CollegeBoard Pre-AP®

Pre-AP® Chemistry

TEACHER RESOURCES

Units 1 and 2

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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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.

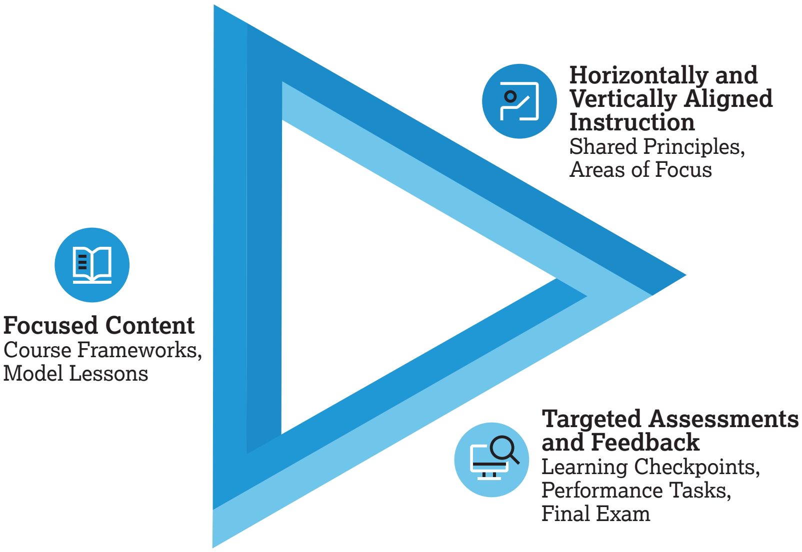
HOW TO GET INVOLVED

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**.

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.

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.

Evidence-Based Writing

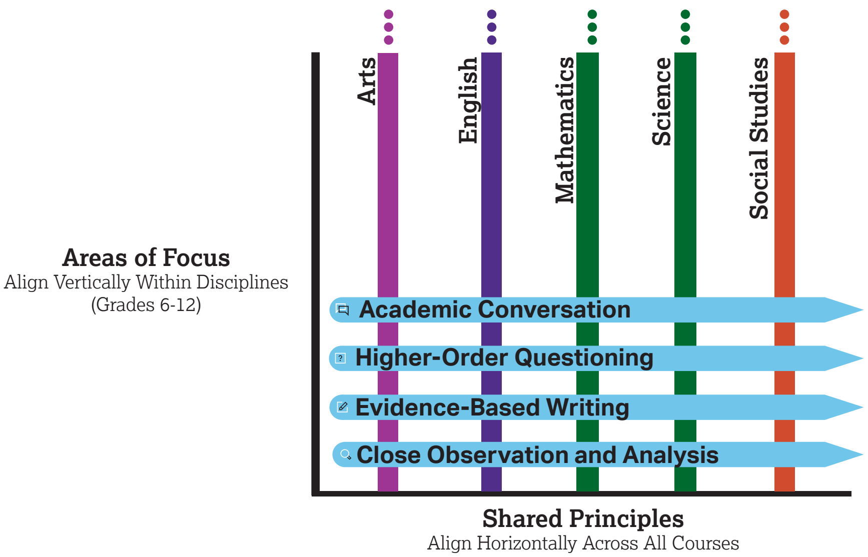
With strategic support, students frequently engage in writing coherent arguments from relevant and valid sources of evidence. Pre-AP courses embrace a purposeful and scaffolded approach to writing that begins with a focus on precise and effective sentences before progressing to longer forms of writing.

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.

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.

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.

About the Course

Introduction to Pre-AP Chemistry

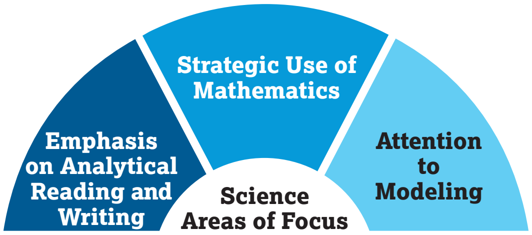
The Pre-AP Chemistry course emphasizes the integration of content with science practices—powerful reasoning tools that support students in analyzing the natural world around them. Having this ability is one of the hallmarks of scientific literacy and is critical for numerous college and career endeavors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



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.

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**.

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.*

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.*

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

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

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.

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.

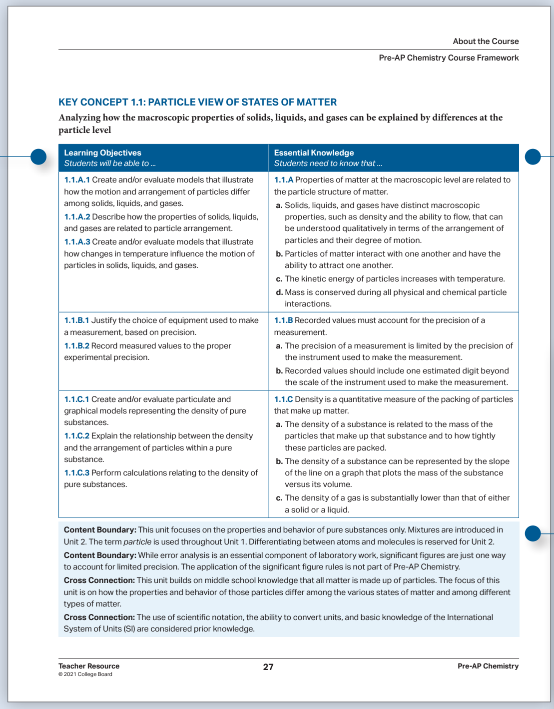
Enduring Understandings

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.

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Pre-AP Chemistry

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.

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.

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.

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

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.

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.

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.

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

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.

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.

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.

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.

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

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.

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.

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

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.

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.

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.

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.

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.

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.

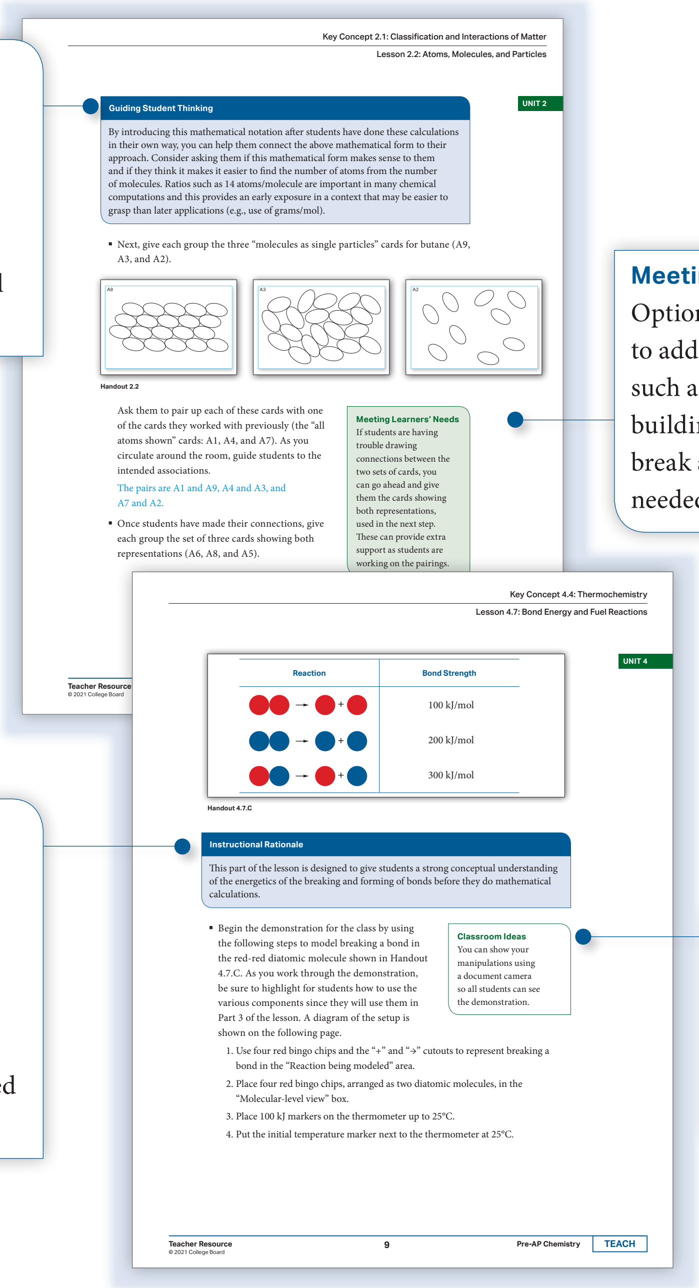
SUPPORT FEATURES IN MODEL LESSONS

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.

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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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.

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

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.*

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

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 1 Structure and Properties of Matter	Practice Performance Task	Determining Properties of an Unknown Substance	Teacher Resources: Units 1 & 2	Student Resources: Unit 1
	Performance Task	Cooling an Alcohol		Teacher-distributed handout
Unit 2 Chemical Bonding and Interactions	Practice Performance Task	Properties of Limonene	Teacher Resources: Units 1 & 2	Student Resources: Unit 2
	Performance Task	Ionic and Covalent Compounds		Teacher-distributed handout

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.

