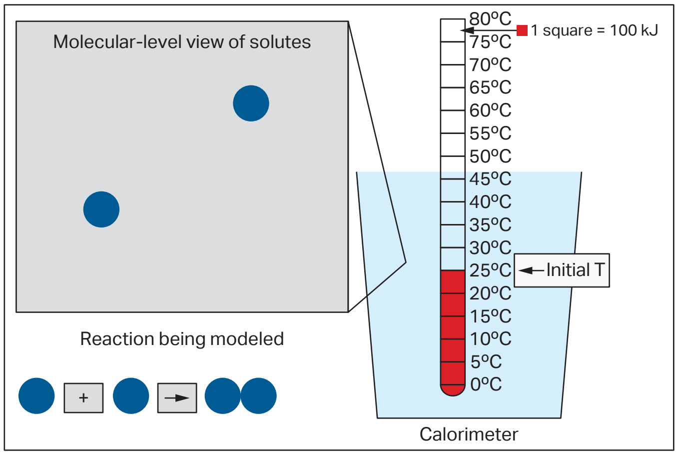
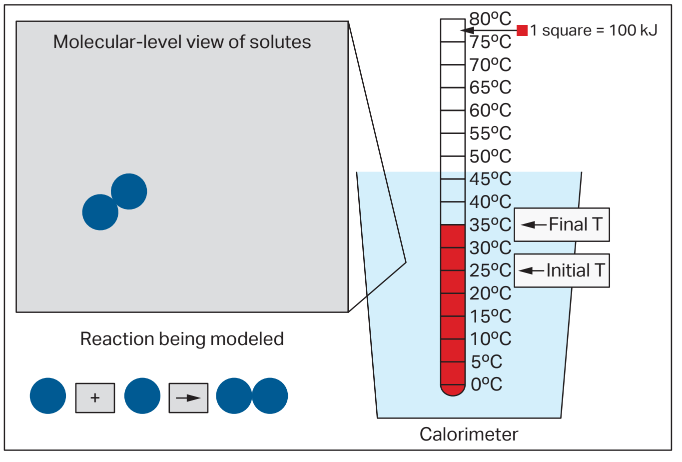
6. Repeat step 5 for the bond in the other molecule, to illustrate that every time you break a bond, you must take the required energy from the solution.



7. Finally, starting again with the solution at room temperature, use the following sequence to illustrate the formation of a bond in a blue-blue diatomic molecule. In this case, the formation of the bond gives off 200 kJ, and the temperature of the solution increases.



Demonstration setup



End of demonstration

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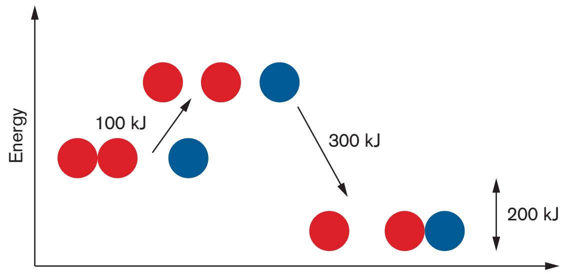
PART 3: HOW CHEMICAL FUELS STORE ENERGY

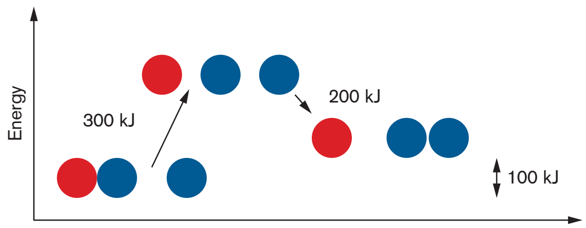
In this last part of the lesson, students use the representations from Part 2 to compare the two types of reactions introduced at the end of Part 1 and evaluate the prediction they made regarding the presence of weak versus strong bonds in fuel molecules.

- Explain to students that they will be using the components from Handout 4.7.B to complete **Handout 4.7.C: Modeling Bond Energy**. This will involve modeling the two types of reactions they considered at the end of Part 1. You may want students to draw or take pictures of the process or have you approve their answers to each step in questions 1 and 2 before they move on.
- Once students have worked through questions 1 and 2, have them complete question 3, which asks them to revisit their prediction from Handout 4.7.A.
- To close, lead a whole-class discussion that highlights the results of this lesson. It may be helpful to connect the idea of energy storage to placing an object in an unstable, high-energy position. For example, you could ask students which has more energy: a rock at the top of a hill or a rock at the bottom of a valley? The rock at the top of the hill is less stable and so rolls downhill. Similarly, molecules with weak bonds are unstable, in that it does not take much energy to break them apart, and they release energy as they "roll downhill." You can illustrate this with diagrams such as the following.

First reaction: breaks weak bonds, forms strong bonds



Second reaction: breaks strong bonds, forms weak bonds



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ASSESS AND REFLECT ON THE LESSON

FORMATIVE ASSESSMENT GOAL

When your students have completed the lesson, you can use this task to gain valuable feedback on and evidence of student learning.

1. When a candle burns, paraffin wax reacts with oxygen in the air to produce a combustion reaction. The unbalanced equation for this reaction is:

   $C_{25}H_{52}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$ + heat

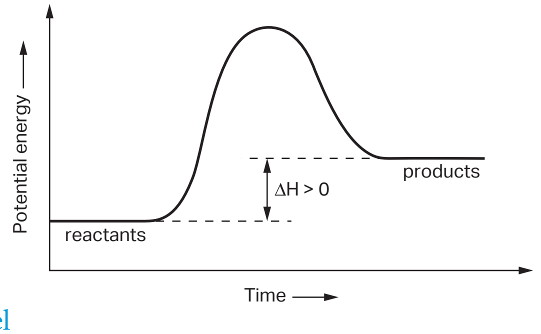
   (a) Is the reaction shown endothermic or exothermic? How do you know?

   The reaction is exothermic since energy is released during the reaction.

   (b) Which are stronger: the bonds in the products or the bonds in the reactants? Justify your answer in terms of the direction of heat flow in the reaction.

   The bonds in the reactants are weaker than the bonds in the products. This difference in energy is released as heat.

2. In the following diagram, is the energy required to break the bonds in the reactants greater or less than the energy released when the bonds in the products are formed?



   The diagram represents an endothermic reaction since the products are at a higher energy level than the reactants. This means that more energy was required to break the bonds in the reactants than was released when the bonds in the products were formed.

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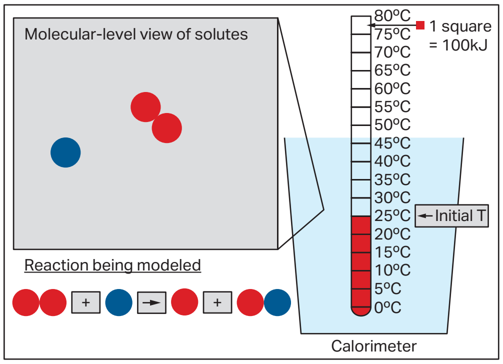
HANDOUT ANSWERS AND GUIDANCE

Handout 4.7.A: Modeling Reactions Using Magnets

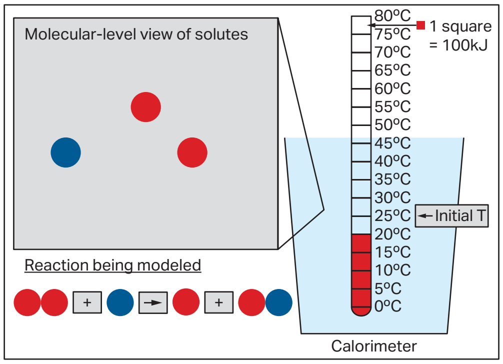
1. You have to pull on the magnets to get them to separate.
2. As the magnets get farther apart you do not need to pull as hard to keep them apart, which means there is less force between them.
3. You now have to push to get the magnets to come together. As the magnets get closer, you have to push harder to keep them at a fixed distance.
4. It is harder to pull the four magnets apart, but otherwise it is similar to what happened with just two magnets in question 1.
5. (a) Energy had to be added to separate the magnets.
   (b) Energy is released as they draw together.
6. Type 2. In such a reaction, it takes less energy to break bonds in the reactants. More energy is released when the strong bonds in the products are formed. That extra energy can be given off as heat, such as the heat of a campfire.

Handout 4.7.C: Modeling Bond Energy

1. (a) Type 2. The red-red bond strength is 100 kJ/mol, while the red-blue bond strength is 300 kJ/mol.
   (b) 35°C



Initial setup for given reaction



Break red-red bond and remove a 100 kJ square

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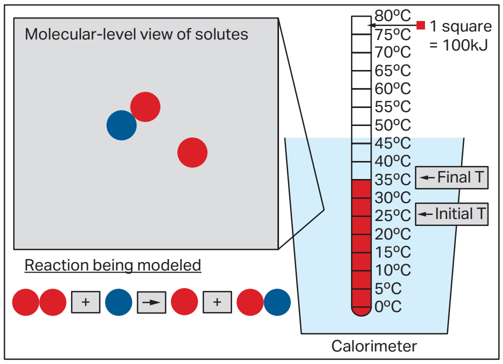


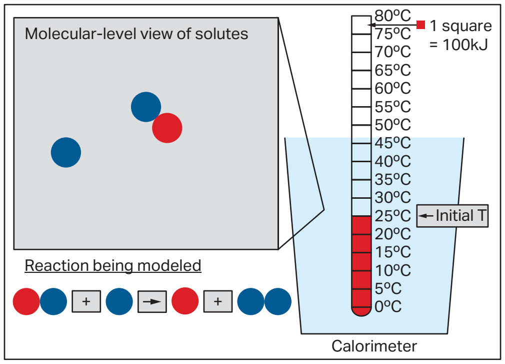
Form red-blue bond and add three 100 kJ squares

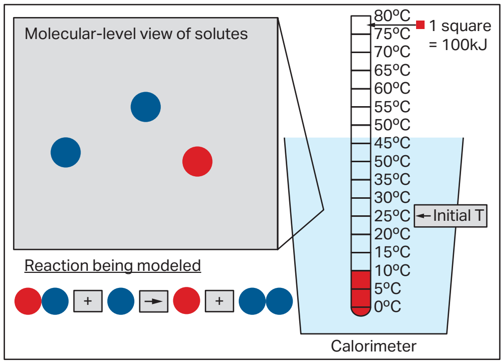
(c) Yes. The reaction is a fuel reaction because the temperature of the solution increased.

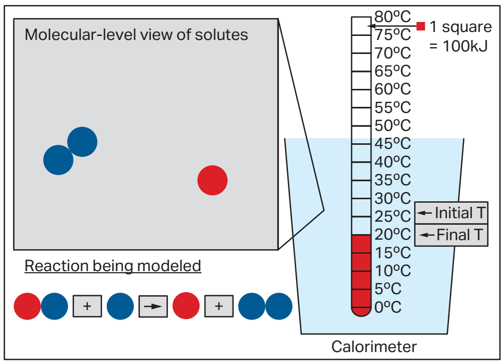
(d) The reaction could be used to heat water.

2. (a) Type 1. The red-blue bond is 300 kJ/mol and the blue-blue bond is 200 kJ/mol.

(b) 20°C







(c) No. This reaction cooled down the solution, so it cannot be used as a fuel.

(d) The reaction could be used as a cold pack.

3. Student answers will vary based on their earlier predictions.

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LESSON 4.8

Antacid Rate of Reaction Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Designing the Experiment
Students determine factors that might influence the rate of reaction between antacid tablets and water. Then, in small groups, they design an experiment to investigate how one of those factors—surface area of tablet, water temperature, stirring method, or volume of water—affects the reaction rate.

Part 2: Conducting the Experiment
Following teacher approval of the investigation they developed in Part 1, students carry out their experiment to collect data and then analyze it to understand the relationship between the independent variable they were assigned and the reaction rate.

Part 3: Sharing Student Work
Students share their findings in a curated gallery walk to learn about the variables tested by the rest of the class and gain feedback on their work.