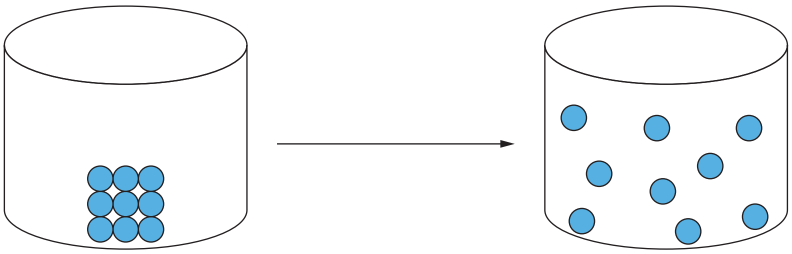
The final exam is designed to be delivered on a secure digital platform in a classroom setting. Educators have the option of administering the final exam in a single extended session or two shorter consecutive sessions to accommodate a range of final exam schedules.

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.

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.

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.

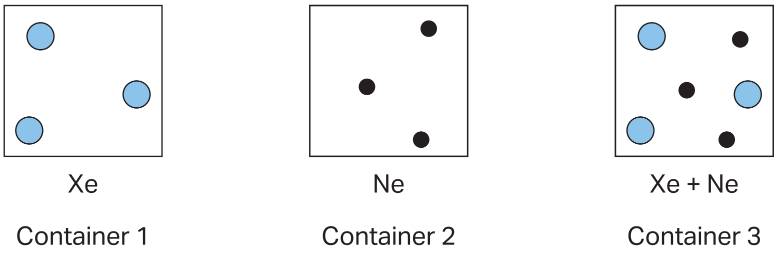
Correct Answer: C

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.

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.

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.

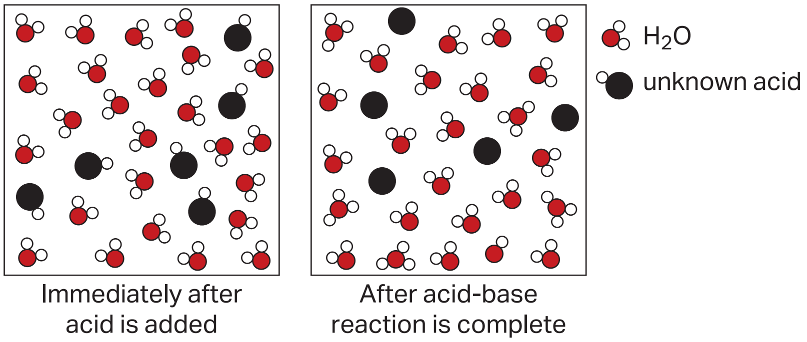
Correct Answer: B

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

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

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

- 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.

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.

Unit 1

Unit 1

Structure and Properties of Matter

Overview

SUGGESTED TIMING: APPROXIMATELY 6 WEEKS

This course progresses from macroscopic to atomic explorations of properties of matter in order to help students develop a deep 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 should develop a set of simple rules to describe the behavior of particles in pure substances through building, discussing, and revising particulate models. They deepen their understanding throughout the unit as they support and verify predictions about 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

This unit focuses on the following enduring understandings:

- 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.

UNIT 1

KEY CONCEPTS

This unit focuses on the following key concepts:

- 1.1: Particle View of States of Matter
- 1.2: Phase Changes and Particle Interactions
- 1.3: Kinetic Molecular Theory

UNIT RESOURCES

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

Lessons for Key Concept 1.1: Particle View of States of Matter				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.1: Launch Lesson – States of Matter Card Sort	1.1.A.1	1.1.A.a, 1.1.A.b	Less than 45 minutes	Attention to Modeling
1.2: Developing a Model of Matter	1.1.A.1, 1.1.A.2, 1.1.A.3	1.1.A.a, 1.1.A.b, 1.1.A.c, 1.1.A.d	~60 minutes	Attention to Modeling
1.3: Confidence in Measurement	1.1.B.1, 1.1.B.2	1.1.B.a, 1.1.B.b	~45 minutes	Strategic Use of Mathematics
1.4: Relating Mass and Volume Lab	1.1.C.1, 1.1.C.2, 1.1.C.3	1.1.C.a, 1.1.C.b, 1.1.C.c	~60 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.				

Learning Checkpoint 1: Key Concept 1.1 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concept 1.1. For sample items and learning checkpoint details, visit the Pre-AP Digital Platform.

Lessons for Key Concept 1.2: Phase Changes and Particle Interactions				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.5: Heat Transfer	1.2.A.1, 1.2.A.2	1.2.A	~90 minutes	Strategic Use of Mathematics, Attention to Modeling
Practice Performance Task for Unit 1 (~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 1.2: Phase Changes and Particle Interactions (*continued*)				
1.6: Phase Diagrams – What's So Dry About Dry Ice?	1.2.C.1, 1.2.C.2, 1.2.D.1	1.2.C, 1.2.D.d	~60 minutes	Attention to Modeling, Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing
1.7: Investigating Heating Curves	1.2.D.1, 1.2.D.2	1.2.D.a, 1.2.D.b, 1.2.D.c, 1.2.D.d	~135 minutes	Attention to Modeling, Strategic Use of Mathematics

The following Key Concept 1.2 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: 1.2.B.1
- Essential Knowledge Statements: 1.2.B.a, 1.2.B.b

Lessons for Key Concept 1.3: Kinetic Molecular Theory				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.8: Launch Lesson – Introduction to Properties of Gases	1.3.A.1	1.3.A.a	~45 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing
1.9: Exploring and Measuring Gas Properties Lab	1.3.B.1, 1.3.B.2, 1.3.C.1, 1.3.C.2	1.3.B, 1.3.C	~135 minutes	Attention to Modeling, Strategic Use of Mathematics

The following Key Concept 1.3 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: 1.3.A.2
- Essential Knowledge Statements: 1.3.A.b

Learning Checkpoint 2: Key Concepts 1.2 and 1.3 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts 1.2 and 1.3. For sample items and learning checkpoint details, visit the Pre-AP Digital Platform.

Performance Task for Unit 1 (~45 minutes)
This performance task assesses learning objectives and essential knowledge statements from the entire unit.

LESSON 1.1

Launch Lesson – States of Matter Card Sort

OVERVIEW

LESSON DESCRIPTION

Students sort descriptions and particle diagrams of matter into appropriate categories. The sorting activity leads into an all-class discussion in which students begin to explore the relationship between the macroscopic nature of matter and the arrangement of the particles that make up the matter.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

Less than 45 minutes

HANDOUTS

- 1.1.A: States of Matter Categories
- 1.1.B: States of Matter Cards (with cards cut out, one set for each student pair)

CONTENT FOCUS

This lesson is designed to elicit prior knowledge students have about the states of matter and help them begin thinking about the particle nature of matter. Although students may not be able to draw accurate particle models of the states of matter yet, they most likely have a foundation in the properties of solids, liquids, and gases from middle school physical science. This lesson challenges them to connect their understanding of the macroscopic nature of matter to the arrangement of the particles that make up matter. Over the course of the unit, students continue to develop this understanding and create increasingly detailed particle models.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings
▪ Solids, liquids, and gases have different properties as a result of the motion of particles and the interactions among them.

Learning Objectives	Essential Knowledge
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** 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.

LAUNCH LESSON

- To begin the lesson, ask students to work with a partner to sort the provided cards describing or depicting different states of matter into the appropriate categories. See **Handout 1.1.A: States of Matter Categories** and **Handout 1.1.B: States of Matter Cards**. Students will likely be able to quickly sort most of the cards based on the state of matter, but there are a few cards that students could place in multiple categories. You may decide not to tell students there are ambiguous cards and just monitor conversations to see how students respond to them.

Instructional Rationale

The goal of the ambiguous cards is to spark debate among students and elicit misconceptions they might have. For example, some students may not realize that all states of matter have mass or that both liquids and gases can flow.

As you circulate around the room, check for student misconceptions and ask students to justify their decisions. For the cards that could be placed into multiple states of matter, you could allow students to create new categories (such as "all states of matter") or use blank paper or sticky notes to create duplicate cards.

- Once groups have finished categorizing most of the cards, lead a whole-class discussion about students' decisions and any challenges they had. The main goal of the discussion is to help students recognize that (1) some properties are shared by multiple states of matter, and that (2) properties unique to each state of matter are the result of the arrangement of particles in that state of matter. The following questions may be useful in guiding the discussion:
  - Were there cards that could be placed in multiple categories? If so, describe what you did with those cards.
  - What evidence is there that all states of matter have mass?

Meeting Learners' Needs

For students who need more support with the fundamentals, you may want to have students disregard the cards that can be placed into multiple categories while they are working in pairs. Then, discuss these cards together as a class.

To add a level of challenge for students who have a solid foundation with properties of liquids, solids, and gases, have them create additional cards on blank paper or sticky notes for each state of matter. Student pairs could even trade the cards they have made and challenge another pair to place them correctly.

- How do you think the arrangement of particles in different states of matter is related to the properties of those states of matter?
- Do you think all solids (or liquids or gases) have the same particle arrangement? Explain why or why not.
- Why do you think liquids and gases can flow, but solids cannot?

Guiding Student Thinking

At this point in the course, it is not necessary for students to distinguish between atoms and molecules, since they may have misconceptions about those terms. For now, the generic term *particle* is sufficient for students to be able to discuss how arrangement at the molecular level is related to the macroscopic properties of matter. Plus, using this term helps students avoid reinforcing misconceptions until they gain a stronger understanding of atoms and molecules.

LESSON 1.2

Developing a Model of Matter

OVERVIEW

LESSON DESCRIPTION

Part 1: Observing Behaviors of Solids, Liquids, and Gases to Refine Models
Students draw models of solids, liquids, and gases as a starting point for the work in this lesson. They then closely observe matter changing state and/or temperature at a series of lab stations and analyze the data collected to refine their initial models.

Part 2: Developing a Consensus Model of Matter
As a class, students discuss and evaluate their models of matter to develop an explanatory model of matter that can be used to understand new phenomena.

Part 3: Applying the Consensus Model of Matter
Students now apply their knowledge and modeling skills from Parts 1 and 2 of this lesson as they observe a new phenomenon—a mirror or window fogging up near boiling water. Students use the consensus model of matter they developed together earlier in the lesson to develop a written explanation of their observations.

CONTENT FOCUS

In this lesson, students build and refine models of matter based on observations of various phenomena involving different states of matter. Students consider how their observations conform to models they have already developed or necessitate revisions to them. Eventually,

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 1.2.A: Observing Behaviors of Solids, Liquids, and Gases
- 1.2.B: Applying the Shared Model of Matter

MATERIALS

- food coloring
- water (hot, room temperature, and cold)
- beakers
- hot plate
- rock salt
- Petri dishes
- hand lenses
- spherical magnets or clay
- beads such as pony beads or pop beads
- essential oil
- flask
- mirror

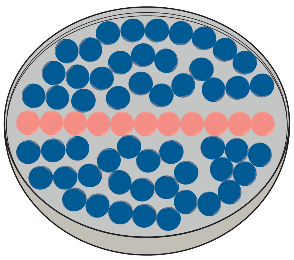
through this work, the class develops a valid explanatory model of matter that can be used to understand new phenomena. This explanatory model will help students move beyond more simplistic perspectives developed in middle school and support them as they experience more complicated phenomena throughout the course. They test this model on the phenomenon of a window that fogs up near boiling water. This lesson emphasizes the role of models as tools for scientists to test and refine their ideas.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solids, liquids, and gases have different properties as a result of the motion of particles and the interactions among them.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- You can create multiple stations for each activity in order to keep groups small.
- For station 1:
  - Provide food coloring, three beakers, and water at different temperatures (cold, room temperature, hot). Also provide a Petri dish filled with two colors of beads, with one color arranged in a line across the dish as shown at right.



  - Using different colors of food coloring for the three different temperatures will make discussion of observations easier. For example, you could ask students to use blue food coloring in the cold water, yellow food coloring in the hot water, and green food coloring in the room temperature water.
- For station 2:
  - Provide a hand lens, rock salt in a Petri dish, spherical magnets, and beads.
  - Spherical magnets are typically sold as magnetic marbles, and can be found in packs of 100 at reasonable prices from several retailers. If spherical magnets are not available, you can make small spheres out of clay for the model. However, magnets will work much better for this activity, as they are great for making crystal models.
- For station 3 (conducted as an all-class demonstration), any odor that is strong enough is suitable for this activity if essential oils are not available. You could use air freshener, perfume, or even a bag of freshly made microwave popcorn, if appropriate. Avoid using flammable liquids or irritants. Make sure students do not have allergies or sensitivities to the substance you plan to use.

SAFETY NOTES

All general safety guidelines should be followed. Make appropriate modifications to station 3 if students have allergies or sensitivities to the substance you plan to use.

UNIT 1

PART 1: OBSERVING BEHAVIORS OF SOLIDS, LIQUIDS, AND GASES TO REFINE MODELS

In the first part of this lesson, students draw models of solids, liquids, and gases as a starting point for the work in this lesson. They then closely observe matter at a series of lab stations and analyze the data collected to refine their initial models.

- First, have students individually draw models that represent matter as a solid, a liquid, and a gas. They can sketch these on a note card or in their notebook. Once they finish their sketches, ask them to work with a shoulder partner to:
  - Compare and describe how their models are similar and how they are different.
  - Discuss reasons for any differences in the models they each developed.
- Next, lead a whole-group discussion with students about the validity of their models by asking questions such as:
  - How confident are you in the models you developed for the different phases of matter?
  - What would increase your confidence that your model for each phase of matter is valid?

  Allow this conversation to lead into a discussion of how models are used in scientific investigations and the importance of being able to revise models.

Guiding Student Thinking

Student will have varying levels of understanding about how scientific models are used. It is important that this whole-group conversation explicitly supports understanding of how models are used as tools for scientists to test, refine, and communicate their ideas as they observe and analyze specific phenomena.

- Let students know they can set aside their initial models for now, and that we will return to them in a bit. Then orient students to what will happen next in the lesson. Students will conduct a few simple experiments, during which they make and analyze observations of various phenomena involving different states of matter.
- Then, direct students' attention to **Handout 1.2.A: Observing Behaviors of Solids, Liquids, and Gases** and give them time to review it. During this time, you can also sort students into small groups for working through the stations. To be sure students understand the various tasks, briefly review what they will do at each station and answer any questions.

- At station 1, students examine how food coloring moves in room temperature water, cold water, and hot water. They also model the movement of food coloring using beads in a Petri dish.
- At station 2, students examine the structure of salt under a hand lens and then attempt to re-create the structure using both magnetic spheres and beads. The magnetic spheres are used to model the idea that there is a force holding the ions together in a salt. Since the beads have no such force, they do not maintain the crystal structure.
- At station 3, which is conducted as an all-class demonstration, students examine how the smell of an essential oil or other fragrance spreads across a room.

Handout 1.2.A guides students through recording observations, making drawings, and providing explanations for what they observe based on their understanding of the particle nature of matter.

- Allow the groups to begin working through stations 1 and 2. As you circulate around the room, probe for understanding of the differences in the states of matter and how temperature affects particle behavior by asking questions such as the following:
  - How does your drawing take evidence into account?
  - How does your evidence support your explanation?
  - What differences are you noticing between your drawings and the models you drew at the beginning of class?
  - How does temperature affect matter? How do you know based on your observations?

Guiding Student Thinking

For station 2, point out to students that they are using magnets to model the forces that hold particles together in a salt. The actual forces are electrostatic rather than magnetic, which they will learn in Unit 2. You might ask students to think of a different material, other than magnetic marbles, that would have worked well for this activity, to emphasize the idea that attractive force in general (not magnetism) is what this model highlights.

- When students have completed their work on stations 1 and 2, ask them to return to their seats. Conduct the station 3 demonstration for the whole class. This demonstration helps students refine their model of the particle nature of gases by tracking how a vapor diffuses throughout the classroom.

  The procedure for the demonstration is as follows:

  1. Direct students' attention to the location of the hot plate that will be used in this demonstration. Ask students to draw an *X* in each of the boxes on their handout to indicate the location of the hot plate in the classroom. They should

also indicate their location using a triangle. The three boxes should look identical when students have finished this step.

2. Show students a sample of a volatile liquid, such as an essential oil. Place the oil in a flask and gently heat it on the hot plate.
3. Ask students to raise their hand when they can first smell the oil and to keep their hand raised so everyone can follow the path of the oil as it diffuses throughout the room.
4. Ask students to finish filling in the three boxes, to show where the particles of the substance were at different stages of the demonstration. The first box represents the distribution of the particles from the oil as soon it starts heating. The second represents the particles when the student could first smell the oil and the last represents the particles once everyone could smell the oil. Students should also represent air particles in their diagrams.
5. Have students record their observations and explanations on their handout.

As students draw their models, challenge them to think about what is between the particles they draw. You can ask them to draw in the particles of air using a different color or shape.

- When all stations have been completed, ask each small group to pair up with another group and compare their observations and diagrams from each station. If groups identify differences, encourage them to engage in academic conversation to uncover the origin of the differences. This step allows students to gain a clearer understanding of what they observed and to test their explanations of why it happened.
- Together the groups can then complete the Analysis section of the handout. This section guides students to identify how their work at the stations has deepened their understanding of the particle nature of matter. The final question in this section of the handout has students evaluate their models from the beginning of class in the context of their observations from the lesson. These Analysis questions prepare students for the upcoming class discussion in which we will collaboratively develop a consensus model of matter.

PART 2: DEVELOPING A CONSENSUS MODEL OF MATTER

In Part 2 of this lesson, students work as a class to discuss and evaluate their models of matter. Using this approach, they collaboratively produce a consensus, explanatory model of matter that can be used to understand new phenomena.

Instructional Rationale

Students will build and revise many models during this course. The process used in this lesson is designed to introduce students to this process. It also mirrors the process used by scientists as they revise their models when new data become available.

- Bring the class back together for a whole-group discussion focusing on the similarities and differences in the arrangement and motion of particles in the various states of matter. Use questions such as the following to guide the discussion:
  - How do the particles in a liquid or gas move? How do we know?
  - What happens to matter when thermal energy is absorbed? What happens to the particles?
  - How is the motion of particles related to the properties of matter?
  - Do the particles in solids, liquids, and gases all behave in similar ways?
  - What is keeping the particles in liquids and solids close together?
  - How did the models you drew at beginning of class hold up? Were they consistent with your observations at the stations? Why or why not?
  - Do we need separate models for solids, liquids, and gases?

Guiding Student Thinking

Pay attention to the language students are using to describe particle motion. An area where students commonly struggle is in understanding that particle motion is truly random. Some students may personify particles by using language that the particles "have to" or "want to" move in a certain direction. They may fail to understand that many other particles traveled in a different direction or that particles collide with other particles and change direction many times.

- As the following key ideas surface in the discussion, summarize and emphasize them for the class:
  - Particles of matter are in constant, random motion.
  - The average speed of particles increases with temperature.

- Macroscopic properties of matter are dependent on motion at the particle level.
- Interactions among particles, particularly in liquids and solids, determine physical properties of matter.

Once these ideas have been identified, explain to students that they have just developed their shared model of the particle nature of matter. It is important to clarify that *model*, in this context, refers to a set of understandings about a phenomenon. Let students know that their model will be essential in understanding the more complex ideas in chemistry they will investigate the rest of this year. They will build on this model when explaining these more complex ideas.