CONTENT FOCUS

In this lesson, students learn about factors affecting the rate of a chemical reaction through a guided inquiry experiment. The focus is on the idea that the rate of reaction increases as the number of collisions among particles increases. The guided inquiry structure supports the development of students' abilities to carry out several science practices, including developing and conducting investigations, analyzing data, and communicating results. Guided inquiry is an appropriate choice for this experiment because of the relative simplicity of the procedure, the absence

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~105 minutes

HANDOUTS

- 4.8.A: Rate of Reaction Experiment
- 4.8.B: Experimental Results Reporting Tool

MATERIALS

For each group:

- 6 antacid tablets, such as Alka-Seltzer
- water
- 100 mL graduated cylinder
- 400 mL or 600 mL beakers
- timer

Have available (dependent on experimental design):

- thermometer
- stirring rod
- hot plate
- ice cubes or chilled water
- small zip-top plastic bags

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of significant chemical hazards, the straightforward and easily organized data collection, and the reliability of the results. Each student group tests the effect of one variable on the rate of the reaction, then shares their results with the class. Students synthesize the information to determine which factors affect the rate of a reaction. This structure allows students to practice their data analysis and argumentation skills.

- hammer
- plastic knife
- tongs

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Chemical reactions occur at varying rates that are related to the frequency and success of collisions between reactants.	
Learning Objectives	**Essential Knowledge**
4.5.A.2 Explain how experimental changes in the rate of a reaction are related to changes in the concentration, temperature, or surface area of the reactants.	**4.5.A** The rate of a chemical reaction can be measured by determining how quickly reactants are transformed into products. **a.** The reaction rate is related to the frequency of collisions between reactant species and the proportion of effective collisions. **b.** The frequency of collisions increases with the concentration of gases or dissolved species and with the surface area of a solid. **c.** The proportion of effective collisions increases directly as temperature increases.

SETUP AND PREPARATION NOTES

- Since groups will test only one variable, it is best to have at least two groups test each variable. This may help prevent students from drawing incorrect conclusions from outlier data.
- The procedures for some variables may be harder for students to write or may take longer to carry out. Be strategic in assigning variables to groups.

SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear chemical splash goggles.
- Dispose of waste products properly.

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PART 1: DESIGNING THE EXPERIMENT

Working in small groups, students design an experiment to investigate how one factor—surface area, water temperature, stirring method, or water volume—affects the rate of reaction of an antacid tablet and water.

- Demonstrate the reaction for students by dropping an antacid tablet into about 200 mL of water in a beaker or glass. Ask students how they would determine how long it takes for the reaction to occur. They may have a variety of ideas, but encourage them to focus on an observation that is measurable. Guide students to the realization that the only way they can determine the reaction time is to measure how long it takes for the solid to no longer be visible and the rapid bubbling to cease.
- Drop another antacid tablet into the same amount of water in another beaker or glass. Have students time how long the reaction takes.

Instructional Rationale

Having multiple students time the reaction allows for a discussion about sources of error and may help students realize they should plan for multiple trials when designing their own procedures later in the lesson.

- Pose the following question to students:
  - What variables could influence the rate of reaction between antacid tablets and water?

  Allow students to think quietly for 2–3 minutes and jot down their ideas. Then have students join their lab groups and share what they wrote down. Give them some time to discuss their ideas together and even generate new ideas.
- Bring the class together and chart all the different variables they have come up with. Conduct a brief discussion to combine similar ideas and eliminate variables that may not be practical or scientifically sound to test. Students should actively engage in the critique of suggested variables and designs. Guide students to narrow the list down to four variables, which can be easily tested in the lab:
  - Surface area of the antacid tablet
  - Temperature of the water
  - How much/how fast the water is stirred
  - The volume of water

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Guiding Student Thinking

The first three variables in the list above will all change the rate of reaction. The fourth variable will not change the reaction rate and is included so students will come to the realization that not every variable will have an effect. If your students don't come up with volume of water as a variable but do come up with another variable that won't have an effect, consider having them test that variable instead.

- Assign each lab group one variable to test, and explain to students that they will design and carry out an investigation to test it. Show students the materials available for their experimental design, noting that each group will get 6 antacid tablets to work with.
- To support students in developing their experimental procedure, ask them to complete questions 1–6 on **Handout 4.8.A: Rate of Reaction Experiment** with their group. Circulate around the room while students are working and provide assistance to individual groups.
- When providing guidance on student-led investigations, consider the following:
    - The amount of support you provide to your students during this portion of the investigation will depend on how much experience your students have had in the lab, as well as your own current comfort level.
    - If you think that some groups will struggle more than others, be strategic in assigning variables since some procedures are easier to design than others.
    - You should provide guidance when student groups submit their proposals to support plans that have a reasonable chance of producing useful information. Even in student-led inquiry, it is not productive to allow students to run

Classroom Ideas

Have the available equipment out on a counter or lab bench so students can view it as they think about exactly what they will need for their experiment. For example, if students don't know how much water they want to use, encourage them to look at the markings on a beaker to think about how much it will take to cover the tablet. Remind them that they don't need to use all the materials since they are investigating only one of the factors.

Meeting Learners' Needs

If students have trouble deciding what to keep constant, ask them to return to your master list of variables. Remind students that the variables they are not testing will now become key, constant variables in their experiment that they need to be sure to keep consistent from test to test.

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investigations in which the potential for success is low or nonexistent. However, that does not mean you should help students make their plans flawless. There is educational value in allowing students to carry out their design on their own and discover the flaws in the design. It is even better if you can provide students with the time to correct their flaws and run the experiment again.

- Sample procedures for each variable are listed in the Assess and Reflect section.

Guiding Student Thinking

Most groups will not produce complete, workable, detailed procedures on their first try. Push students to write their procedures in the manner they are written on lab handouts they have been given for past experiments, as numbered lists of sequential steps where exact amounts and materials to be used are clearly stated. If students include a procedural step that will lead to experimental failure (e.g., using 10 mL of water, which is not enough to react with an entire tablet) explain why this won't work and ask them to revise it. Students often want the teacher to tell them what to do and become frustrated if you will not do so. It is important for them to understand that part of what they are learning is how to design an experiment and that you do not expect them to do it perfectly the first time.

PART 2: CONDUCTING THE EXPERIMENT

Following teacher approval of the investigation they developed in Part 1, students carry out their experiment to collect data and then analyze it to understand the relationship between the independent variable they were assigned and the reaction rate.

- Once groups have completed questions 1–6 on Handout 4.8.A, they should ask you to look at their answers. Sign off on their handout when it meets your approval. If changes need to be made, have students make those changes and then resubmit the form. When a group has had their experimental design approved, they should begin data collection.