- Since an understanding of the particle nature of matter is fundamental to the course, you might want to prompt students to suggest ways to capture this shared model for easy reference in the future, like placing a sticky note on the appropriate page of their notebooks or making a poster for the classroom.
- To help solidify students' understanding of each of the four ideas in the model, give them time to revise the diagrams on the handout. Students should make sure that each aspect of this particle model is now accurately reflected in the diagrams. Consider giving this task as a homework assignment and letting groups of students discuss during the next class.

Classroom Ideas
For examples of facilitating discussion about models, see the series of videos from the National Science Teaching Association (NSTA) at **https://ngss.nsta.org/ngss-videos.aspx**. Scroll down to "In the *NGSS* Classroom with Teacher Kristen Mayer."

PART 3: APPLYING THE CONSENSUS MODEL OF MATTER

Students now apply their knowledge and modeling skills from Parts 1 and 2 of this lesson as they observe a new phenomenon—a mirror or window fogging up near boiling water. Students use the consensus model of matter they developed together earlier in the lesson to develop a written explanation of their observations.

- To provide a new phenomenon for students to observe, boil a beaker of water near a mirror or other surface that will easily collect condensation from the water vapor produced. Have students observe the foggy surface.
- Let students know that they will now create a written explanation of why the mirror fogs up,

Classroom Ideas
You may want to start boiling the water a few minutes before you are ready for the demonstration.

based on the class's shared model of matter. **Handout 1.2.B: Applying the Shared Model of Matter** guides students through this writing task. The first question on the handout supports students in collecting their ideas. The second question asks students to weave their ideas together into a paragraph.

- Provide ample time for students to write. As you circulate around the room during this activity, it may help to remind students to consult their notes where they recorded the details of the class's shared model of matter. Once students have finished writing, ask them to trade their paragraphs with a partner in order to provide and receive feedback. Students should then use the feedback to revise as needed.
- To conclude the lesson, lead a whole-group debrief about the phenomenon to determine if there are still misconceptions or misunderstandings. You can also collect the handouts from students to examine their thinking.

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 1.2.A: Observing Behaviors of Solids, Liquids, and Gases

Station 1

Responses for the stations will vary. Sample responses are provided below.

Observations

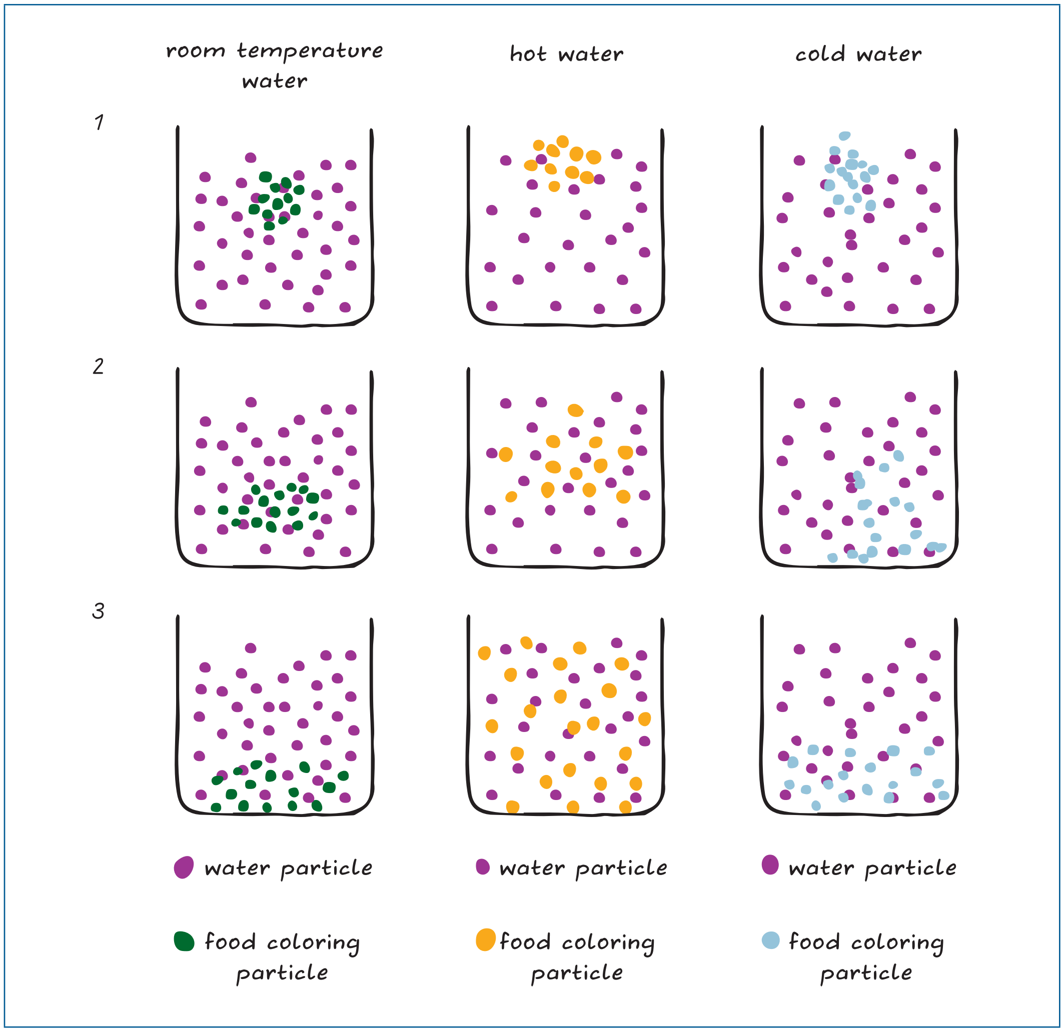
The food coloring in the room temperature water spread out and filled most of the beaker. The food coloring in the warm water spread out quickly and filled the whole beaker. The food coloring in the cold water spread out more slowly and moved to the bottom of the beaker.

In the Petri dish that was shaken slowly, the blue beads in the middle didn't move very far. In the Petri dish that was shaken a medium amount, the blue beads in the middle spread out a little more. In the Petri dish that was shaken the most, the blue beads spread out in the entire dish.

Explanation

Increasing the temperature of the water increases the energy of the particles so they move faster, leading to more collisions between the food coloring particles and the water particles, causing the food coloring to spread throughout the beaker of water. This is similar to how the beads collide and spread out more when we shake the Petri dish quickly. In the cold water, there are fewer collisions, so the food coloring mostly just falls to the bottom of the beaker because of gravity.

Diagrams



Station 2

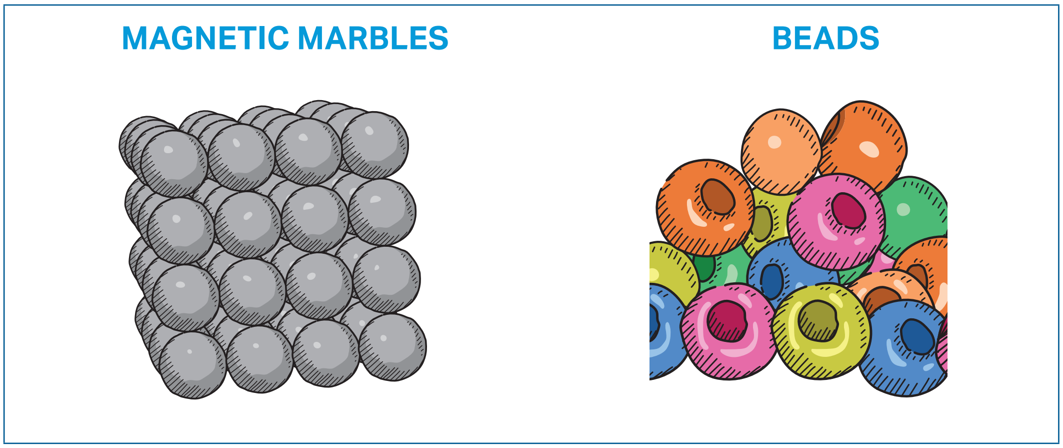
Observations

The salt has sharp edges and is cubic. The image in question 2 shows that the Na and Cl particles are in an orderly arrangement within this cubic structure.

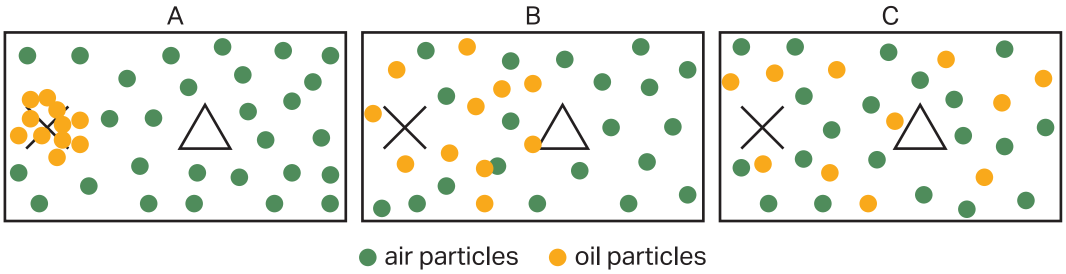
Explanation

The magnetic marbles stuck together to make a shape similar to that of salt. The beads did not stick together. There is a force that holds the magnets together, but no force to hold the beads together. This may mean that there is some kind of force holding the particles together in the salt.

Diagrams



Station 3



Observations

The vapor from the oil spread throughout the room.

Explanation

The forces among gas particles are very weak, so the particles are more free to move than those in liquids or solids. Gases spread out to fill any container they are in. Gas particles move randomly and collide with other gas particles as they move.

Analysis

1. Solids have an orderly arrangement. Gases spread out to fill their container.
2. Temperature determines how fast particles move. At higher temperatures, particles move faster. Even within one state of matter, there can be a range of motion of particles. Particle motion depends on collisions among particles.

3. Answers will vary. Questions could include further study in how the particles in a solid are held together or if all gases behave in the same manner as the one they observed in the diffusion demonstration.
4. The models from the beginning of class are still valid in some ways. They show how a solid, a liquid, and a gas might differ under certain conditions. However, they aren't complex enough to represent a variety of situations. For instance, they don't reflect differences in particle behavior within a certain state of matter at different temperatures.

Handout 1.2.B: Applying the Shared Model of Matter

1. - Particles of matter are in constant, random motion: Some of the water particles traveled from the air to the mirror.
   - The average speed of particles increases with temperature: As the water particles were heated, they sped up.
   - Macroscopic properties of matter are dependent on motion at the particle level: Some water particles gained enough energy to eventually boil and leave the surface of the water.
   - Interactions among particles, particularly in liquids and solids, determine physical properties of matter: When water is in the liquid phase, there are interactions between the particles. The energy that is added in the form of heat goes to overcoming those interactions so the water can boil.
2. Sample response: The fog on the mirror is water from the beaker because some of the water gained enough energy to become a vapor and then condensed on the mirror. The water particles gained thermal energy as the beaker was heated, and once enough energy was absorbed, the water began to boil. Some water particles had enough energy to overcome the attractive forces between particles and escape the surface of the water. Some of those particles landed on the mirror and lost energy to the environment, which caused them to condense back to a liquid.

UNIT 1

LESSON 1.3

Confidence in Measurement

OVERVIEW

LESSON DESCRIPTION

Part 1: Data Collection

Students measure an unknown volume of water using two containers with different precision. They then determine the percent error of their measurements using values for the predicted mass of the water and the actual mass of the water.

Part 2: Data Analysis

Students use their data and a class discussion to explore the idea that all measurements have error and that the type of instrument they use to collect data is a factor in that error.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- 1.3: How Confident Are You?

MATERIALS

For each group:

- balance
- small cup of water (less than 50 mL, prepared ahead of time)
- 250 mL beaker
- 50 mL graduated cylinder

CONTENT FOCUS

This lesson is intended to start a discussion about error and precision in measurement. Many students are not familiar with the types of glassware in the chemical laboratory and why these different types exist. This activity allows them to compare the relative precision of beakers and graduated cylinders with the goal of understanding which would be the best to use to measure specific volumes of liquids.

The term *significant figures* is purposefully not used in this lesson. Instead, students evaluate and discuss their confidence level in the values they are reporting. The focus of this lesson and the Pre-AP Chemistry course in general is about precision of measurement and ways to minimize error. The rules for significant figures are not part of Pre-AP Chemistry.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ All measurements have uncertainty, and their level of precision must be accounted for in the design of an experiment and the recording of data.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- Before the lesson, measure out a different volume of water (less than 50 mL) for each group. So that students can practice estimating, it is best to use a volume that is not a mark on a 50 mL graduated cylinder. Pour the water into plain cups (or other containers without measurement markings) to give to the groups.
- Other glassware can be used if 50 mL graduated cylinders and 250 mL beakers are unavailable. It is only important that the two different types of glassware give different precisions. Avoid 10 mL graduated cylinders because the smallest division is 0.2 mL and estimating one digit further can be challenging.
- For the data reporting portion of the lesson, set up a way for groups to share their data with the class. You might use large pieces of paper, whiteboards, shared electronic documents, or similar tools. Anything that allows all students to see the data for all groups will work.

SAFETY NOTES

All general safety guidelines should be followed.

PART 1: DATA COLLECTION

In the first part of this lesson, students measure an unknown volume of water using two containers with different precision. They then determine the percent error of their measurements, using values for the predicted mass of the water and the actual mass of the water.

- To begin the lesson, divide the class into small groups. Give each group one of the cups of water you prepared before class as well as a 250 mL beaker, a 50 mL graduated cylinder, and a balance. Groups can then begin working at their own pace through **Handout 1.3: How Confident Are You?** This handout is designed to guide students through the steps of data collection and data reporting for this lesson, so that you can provide ample individualized support to student groups as they are working.
- As you circulate among the groups, you may want to offer the following guidance for the individual steps of each procedure:
    - Step 2: To emphasize the idea of estimation, encourage students to report as many digits as they think is reasonable, including ones they estimate. Avoid directly teaching how many digits should be reported. Instead, have students focus on how confident they are about each digit. Encourage students to focus on the increments that are marked on each instrument and how those markings can help them estimate.
    - Steps 4 and 5: Students may express confusion if they are using an electronic balance and the last digit on the balance's display fluctuates. If this happens, let students know that they can estimate here as well. To help students stay focused on the main points of the lesson, it is best not to introduce the idea of uncertainty yet.
    - Step 6: Students may need support understanding why they use the value from the balance as the actual value in their percent error calculation. The value read from the balance, even with a triple beam balance, is much more precise than the calculation of mass based on reading the volume from a graduated cylinder or beaker.

PART 2: DATA ANALYSIS

Students now use their data and a class discussion to explore the idea that all measurements have error and that the type of instrument they use to collect data is a factor in that error.

- Have students share their data from the Data Reporting section of the handout with the rest of the class. Students can do this using any system you prefer, such as large sheets of paper, whiteboards, or shared electronic documents. When all groups have made their data visible to the class, allow students a few minutes to closely observe each other's data and look for trends.
- Invite students to share and discuss the trends they have noticed in a whole-class discussion. When possible, encourage students to respectfully challenge and support each other's ideas directly, rather than relying on you to orchestrate the conversation. A goal of this discussion is to have students articulate the key takeaways about measurement that you want them to achieve in this lesson. You can use questions such as those listed below to guide student thinking.
  - Are you more confident in your recorded volume for the graduated cylinder or the beaker? Why?
  - Did everyone report their values with the same number of decimal places?
  - Which digits are you certain of? Which ones are estimated? Did your lab partner agree with your estimate? If you did not agree, how did you decide what volume to record?
  - How did the estimated digit relate to the smallest division on the glassware?
  - Are you more confident in the mass or volume you measured? Why?
  - Why did we use the measured mass of the water to calculate the percent error of our volume measurements?
  - Compare your percent error measurements for each piece of glassware with those of your classmates. Did the same piece of glassware always yield the lowest percent error? Why do you think this is?
  - During future chemistry labs, how will you decide which type of glassware you will use to measure volumes?

Meeting Learners' Needs

If students struggle with supporting and challenging each other's ideas during the discussion, you may want to provide some sentence starters for them to use. Sentence starters that might be useful here include:

- What do you mean by ____________?
- I don't quite understand ____________.
- I like how you said ____________ because ____________.
- I'm not sure I agree with ____________ because ____________.

During the discussion, listen for indications that students are more confident in the volume measured in the graduated cylinder because it has smaller increments of measure. Students should also indicate that their estimated value is always one more digit to the right of what the increments on the tool are. If the graduated cylinder did not always have the smaller percent error, it is likely due to lack of experience using laboratory glassware and you can use this opportunity to discuss errors in measurement as well as precision in measurement. You could also use this opportunity to introduce other types of glassware, including burets, and then ask students to determine which piece of glassware would be best in different scenarios.

Instructional Rationale

Now that students have learned that all measurements have error and that the type of instrument they use to collect data is a factor in that error, it is an appropriate time to introduce students to the error analysis methods you will expect them to use in the course.

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 1.3: How Confident Are You?

Student answers will vary. Sample data are provided below for reference.

Measuring Volume with a Beaker

Mass of empty 250 mL beaker (g)	62.50 g
Volume of water measured (mL)	27 mL
Predicted mass of water in beaker (g)	27 g
Mass of beaker and water (g)	91.75 g
Actual mass of water (g)	29.25 g
Percent error	7.7%. Sample calculations: (|27 g – 29.25 g| / 29.25 g) × 100 = 7.7%
Smallest increment of measurement marked	50 mL

Measuring Volume with a Graduated Cylinder

Mass of empty 50 mL graduated cylinder (g)	62.25 g
Volume of water measured (mL)	29.0 mL
Predicted mass of water in graduated cylinder (g)	29.0 g
Mass of graduated cylinder and water (g)	91.50 g
Actual mass of water (g)	29.25 g
Percent error	0.9%. Sample calculations: (|29.0 g – 29.25 g| / 29.25 g) × 100 = 0.9%
Smallest increment of measurement marked	1 mL

UNIT 1

LESSON 1.4

Relating Mass and Volume Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Data Collection

Students develop and implement a procedure for collecting mass and volume data for various metal samples. Students then record their data in a data table that they design.

Part 2: Analysis

Students graph the mass and volume data they collected and then group the data according to trends they observe to determine how many different substances they tested. Students demonstrate an understanding of density using calculations of slope of fit lines, particulate representations, and graphical analysis.

Part 3: Application

Students are challenged to use what they learned in the lab to calculate the mass of a sample of a substance without using a balance.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~60 minutes

HANDOUT

- 1.4: Relating Mass and Volume Lab

MATERIALS

For each group:

- metal samples (3 or 4 samples each of 2 different metals; the samples for each metal should vary in size and shape)
- water
- balance
- ruler
- graduated cylinder

CONTENT FOCUS

Density is a concept traditionally introduced in middle school and reinforced in chemistry. The approach to teaching density in this lesson builds on students' prior knowledge that a relationship between mass and volume exists, with the goal of helping students deepen their understanding of density so they can represent a sample's density using multiple methods: particulate, graphical, and algebraic.