Classroom Ideas

If time allows, have groups exchange procedures and provide feedback about the clarity of each procedure.

- As students are working, monitor their data collection procedures and offer assistance as needed.
- Tell students that they can pour the reaction products down the sink when each trial is complete.
- Once they have conducted their six trials, they should clean up their materials and then begin the analysis of data.

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PART 3: SHARING STUDENT WORK

To conclude the lesson, students share their findings in a curated gallery walk to learn about the variables tested by the rest of the class and gain feedback on their work.

- Have students find **Handout 4.8.B: Experimental Results Reporting Tool**.
- If time permits, group members may work together in class to complete the reporting tool or, to save class time, you can assign the reporting tool as homework. If students do have class time to work together, you should stress that the final page of the reporting table should be completed individually because the questions ask students to reflect on their own learning.
- Before beginning the class-curated gallery walk, each group should select one member's reporting tool to share with the class. The selected reporting tool can be displayed on a table, posted on a wall, posted on a display board, etc.—somewhere that other groups will be able to easily view the document.
- The class will then participate in the curated gallery walk. This provides a method for groups to share their results and learn about how the other variables (those they didn't test) influenced the reaction rate of antacid and water.

Instructional Rationale

The approach of having each group test only one variable and then share results with the class serves several purposes. First, it allows the experiment to be completed in less time. Second, students get to practice supporting their claims with evidence they collected, with a limited amount of data, which makes the task more manageable. Lastly, students get to practice their argumentation and communications skills as they share their data and results with their peers.

- In the curated gallery walk several things will be happening:
  - One member of each group will be the curator. The curator's role is to stay with the display during the gallery walk, give a brief verbal overview of their research findings to visiting groups, and answer any questions visiting group members might have about their research.
  - The remaining group members will travel together to visit each of the other research groups. During each visit, it will be the traveling group's job to learn about how the variables tested by the other research groups in the class affected the reaction rate. The group should have a plan for documenting the information they gather, which can be shared and discussed later.

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- Curators and their reporting tools should be spread around the room. Set up a rotation so that one group is visiting each curator during each cycle. Have each group visit the curator for 3–5 minutes and then instruct each group to rotate to the next designated curator. Repeat this process until all groups have had a chance to visit each curator. (This will typically take 30–45 minutes.)

- After the gallery walk, the traveling group members will reunite with their curator and have a discussion about:
  - The feedback the curator received from visiting groups about their research.
  - The claims and supporting evidence gathered from other groups' curators about how the other tested variables affected reaction rate.
- All group members are responsible and accountable for describing and justifying the influence on reaction rate of not only the variable tested by their group but also the variables tested by the rest of the class.

Extending the Lesson

You may wish to have students do a project that gives them an opportunity to synthesize the information they gathered about all variables that were researched in class. This project can allow students to build a broad understanding of how different factors can influence reaction rate.

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ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 4.8.A: Rate of Reaction Experiment

1. How does temperature of water (or volume of water, surface area of the tablet, or stirring speed) influence the rate of reaction between antacid tablets and water?
2. Sample responses:
    - The rate of reaction will increase when the temperature of the water is increased, because the higher the temperature, the faster the particles are moving.
    - The rate of reaction is not affected by a change in the amount of water, because as long as the water covers the tablet, more water will not increase the number of collisions.
    - The rate of reaction will increase when the surface area of tablet pieces increases, because the more surface area, the more collisions between the antacid and water particles will occur.
    - The rate of reaction will increase when the stirring speed is increased, because more collisions will occur.
3. (a) Possible independent variables: temperature of water, volume of water, surface area of the tablet, or stirring speed

    (b) Sample levels of independent variable:
    - For temperature of water: 5°C, 20°C, 70°C
    - For volume of water: 100 mL, 200 mL, 300 mL
    - For surface area of tablet: whole tablet, tablet broken into quarters, crushed tablet
    - For stirring speed: none, slow, fast

    (c) Amount of time for 1 antacid tablet to react

    (d) Sample responses:
    - For temperature of water: volume of water, surface area of antacid tablet, stirring speed
    - For volume of water: temperature of water, surface area of antacid tablet, stirring speed
    - For surface area of antacid tablet: volume of water, stirring speed, temperature of water
    - For stirring speed: temperature of water, volume of water, surface area of antacid tablet

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4. Sample responses:
    - For temperature of water: three 400 mL beakers, hot plate, 100 mL graduated cylinder, 6 antacid tablets, 600 mL water, thermometer, tongs, ice, timer
    - For volume of water: 400 mL beaker, 100 mL graduated cylinder, 6 antacid tablets, 1800 mL water, timer
    - For surface area of tablet: 400 mL beaker, 100 mL graduated cylinder, 6 antacid tablets, 600 mL water, plastic knife, hammer, small zip-top plastic bag, timer
    - For stirring speed: 400 mL beaker, 100 mL graduated cylinder, 6 antacid tablets, 600 mL water, timer, stirring rod
5. Sample responses:

    Potential Procedure for Testing the Effect of the Temperature of the Water on the Rate of Reaction

    1. Fill a beaker with about 300 mL water and heat on a hot plate.
    2. Monitor the temperature of the water with a thermometer.
    3. When the water reaches 70°C, use tongs to pour 100 mL into a graduated cylinder.
    4. Pour the 200 mL of water into a second beaker.
    5. Immediately add an antacid tablet to the water in the beaker and start a timer.
    6. Observe the reaction closely.
    7. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
    8. Dump the mixture in the sink and rinse the beaker.
    9. Repeat steps 1–8 a second time.
    10. Measure 100 mL of room temperature water using a graduated cylinder and transfer to a beaker.
    11. Immediately add an antacid tablet to the water in the beaker and start a timer.
    12. Observe the reaction closely.
    13. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
    14. Dump the mixture in the sink and rinse the beaker.
    15. Repeat steps 10–14 a second time.
    16. Fill a beaker with ice and about 300 mL water.
    17. Monitor the temperature of the water with a thermometer.

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18. When it reaches 5°C, pour 100 mL of the cold water into a graduated cylinder.
19. Pour the 200 mL of water into a second beaker.
20. Immediately add an antacid tablet to the water in the beaker and start a timer.
21. Observe the reaction closely.
22. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
23. Dump the mixture in the sink and rinse the beaker.
24. Repeat steps 18–23 a second time.