To do this, students investigate the relationship between mass and volume using multiple samples of two metals. This exploration gives students the opportunity to manipulate simple algebraic formulas, determine density by graphical analysis, and model relative densities using particulate diagrams. This lab may be the first time that students are introduced to the idea that the slope of a graph can have a physical meaning. This lesson also allows students to reinforce their skills with measurement and calculations as they attend to appropriate experimental precision.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

If metal samples are not readily available at your school, one possible option is to buy metal rods of different diameters from a hardware store and have them cut to varying lengths. One advantage to obtaining samples this way is that you can vary both the diameter and length of the samples of each metal so students don't automatically assume they are the same material. Common metals used in this type of investigation include aluminum, zinc, and steel (rods of which are fairly inexpensive at the hardware store), but any metal will work.

SAFETY NOTES

All general safety guidelines should be followed.

PART 1: DATA COLLECTION

In this part of the lab, students work in small groups to develop and implement a procedure for collecting mass and volume data for various metal samples. Students record their data in a data table that they design.

Guiding Student Thinking

Students will likely know that density relates the mass and volume of a substance, but may not know that the slope of a mass-versus-volume graph for a substance is the density. You may want to refrain from using the word *density* until students get to the Analysis section of the lab.

- Introduce the lesson by providing each group with the samples of unidentified metals they will be working with. Each group will need at least three samples of various shapes and sizes for each of two different metals. Try not to reveal that some of the samples are the same materials because students will analyze data later in the lesson to determine this.
- Explain that each group's first goal is to write a procedure to determine the relationship between mass and volume for these samples. Show students the materials that are available to them for use during the lab: a graduated cylinder, a balance, and a ruler. Then allow students time to collaboratively develop their procedure. As you circulate around the room, support student groups by asking questions such as the following:
    - How could you determine the mass of each sample? How could you determine its volume?

      Student responses should include measuring mass with a balance and measuring volume using water displacement.
    - Is there a particular order in which the measurements should be made?

      Student responses should include that mass should be measured first or that the sample should be dried before measuring its mass so as to not introduce error due to water on the sample.
    - Does it matter how much water is used?

      Student responses should include that since they will measure the change in volume of the water, the amount of water doesn't matter.

- Once lab groups have had time to discuss their procedure, direct their attention to Part 1 of **Handout 1.4: Relating Mass and Volume Lab**. They should use this handout to record the steps of their procedure and to create the data table they use to record their data.

  You may want to review each group's procedure and data table and help them gather materials before allowing them start the lab. Once students have begun their procedure and you are circulating around the room, remind them to record their data to the appropriate precision, based on the available equipment. If students are using glass graduated cylinders, instruct them to carefully slide the samples into the graduated cylinder rather than dropping them in, which can break the bottom of the cylinder.
- When a student group has completed Part 1 of the handout, on data collection, they can move on to Part 2, on data analysis.

PART 2: ANALYSIS

In this portion of the lesson, students graph the mass and volume data they collected and then group the data according to trends they observe to determine how many different substances they tested. Students demonstrate an understanding of density using calculations of slope of fit lines, particulate representations, and graphical analysis.

- As students work on the data analysis portion of the handout, circulate around the room to support groups as needed. Some particular kinds of support you will likely need to provide include the following:
  - Question 2: You may have to help students group their data into distinct regions for each material.
  - Question 3: Be sure to look for students who connect the plotted points rather than drawing a fit line. Also, prompt students to consider whether the lines of fit should include (0, 0). As students calculate the slope of their lines, you can reinforce language they have learned in math class by using the term *slope triangle*. This may be your students' first exposure to the slope of a graph having a physical meaning.
  - Question 4: Students may not immediately realize that drawing lines of fit is the best way to make predictions about other samples from their data, so you may need to prompt them about the purpose of fit lines.
  - Question 5: This question requires students to establish connections between particle diagrams and other methods of representing density. You might want to have students redraw the two particle diagrams on their graph next to the fit line for each substance.

Guiding Student Thinking

Students may not immediately realize the samples are from different materials, depending on what metals you choose to use. They will discover this when they graph the data and see different clusters. Each cluster of data should correspond to a different material.

PART 3: APPLICATION

Students use the graph and fit lines constructed in Part 2 to determine the mass of an additional sample of one of the substances they studied. This task reinforces that a line of fit can be used to make predictions.

- Give each lab group a new sample of one of their substances and explain that their challenge is to determine the mass of the sample without using a balance.
- Allow each lab group time to brainstorm how they can determine the mass without using a balance. You may want to approve procedures before allowing groups to continue. Students groups can then complete Part 3 on the handout, which guides them through writing and implementing their procedure and calculating their percent error.
- Once students have finished this final part of the lab, discuss as a class how students accomplished the task, and circle back to the main ideas that were introduced in this lesson. Questions you can use to fuel the discussion include:
  - How did different groups determine the mass of the unknown substance?
  - What are some advantages and disadvantages of the various methods different groups used?
  - Did everyone collect measurements to the same precision?
  - What does the slope of a mass-versus-volume graph represent?
  - What are the three ways you represented density during this lab?
  - What are some advantages and disadvantages of each representation?
  - When might a particular representation be more useful than others?

Meeting Learners' Needs

If you want to give some groups an extra challenge, you can give them a sample large enough that the volume is not a point on their graph. This requires students to use the slope or the density equation to determine the mass. You could also give them a sample that is too large to use water displacement as a means to determine the volume.

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.

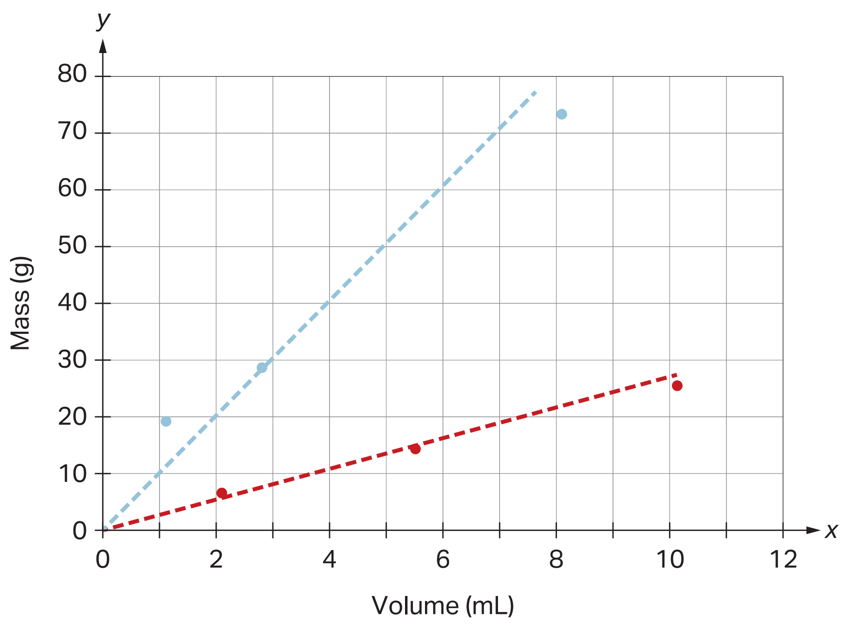
Handout 1.4: Relating Mass and Volume Lab

Part 1: Data Collection

1. Student procedures should indicate using a balance to determine the mass of each sample and using water displacement to determine the volume of each sample. You may require students to conduct multiple trials for each sample.
2. The data table should have a place for students to record the mass and initial and final volumes of their samples.

Part 2: Analysis

1. Sample response:



2. There are two different substances because the data fall into two distinct groups.
3. Answers will vary depending on the substances used. The slope of the fit line represents the density of the material.
4. You could determine either the mass or the volume of another sample and see where it would be on the line of fit to determine the other variable.

5. The diagram with more particles represents the substance that is more dense. The diagram with fewer particles represents the substance that is less dense. Density relates the mass of a substance to the volume, so a denser substance has more particles in the same amount of space than a less dense substance.

Part 3: Application

1. Student responses should indicate determining the volume of the sample using water displacement. Students should then use the best fit line to determine the mass of the sample.

LESSON 1.5

Heat Transfer

OVERVIEW

LESSON DESCRIPTION

Part 1: Distinguishing Between Heat and Temperature
Students engage in several thought experiments that help them begin to uncover the difference between heat and temperature and how energy is transferred from one substance to another. Through these thought experiments students also build a conceptual and mathematical model of heat transfer.

Part 2: Specific Heat Calorimetry Lab
Students perform a simple constant-pressure calorimetry experiment in which they heat a piece of metal, submerge it in room temperature water, and measure the temperature change of the water. They then calculate the specific heat capacity of the metal analyzed in the lab. Students connect their observations and data from the experiment to their understanding of heat transfer.

Part 3: Discussion
The lesson concludes with a debrief to help students solidify the ideas introduced before and during the lab.

CONTENT FOCUS

This lesson is designed to serve as an introduction to specific heat capacity. Its purpose is to help students begin to distinguish between temperature and heat by using commonplace examples to frame their thinking. Through a series of thought experiments, students

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUT

- 1.5: Specific Heat Calorimetry Lab

MATERIALS

For each group:

- water
- metal sample
- balance (0.1 or 0.01 g precision)
- 400 mL beaker
- 250 mL beaker
- plastic foam cups
- tongs
- stirring rod
- hot plate
- thermometer
- probeware and software (optional)
- goggles

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build on their existing conceptual understanding to differentiate between heat and temperature. They also draw on their algebra knowledge to develop a mathematical model that shows that the amount of heat transfer depends on the mass of a substance and the temperature change. To reinforce the thought experiments, students perform a calorimetry experiment to collect data that they use to identify an unknown metal based on its specific heat capacity.

Having students develop the equation for heat transfer themselves helps them see that the equations they use in science are developed based on real-world observations. This understanding can support students in moving beyond a formulaic approach to problem solving. By using simple numbers and basic proportional reasoning before working with the equation, students are better positioned to not only understand the equation but also to evaluate whether their answers make physical sense.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- If possible, use a variety of metals for the samples, for comparison at the end of the lab. You can reuse some of the samples you used in Lesson 1.4: Relating Mass and Volume Lab. If you use metals other than those listed in the table on the handout, be sure to give students an alternative data table that includes the metals you used.
- Infrared thermometers, if you have them, are easier to use to determine the surface temperature of materials.
- Probeware may be used to increase accuracy of the data collected.

SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear chemical splash goggles throughout the lab.

FORMATIVE ASSESSMENT GOAL

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

Water at room temperature is poured into a hot metal pot. Assume the only energy exchanged is between the water and the pot.

1. Will energy be transferred from the pot to the water or from the water to the pot? Explain.
2. After the water and the pot have been in contact for a long time, which of the following will be true about the final temperatures of the water and the pot?
   (a) The pot will be hotter than the water.
   (b) The water will be hotter than the pot.
   (c) The water and the pot will be at the same temperature.
   (d) The final temperatures of the water and the pot depend on what metal the pot is made of.
3. The specific heat capacity of the metal the pot is made of is much lower than the specific heat capacity of water. Will the final temperature of the pot be closer to the initial temperature of the pot, the initial temperature of the water, or exactly halfway between the two? Explain your reasoning.
4. A 134.0 g sample of an unknown metal is heated to 91.0°C and then placed in 125 mL of water at 25.0°C. The final temperature of the water is measured at 31.0°C. Calculate the specific heat capacity of the unknown metal.

PART 1: DISTINGUISHING BETWEEN HEAT AND TEMPERATURE

Students engage in several thought experiments that help them begin to uncover the difference between heat and temperature and how energy is transferred from one substance to another. Through these thought experiments students also build a conceptual and mathematical model of heat transfer.

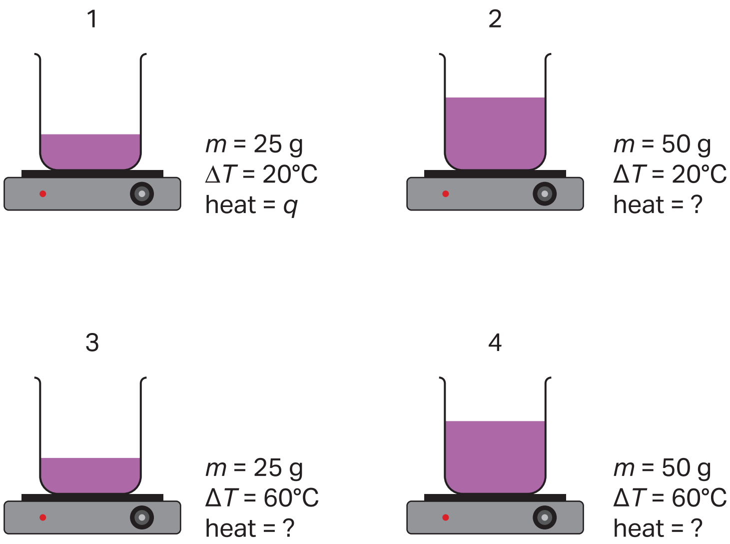
- To elicit students' prior understanding of the connection between temperature and particle motion, ask students to describe how hot and cold water are different at the particle level. From previous lessons, students should be able to articulate that, as with any hot or cold substance, hot water has a greater amount of particle motion than cold water.
- Next, to have students begin to think about temperature as distinct from heat, ask them which of the following would be more painful: putting their hand in a bucket of very hot water, or having a drop of the same very hot water placed on their hand. As students respond, listen for students to say the drop of water is preferable because "there is less of it" or "it's not as hot." Consider follow-up questions such as these:
  - Why would a smaller amount of very hot water be less painful?
  - Is the temperature of the drop of water different from the temperature of the bucket of water?
  - Are heat and temperature the same thing?
- After some discussion, point out to the students that they actually already have an intuitive understanding that there is more at play than just the temperature of the water. If only the temperature of the water mattered, then the amount of water wouldn't matter. The bucket of water and the drop of water would both be just as painful. Explain to students that the difference they are beginning to uncover is the difference between *energy transferred via heating* and *temperature*.
- Next, begin a sequence of questions to help students build their understanding of heat transfer and to prime their thinking for questions they will explore in the lab. First, ask students why their hand feels hot when they touch a hot object. Students may have some background knowledge of heat transfer from middle school, so listen carefully for what they know and what misconceptions they may have so you can address those misconceptions through this lesson and future lessons.

  Then, show students a book and a metal pan (or similarly sized metal object) and ask them which one they think is colder. They will likely say the metal is colder because it feels cold to the touch. Using a thermometer, demonstrate that the metal and the book are both at room temperature. Ask students why the metal feels colder than the book, if they are both at the same temperature. Consider their responses and record them on the board to come back to after they have conducted the lab and know more about heat transfer.

- Explain to students that, in preparation for today's lab, we will develop a mathematical model that describes heat transfer as well as the difference between heat and temperature. Show students the following set of images, which we will use to develop the model.

Meeting Learners' Needs

If your students are not familiar with delta (Δ) being used to represent change, take a few minutes to explain this notation to them before proceeding. You may also need to explain to students why we use *q* for heat.



Instructional Rationale

This part of the lesson is designed to help students build a mathematical model as well as deepen their conceptual understanding of heat. This approach, in contrast to simply giving students an equation to use, promotes more meaningful and lasting understanding.

Ask students what we know about beaker 1 from the image. Be sure students recognize that the image shows that it takes *q* amount of heat to raise the temperature of 25 grams of the liquid by 20 degrees Celsius.

- Next, students work toward constructing a mathematical model by looking at the other beakers and making comparisons to beaker 1. Guide them through these comparisons using the questions and prompts below. For each set of questions, have students first work with a partner so they can brainstorm and discuss ideas. Then, have them share their results with the class and engage in a class discussion to come to a consensus.

Beaker 2

- What is different about beaker 2 compared to beaker 1?
- How much heat, in terms of q, would it take to produce the change in temperature indicated in the picture? What is your reasoning?

  Let the class come to the consensus that it would take $2q$ (twice as much) energy to raise the temperature of the sample in beaker 2 by the same amount because there is twice as much liquid.

  Point out that comparing beakers 1 and 2 shows us that q is directly proportional to mass, and that we can write this relationship mathematically as $q \propto m$.

Guiding Student Thinking

You can expect most students to be familiar with directly proportional relationships from middle school math and Algebra 1. From math, students may be more familiar with the terminology *direct variation* or *vary directly* rather than *directly proportional*, so it may be helpful to use all three terms.

Students have likely learned that two quantities vary directly if the ratio between them is constant, so you can point out that in this case, when one quantity doubles, the other also doubles. Students have also likely learned that direct variation relationships can be expressed algebraically as $y = kx$ where k is the proportionality constant. You could point out here that we are using q instead of y and m instead of x. We are building to the idea that the specific heat capacity is the proportionality constant, but save that until after students have examined the scenarios in all four beakers.

Beaker 3

- What is different about beaker 3 compared to beaker 1?
- How much heat, in terms of q, would it take to produce the change in temperature indicated in the picture? What is your reasoning?
- Write a mathematical expression to relate heat and change in temperature.

  Let the class come to the consensus that it would take $3q$ amount of heat to raise the temperature of the same amount of water by three times as much. An expression for the relationship is $q \propto \Delta T$.

Beaker 4

- What is different about beaker 4 compared to beaker 1?
- How much heat, in terms of q, would it take to produce the change in temperature indicated in the picture? What is your reasoning?

  If possible, let the class come to a consensus that it would take $6q$ amount of energy. However, you may need to provide additional support, as students may not realize how to mathematically handle this situation, which involves twice as much water and three times the temperature increase of beaker 1. Some will want to add values; others will correctly guess they should be multiplied.

Meeting Learners' Needs

If you feel students need more support, you can also ask them to compare beaker 4 to beaker 2 or beaker 3, rather than beaker 1. This approach allows students to focus on the one variable that is changing for each comparison. This approach also increases the chances that students will arrive at an answer of $6q$ instead of $5q$.

- To tie together and affirm the value of students' work in this part of the lesson, explain that we can combine the two relationships that the class has developed into a single equation using a proportionality constant, c. The equation is $q = cm\Delta T$. You can again ask students to think back to what they may have learned in Algebra 1 about direct variation and point out how this equation is similar to $y = kx$, with the specific heat capacity as the proportionality constant.
- Introduce the definition of the proportionality constant c. Explain that c, or specific heat capacity, is the amount of energy required to raise the temperature of 1 g of a substance by 1 degree Celsius. Talk a little about the fact that different substances have different specific heat capacities. The higher the specific heat capacity of a substance, the more energy it takes to raise its temperature.
- Some students are likely feeling that there are some complex ideas at play. You can reassure the class that they will continue to develop their understanding of the concept of specific heat capacity by carrying out the upcoming lab: a constant-pressure calorimetry experiment.

PART 2: SPECIFIC HEAT CALORIMETRY LAB

In this part of the lesson, students perform a simple constant-pressure calorimetry experiment in which they heat a piece of metal, submerge it in room temperature water, and measure the temperature change of the water. They then calculate the specific heat capacity of the metal analyzed in the lab. Students connect their observations and data from the experiment to their understanding of heat transfer.