Potential Procedure for Testing the Effect of Volume of Water on the Rate of Reaction

1. Measure 100 mL of room temperature water using a graduated cylinder and transfer to a beaker.
2. Immediately add an antacid tablet to the water in the beaker and start a timer.
3. Observe the reaction closely.
4. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
5. Dump the mixture in the sink and rinse the beaker.
6. Repeat steps 1–5 for a second trial.
7. Repeat steps 1–6, except use 200 mL water.
8. Repeat steps 1–6, except use 300 mL water.

Potential Procedure for Testing the Effect of the Surface Area of Antacid on the Rate of Reaction

1. Measure 100 mL of room temperature water using a graduated cylinder and transfer to a beaker.
2. Immediately add an antacid tablet to the water in the beaker and start a timer.
3. Observe the reaction closely.
4. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
5. Dump the mixture in the sink and rinse the beaker.
6. Repeat steps 1–5 for a second trial.
7. Use a plastic knife to cut an antacid tablet into 4 approximately equal pieces.
8. Repeat steps 1–6, except use the 4 pieces of antacid tablet instead of a whole tablet in step 2.
9. Put an antacid tablet in a plastic baggie.

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10. Hit the antacid tablet with a hammer to crush it.
11. Repeat steps 1–6, except use the crushed antacid tablet instead of a whole tablet in step 2.

Potential Procedure for Testing the Effect of Stirring on the Rate of Reaction

1. Measure 100 mL of room temperature water using a graduated cylinder and transfer to a beaker.
2. Immediately add an antacid tablet to the water in the beaker and start a timer.
3. Do not stir. Observe the reaction closely.
4. When the solid disappears and the rapid bubbling stops, stop the timer and record the time in the data table.
5. Dump the mixture in the sink and rinse the beaker.
6. Repeat steps 1–5 for a second trial.
7. Repeat steps 1–6, except in step 3, stir the mixture slowly using a stirring rod.
8. Repeat steps 1–6, except in step 3, stir the mixture rapidly using a stirring rod.

6. Sample blank data table:

	Condition 1	**Condition 2**	**Condition 3**
Trial 1			
Trial 2			
Average			

Sample Data for Testing the Effect of the Temperature of the Water on the Rate of Reaction

	Hot Water	**Room Temperature Water**	**Cold Water**
Trial 1	23 s	76 s	89 s
Trial 2	24 s	76 s	83 s
Average	23.5 s	76 s	86 s

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Sample Data for Testing the Effect of Volume of Water on the Rate of Reaction

	100 mL	200 mL	300 mL
Trial 1	73 s	76 s	70 s
Trial 2	71 s	71 s	72 s
Average	72 s	73.5 s	71 s

Sample Data for Testing the Effect of the Surface Area of Antacid on the Rate of Reaction

	Whole Tablet	4 Pieces	Crushed
Trial 1	77 s	46 s	14 s
Trial 2	76 s	54 s	18 s
Average	76.5 s	50 s	16 s

Sample Data for Testing the Effect of Stirring on the Rate of Reaction

	No Stirring	Slow Stirring	Fast Stirring
Trial 1	70 s	61 s	54 s
Trial 2	75 s	63 s	49 s
Average	72.5 s	62 s	51.5 s

7. See data tables for question 6.
8.
   - Temperature of water: hot water, smallest; cold water, largest
   - Volume of water: 300 mL, smallest; 200 mL, largest
   - Surface area of tablet: crushed, smallest; whole, largest
   - Stirring speed: fast stir, smallest; no stir, largest
9. Answers will vary, but should refer back to the original hypothesis.

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10.
    - Temperature of water: The hotter the water, the greater the rate of the reaction.
    - Volume of water: There is not a clear relationship between the variables.
    - Surface area of tablet: The greater the surface area, the greater the rate of the reaction.
    - Stirring speed: The greater the stirring rate, the greater the rate of the reaction.
11.
    - Temperature of water: When particles are at a higher temperature, they have greater average kinetic energy, meaning they move faster. This leads to a larger number of collisions between reactant particles and more forceful collisions, increasing the number of successful collisions.
    - Volume of water: The addition of more water does not affect the number or forcefulness of collisions, so it does not affect the rate.
    - Surface area of tablet: Greater surface area leads to more collisions between particles, so the rate increases.
    - Stirring speed: Stirring leads to more collisions between particles, so the rate increases.

Handout 4.8.B: Experimental Results Reporting Tool

Student answers will vary.

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Unit 4

Performance Task

PERFORMANCE TASK

Applications of Chemical Transformations

OVERVIEW

DESCRIPTION

In this performance task, students first analyze particulate representations of weak and strong acids and bases in order to characterize them and compare their pH values. Students then examine different representations of a combustion reaction to determine the heat of reaction, compare the potential energy of reactants and products, and evaluate a claim about the temperature change of the surroundings. Finally, students analyze reaction rate data in order to compare reaction conditions and make predictions about reaction times; they then explain the results in terms of collision theory.

CONTENT FOCUS

The goal of this performance task is to assess students' knowledge related to Key Concepts 4.3, 4.4, and 4.5 through a variety of task types, including the use of mathematics, model analysis, and argumentation. The task consists of three distinct parts, each designed to highlight common misconceptions and challenges associated with one of the three key concepts. Part 1 centers on Key Concept 4.3: Acid–Base Chemistry and focuses on the difference between strong and weak versus concentrated and dilute acids and bases. Part 2, covering Key Concept 4.4: Thermochemistry, focuses on energy changes in transformations and addresses the common misconception that breaking chemical bonds releases energy. Part 3, addressing Key Concept 4.5: Reaction Rates, asks students to relate reaction rates to solution concentration and collision theory.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 4 Performance Task: Applications of Chemical Transformations

MATERIALS

- calculator
- equation sheet
- periodic table

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UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solubility, electron transfer, and proton transfer are driving forces in chemical reactions. ▪ All chemical reactions are accompanied by a transfer of energy. ▪ Chemical reactions occur at varying rates that are related to the frequency and success of collisions between reactants.	

Learning Objectives	Essential Knowledge
4.3.A.1 Create and/or evaluate models of strong and weak acids and bases. **4.3.A.2** Distinguish between strong and weak acids in terms of degree of dissociation in aqueous solution. **4.3.A.3** Evaluate a claim about whether a compound is a strong or weak acid or base.	**4.3.A** Acids and bases are described as either strong or weak based on the degree to which they dissociate in aqueous solution.
4.3.B.1 Explain the relationship between the hydrogen ion concentration and the pH of a solution.	**4.3.B** The pH of a solution is a measure of the molarity of H_3O^+ (or H^+) in the solution.
4.3.C.1 Predict the products of a reaction between a strong acid and a strong base.	**4.3.C** Acid–base reactions involve the transfer of a hydrogen ion from the acid to the base. Strong acid–base reactions produce water and an aqueous ionic compound.
4.4.A.1 Create and/or evaluate a claim about whether a reaction is endothermic or exothermic from experimental observations. **4.4.A.2** Explain the relationship between the measured change in temperature of a solution and the energy transferred by a chemical reaction.	**4.4.A** A temperature change during a reaction is the result of energy transfer during the process of breaking and forming bonds. **a.** Bond breaking is always an endothermic process and bond formation is always an exothermic process.

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4.4.B.1 Create and/or evaluate a claim about the energy transferred as a result of a chemical reaction based on bond energies.	**4.4.B** The relative strength of bonds in reactants and products determines the energy change in a reaction. Bond energy tables and Lewis diagrams provide a way to estimate these changes quantitatively for a wide variety of chemical reactions.
4.5.A.2 Explain how experimental changes in the rate of a reaction are related to changes in the concentration, temperature, or surface area of the reactants.	**4.5.A** The rate of a chemical reaction can be measured by determining how quickly reactants are transformed into products. **a.** The reaction rate is related to the frequency of collisions between reactant species and the proportion of effective collisions. **b.** The frequency of collisions increases with the concentration of gases or dissolved species and with the surface area of a solid.

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SCORING GUIDELINES

There are 20 possible points for this performance task.

Part 1, Question 1

Sample Solutions	Points Possible
Solution 1 – weak acid; contains H^+ ions and is partially ionized Solution 2 – strong base; contains OH^- ions and is completely ionized Solution 3 – strong acid; contains H^+ ions and is completely ionized Solution 4 – strong acid; contains H^+ ions and is completely ionized	**2 points maximum** 1 point for identifying the solution correctly 1 point for a correct justification
Targeted Feedback for Student Responses	
Many students confuse concentration with degree of ionization. You may want to emphasize the distinction by comparing solutions 1 (concentrated and weak) and 3 (dilute and strong).	

TEACHER NOTES AND REFLECTIONS

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Part 1, Question 2

Sample Solutions	Points Possible
4 < 1 < 3 < 2 For acids, the greater the concentration of H^+ ions, the lower the pH. Solution 4 has the most H^+ ions, Solution 1 has the second most, and Solution 3 has the least. Bases have pH values greater than acids' pH values.	**3 points maximum** 1 point for a correct ranking 1 point for a justification of acid ranking based on H^+ ion concentration or number 1 point for stating that bases have higher pH values than acids do
Targeted Feedback for Student Responses	
Some students find the greater-than and less-than symbols (> and <) confusing. Encourage those students to write out their rankings in words to avoid making errors because of symbol confusion.	

TEACHER NOTES AND REFLECTIONS

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Part 1, Question 3(a)

Sample Solutions	Points Possible
water and a salt (or NaCl)	**1 point maximum** 1 point for a correct answer

Targeted Feedback for Student Responses
Remind students that water is always a product of an aqueous strong acid–strong base reaction. The other product or products form from the cation of the base and the anion of the acid.

TEACHER NOTES AND REFLECTIONS

Part 1, Question 3(b)

Sample Solutions	Points Possible
pH or temperature	**1 point maximum** 1 point for a correct answer

Targeted Feedback for Student Responses
Remind students that acid–base reactions are also called "neutralization" because the pH moves closer to neutral with respect to the original pH of the acid and the base.

TEACHER NOTES AND REFLECTIONS

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Part 2, Question 1

Sample Solutions	Points Possible
4 mol C – H bonds: $4 \text{ mol} \times \frac{413 \text{ kJ}}{1 \text{ mol}} = 1{,}652 \text{ kJ}$ 2 mol O = O bonds: $2 \text{ mol} \times \frac{495 \text{ kJ}}{1 \text{ mol}} = 990 \text{ kJ}$ $1{,}652 \text{ kJ} + 990 \text{ kJ} = 2{,}642 \text{ kJ}$	**2 points maximum** 1 point for correct energy for breaking all the bonds in one substance (either CH_4 or O_2) 1 point for a correct answer
Targeted Feedback for Student Responses	
You may need to remind students that the energy listed in the table is only for one bond, so they need to be sure to account for the number of each type of bond in each molecule, as well as the number of moles of each substance in the reaction.	

TEACHER NOTES AND REFLECTIONS

Part 2, Question 2

Sample Solutions	Points Possible
4 mol O – H bonds: $4 \text{ mol} \times \frac{463 \text{ kJ}}{1 \text{ mol}} = 1{,}852 \text{ kJ}$ 2 mol C = O bonds: $2 \text{ mol} \times \frac{799 \text{ kJ}}{1 \text{ mol}} = 1{,}598 \text{ kJ}$ $1{,}852 \text{ kJ} + 1{,}598 \text{ kJ} = 3{,}450 \text{ kJ}$	**2 points maximum** 1 point for correct energy for forming all the bonds in one substance (either H_2O or CO_2) 1 point for a correct answer
Targeted Feedback for Student Responses	
You may need to remind students that the energy listed in the table is only for one bond, so they need to be sure to account for the number of each type of bond in each molecule, as well as the number of moles of each substance in the reaction.	

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UNIT 4

TEACHER NOTES AND REFLECTIONS

Part 2, Question 3

Sample Solutions	Points Possible
$\Delta H_{rxn} = \Sigma(\Delta H_{\text{bonds broken}}) - \Sigma(\Delta H_{\text{bonds formed}})$ $\Delta H_{rxn} = 2{,}642\text{ kJ} - 3{,}450\text{ kJ}$ $\Delta H_{rxn} = -808\text{ kJ}$	**1 point maximum** 1 point for a correct answer *Scoring note:* If students made errors in either question 1 or 2, but used their answers for that part correctly in this question, they should receive full credit for this question.
Targeted Feedback for Student Responses	
Some students may mistakenly reverse the terms of the subtraction. Continue to remind students that breaking bonds requires energy and that forming bonds releases energy.	

TEACHER NOTES AND REFLECTIONS

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Part 2, Question 4

Sample Solutions	Points Possible
The product molecules have stronger bonding. The reaction overall releases energy to the surroundings, which means that more energy was released when the products' bonds formed than was required to break the reactants' bonds.	**1 point maximum** 1 point for a correct choice and explanation
Targeted Feedback for Student Responses	
The goal of this question is for students to understand that the products' bonds as a whole are stronger than the reactants' bonds. Rather than focusing on algorithmic processes, encourage students to analyze the situation by thinking about what energy is required to break all the bonds in the reactants and then compare than energy to what is released when bonds form in the products.	

TEACHER NOTES AND REFLECTIONS

Part 2, Question 5

Sample Solutions	Points Possible
The container would get warmer as a result of the reaction. The reaction is exothermic, meaning that it releases energy as heat to its surroundings.	**2 points maximum** 1 point for a correct choice 1 point for explanation
Targeted Feedback for Student Responses	
Students often take the negative sign of the heat of reaction to mean that the temperature measured during the reaction goes down. Reinforce the idea that the negative value of the heat in a reaction indicates that energy is transferred from the system to the surroundings, which means an increase in the temperature of the surroundings.	

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UNIT 4

TEACHER NOTES AND REFLECTIONS

Part 2, Question 6

Sample Solutions	Points Possible
Disagree. Bonds do not require energy input to make; rather, they release energy when they form.	**1 point maximum** 1 point for a correct choice and explanation

Targeted Feedback for Student Responses
This question addresses the extremely common misconception that bond making requires energy. Students may need to grapple with this fact many times before they internalize it.

TEACHER NOTES AND REFLECTIONS

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Part 3, Question 1

Sample Solutions	Points Possible
Solution A is more concentrated, which explains the shorter reaction time for both powder and chunks. Since the solution is more concentrated, there will be more collisions between reactants.	**2 points maximum** 1 point for a correct choice 1 point for explanation
Targeted Feedback for Student Responses	
Encourage students to first identify which data points should be compared in order to answer the question. Here they should compare the reaction times of the two acid concentrations, focusing on one form of calcium carbonate (either powder or chunks) at a time, to determine relative concentration.	

TEACHER NOTES AND REFLECTIONS

Part 3, Question 2

Sample Solutions	Points Possible
The powder form has a shorter reaction time with both solutions compared to the chunk form because powder has a greater total surface area. The greater surface area means that more calcium carbonate units are able to collide with acid particles, and according to collision theory, particles must collide in order to react. More collisions means the reaction as a whole will be completed in less time.	**2 points maximum** 1 point for relating an increase in collisions with a powdered form of reactant 1 point for relating more collisions to an increased rate

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Targeted Feedback for Student Responses

The idea that smaller pieces of material correspond to a greater total surface area is often confusing for students. Relating this idea to a simple geometry concept may help. For example, two half circles have a larger perimeter than a whole circle with the same total area. You can also ask students to refer back to their conclusions from Lesson 4.8.

TEACHER NOTES AND REFLECTIONS

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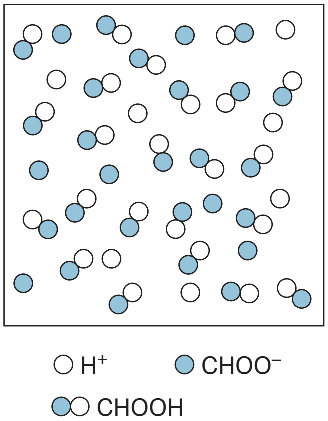
Applications of Chemical Transformations

PERFORMANCE TASK

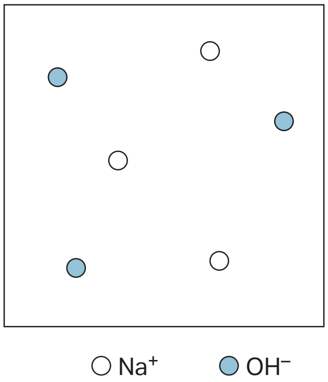
PART 1

Below are particle-level representations of four different solutions. Water molecules are not shown. Each representation contains the same volume of solution.

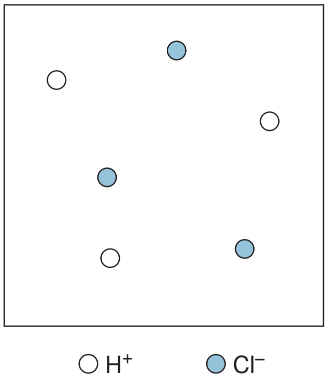
Solution 1



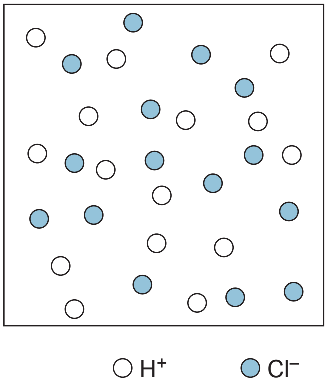
Solution 2



Solution 3



Solution 4



1. Choose one of the solutions represented above. Identify the solution as a weak acid, a strong acid, a weak base, or a strong base and justify your choice.

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PERFORMANCE TASK

2. Rank the solutions from lowest to highest pH. Justify your ranking.

3. Equal volumes of Solutions 2 and 3 were mixed in the lab.

   (a) What products are produced?

   (b) Suggest a measurement that could be made in the lab to provide evidence that a chemical reaction occurred when Solutions 2 and 3 were mixed.

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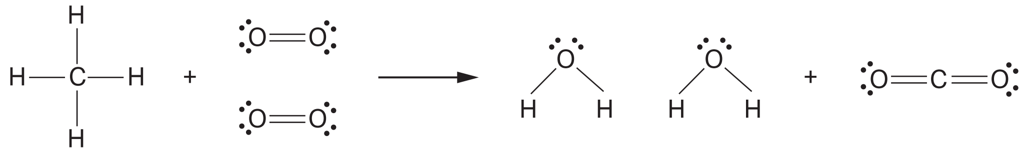
PART 2

Below are two representations of a chemical reaction and a table of bond energies.

Representation 1



Representation 2

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

BOND ENERGIES

Bond Type	Energy (kJ/mol)
C – H	413
O = O	495
O – H	463
C = O	799

1. Using the bond energies given in the table, determine the total bond energy of the reactant molecules, 1 mole of CH_4 and 2 moles of O_2, in kilojoules (kJ).

2. Using the bond energies given in the table, determine the total bond energy of the product molecules, 2 moles of H_2O and 1 mole of CO_2, in kJ.

PERFORMANCE TASK

3. Calculate the energy change of the reaction.

4. Do the reactant molecules or the product molecules have stronger bonding? Justify your choice.

5. If this reaction were carried out in a metal container in the lab, would the container get warmer, colder, or not change temperature as a result of the reaction? Explain your choice.

6. A student claims "C = O bonds have a larger bond energy than the other types of bonds involved in this reaction, which means they require more energy input to make." Do you agree or disagree with the student's claim? Explain your response.

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PART 3

A student conducts an experiment to study the reaction between calcium carbonate ($CaCO_3$) and hydrochloric acid (HCl). The equation for the reaction is shown below.

$$CaCO_3 + 2HCl \rightarrow H_2O + CO_2 + CaCl_2$$

The student measures the amount of time required for 1 g of calcium carbonate in two different forms, powder and chunks, to react completely using two solutions of hydrochloric acid of unknown concentration in excess. The data from the experiment are shown below.

Calcium Carbonate Form	Average Time of Reaction with Acid Solution A (s)	Average Time of Reaction with Acid Solution B (s)
Powder	45.2	67.1
Chunks	132.1	220.5

1. Which acid solution is more concentrated, A or B? Explain your response.

2. Explain the difference in reaction time between the powder and chunk forms of calcium carbonate using principles of collision theory.

Appendix

Pre-AP Chemistry Equations, Constants, and Tables of Information

Units	
Symbol	**Name**
L	liter(s)
g	gram(s)
atm	atmosphere(s)
Pa	pascal(s)
mm Hg	millimeters of mercury
J	joule(s)
mol	mole(s)
K	kelvin
M	molarity
cal	calorie(s)

Polyatomic Ions	
Name	**Formula**
acetate	CH_3COO^- or $C_2H_3O_2^-$
ammonium	NH_4^+
bicarbonate or hydrogen carbonate	HCO_3^-
carbonate	CO_3^{2-}
chromate	CrO_4^{2-}
cyanide	CN^-
dichromate	$Cr_2O_7^{2-}$
hydroxide	OH^-
nitrate	NO_3^-
nitrite	NO_2^-
phosphate	PO_4^{3-}
sulfate	SO_4^{2-}
sulfite	SO_3^{2-}

Constants	
Constant	**Value**
Avogadro's number	6.02×10^{23} particles per mole
Gas constant, R	$0.0821 \dfrac{\text{L} \bullet \text{atm}}{\text{mol} \bullet \text{K}}$
Specific heat capacity of $H_2O(l)$	$4.18 \dfrac{\text{J}}{\text{g} \bullet \text{K}}$
Standard temperature and pressure	273 K and 1 atm

Metric Prefixes		
Factor	**Prefix**	**Symbol**
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n

Conversions
1 atm = 760 mm Hg = 760 torr = 101 kPa
1 cal = 4.18 joules
0°C = 273 K

Activity Series	
	Metals
most easily oxidized	Li
	K
	Ba
	Ca
	Na
	Mg
	Al
	Mn
	Zn
	Cr
	Fe
	Co
	Ni
	Sn
	Pb
	(H_2)
	Cu
	Hg
	Ag
	Pt
least easily oxidized	Au

Solubility Guidelines
All sodium, potassium, ammonium, and nitrate salts are soluble in water.

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Equations		
Density	$D = \frac{m}{V}$	D = density m = mass V = volume
Percent error	$\text{percent error} = \left(\frac{\lvert \text{accepted value} - \text{experimental value} \rvert}{\text{accepted value}} \right) \times 100$	
Percent yield	$\text{percent yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}} \right) \times 100$	
Molarity	$\text{molarity} = \frac{\text{moles of solute}}{\text{liter of solution}}$	
Gas laws	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ $P_A = X_A \times P_{total}$ $P_{total} = P_A + P_B + P_C + \ldots$ $PV = nRT$	P = pressure V = volume T = temperature n = moles of gas R = gas constant X = fraction of the gas
Heat	$q = mc\Delta T$	q = heat m = mass c = specific heat capacity ΔT = change in temperature
pH	$\text{pH} = -\log[H_3O^+]$	

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PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** Hydrogen 1.008																	2 **He** Helium 4.00
3 **Li** Lithium 6.94	4 **Be** Beryllium 9.01											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18
11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.30											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95
19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.87	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.63	33 **As** Arsenic 74.92	34 **Se** Selenium 78.97	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.95	43 **Tc** Technetium	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.87	48 **Cd** Cadmium 112.41	49 **In** Indium 114.82	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.76	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.91	56 **Ba** Barium 137.33	57–71 *	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.21	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.97	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98	84 **Po** Polonium	85 **At** Astatine	86 **Rn** Radon
87 **Fr** Francium	88 **Ra** Radium	89–103 †	104 **Rf** Rutherfordium	105 **Db** Dubnium	106 **Sg** Seaborgium	107 **Bh** Bohrium	108 **Hs** Hassium	109 **Mt** Meitnerium	110 **Ds** Darmstadtium	111 **Rg** Roentgenium	112 **Cn** Copernicium	113 **Nh** Nihonium	114 **Fl** Flerovium	115 **Mc** Moscovium	116 **Lv** Livermorium	117 **Ts** Tennessine	118 **Og** Oganesson

*Lanthanoids	57 **La** Lanthanum 138.91	58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.97	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.05	71 **Lu** Lutetium 174.97
†Actinoids	89 **Ac** Actinium	90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium	94 **Pu** Plutonium	95 **Am** Americium	96 **Cm** Curium	97 **Bk** Berkelium	98 **Cf** Californium	99 **Es** Einsteinium	100 **Fm** Fermium	101 **Md** Mendelevium	102 **No** Nobelium	103 **Lr** Lawrencium

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