- First, allow students time to read the introduction to **Handout 1.5: Specific Heat Calorimetry Lab**, which provides an overview of calorimetry. Support students as needed in understanding this text. Then, to prime their thinking about the upcoming lab, ask them to write their responses to the following questions (in the Making Predictions section of the handout):
  1. If you place a sample of hot metal in room temperature water, what will happen to the temperature of the metal and the water? Explain your reasoning.
  2. Suppose you placed a sample of metal in boiling water (at 100°C) in a beaker on a hot plate. What would happen to the temperature of the metal after several minutes? Explain your reasoning.

  Call on students to share their responses with the class and invite other students to support or challenge their reasoning, as appropriate.

Guiding Student Thinking

Try not to validate any of the predictions as right or wrong at this point; that comes later in the lesson. The process of making and discussing the predictions will help students make sense of the data they will collect in the lab.

- Divide students into small groups to complete the calorimetry lab in the handout, including the Caculations and Analysis sections. Assign each group a metal sample to work with.
- As you circulate around the room during the lab, consider asking students some of the following questions to probe for understanding:
  - What is the maximum temperature reached by the metal when it is in the boiling water?

    It will be the same as the water temperature because the water transfers energy to the metal until they are at the same temperature.
  - What is the purpose of nesting two foam cups together?

    They insulate the system (water and hot metal) to minimize heat transfer to the surroundings (the classroom).

Classroom Ideas

You may want to demonstrate how to nest the plastic foam cups and how to place them in a beaker for stability.

If you choose to use probeware, have students determine the maximum temperature reached by the water by clicking on Analyze, then Statistics (or the equivalent menu options), in the data analysis program.

- What are the sources of error in the experiment?

  The largest source of error is that the calorimeter does not have a lid, which allows for energy transfer to the room. Another source of error is the drops of water that cling to the metal as it is transferred to the calorimeter.

- Where does the energy from the hot metal go?

  It is transferred to the water and increases the temperature of the water.

Meeting Learners' Needs

Some students may need help using the negative sign on the energy change of the metal (question 7 under Calculations). Explain that, by convention, we use a negative sign to indicate a loss of energy.

- Why is the temperature change different for the metal and the water?

  It is different because they have different specific heat capacities. This means that even though they transferred the same amount of energy, it will affect the temperature differently.

PART 3: DISCUSSION

The lesson concludes with a debrief to help students solidify the ideas introduced before and during the lab.

- Lead a whole-group discussion to probe for understanding and to clarify student misconceptions. Be sure to revisit the students' thoughts about why the book and metal pan feel different even if they are at the same temperature. You may also want to revisit questions 4 and 5 from the Calculations section of the handout, shown below:

4. Did the water in the calorimeter gain or lose energy when the metal was placed in it? How do you know?

   The water in the calorimeter gained energy. I know this because its temperature increased, and an increase in temperature indicates an increase in thermal energy.

5. Did the metal sample gain or lose energy when it was placed in the water in the calorimeter? How do you know?

   The metal sample lost energy. I know this because its temperature decreased, and a decrease in temperature indicates a decrease in thermal energy.

Handout 1.5

You may also want to incorporate the following questions into the discussion:

- Where did the energy the metal lost go? How was the energy transferred?

  The fast-moving hot metal particles collided with the water particles and, in doing so, transferred energy to them.

- Aluminum has a higher specific heat capacity than copper. You heat aluminum and copper to the same temperature and add them to two different calorimeters with water at the same temperature. What would you predict about the temperature change of the water in the calorimeter for each metal?

  The temperature change of the water with the aluminum sample will be greater than the temperature change of the water with the copper sample. The aluminum initially contained more energy because more energy was required to raise the temperature of the aluminum to the same temperature of the copper so it had more energy to give to the water.

- You can now let students know which metal they used and then ask a few groups who used the same metal but had different temperature changes to share their data. Then pose the following questions:

  - Why do you think different samples of the same metal, all starting at the same temperature, changed the temperature of the water by different amounts?

    The metals had different masses and/or the groups used different amounts of water.

  - Even though the temperature changes were different for samples of the same metal, the values for the measured specific heat capacities were similar. Why do you think this is?

    The specific heat capacity is the proportionality constant. With a smaller mass of metal, a smaller amount of energy would be transferred to the water. With a smaller amount of water, there would be a larger temperature change of the water.

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.

Water at room temperature is poured into a hot metal pot. Assume the only energy exchanged is between the water and pot.

1. Will energy be transferred from the pot to the water or from the water to the pot? Explain.

   Energy will be transferred from the pot to the water because energy is transferred from the hotter object or substance to the cooler object or substance.

2. After the water and the pot have been in contact for a long period of time, which of the following will be true about the final temperatures of the water and the pot?

   (a) The pot will be hotter than the water.

   (b) The water will be hotter than the pot.

   (c) The water and the pot will be at the same temperature.

   (d) The final temperature of the water and the pot depends on what metal the pot is made of.

   The correct answer is (c).

3. The specific heat capacity of the metal the pot is made of is much lower than the specific heat capacity of water. Will the final temperature of the pot be closer to the initial temperature of the pot, the initial temperature of the water, or exactly halfway between the two? Explain your reasoning.

   The final temperature of the pot (and water) will be closer to the initial temperature of the water. Because water requires a greater amount of energy to be exchanged to change its temperature, its temperature will not change as much as the metal.

4. A 134.0 g sample of an unknown metal is heated to 91.0°C and then placed in 125 mL of water at 25.0°C. The final temperature of the water is measured at 31.0°C. Calculate the specific heat capacity of the unknown metal.

   Water

   $$q = mc\Delta T$$

   $$q \text{ gained by water } = (125\text{ g})\left(4.18\frac{\text{J}}{\text{g}\bullet{}^{\circ}\text{C}}\right)(31.0^{\circ}\text{C} - 25.0^{\circ}\text{C})$$

   $$q \text{ gained by water } = 3{,}100\text{ J}$$

Continues on next page.

Metal

q lost by metal $= -q$ gained by water

$q = mc\Delta T$

$-3{,}100\ \text{J} = (134.0\ \text{g})(c)(31.0°\text{C} - 91.0°\text{C})$

$c = 0.39 \dfrac{\text{J}}{\text{g} \bullet °\text{C}}$

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 1.5: Specific Heat Calorimetry Lab

Data

Student answers will vary. Sample data are provided below for reference.

	Trial 1
Mass of metal	25.0 g
Mass of calorimeter	7.5 g
Mass of calorimeter and water	47.5 g
Mass of water	40.0 g
Initial temperature of water in calorimeter	23.4°C
Initial temperature of hot metal sample	99.5°C
Final temperature reached by the water in calorimeter	31.6°C

Calculations

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

1. $\Delta T = 31.6°\text{C} - 23.4°\text{C}$
   $\Delta T = 8.2°\text{C}$
2. The final temperature of the metal is the same as the final temperature of the water. The metal cooled down and the water heated up until they were at the same temperature.
3. $\Delta T = 31.6°\text{C} - 99.5°\text{C}$
   $\Delta T = -67.9°\text{C}$
4. The water in the calorimeter gained energy. I know this because its temperature increased, and an increase in temperature indicates an increase in thermal energy.
5. The metal sample lost energy. I know this because its temperature decreased, and a decrease in temperature indicates a decrease in thermal energy.
6. $q = mc\Delta T$
   $$q = (40.0\text{ g})\left(4.18\frac{\text{J}}{\text{g} \bullet °\text{C}}\right)(8.2°\text{C})$$
   $q = 1{,}400\text{ J}$
7. 1,400 J. If we assume no heat was lost to the surroundings, the energy gained by the water came from the metal as it cooled.
8. $q = mc\Delta T$
   $-1{,}400\text{ J} = (25.0\text{g})(c)(-67.9°\text{C})$
   $$c = 0.8247\frac{\text{J}}{\text{g} \bullet °\text{C}} \approx 0.82\frac{\text{J}}{\text{g} \bullet °\text{C}}$$
9. Sample response: My unknown metal was aluminum. The value of the specific heat capacity I determined is closer to that of glass, but my sample was clearly a metal and the metal with the closest specific heat capacity is aluminum.
10. Sample response: I could determine the density of the metal and see if it is close to the accepted value for the density of aluminum.

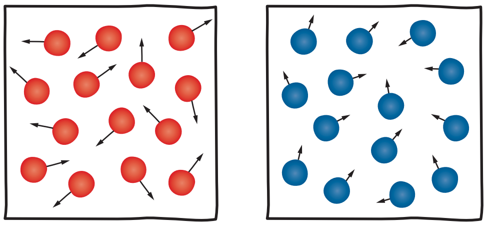
UNIT 1

11. $$\text{percent error} = \frac{|0.90 - 0.82|}{0.90} \times 100$$
$$\text{percent error} = 8.9\%$$

Possible sources of error include the fact that the calorimeter is not a perfect insulator, so some energy is transferred to the surroundings. Another source of error is that some water may have clung to the metal sample, so the mass used in the calculations was not correct.

Analysis

1. Sample response:



2. The fast-moving hot metal particles collided with the water particles and, in doing so, transferred energy to them.
3. The high specific heat capacity of water means that it takes a lot of energy to change the temperature of water. This means that the temperature of the water in our body, and therefore our body temperature, stays relatively constant.

PRACTICE PERFORMANCE TASK

Determining Properties of an Unknown Substance

OVERVIEW

DESCRIPTION

In this practice performance task, students draw a particle model, rank the density of three materials, use volume displacement to determine the density of a solid, and then use principles of heat transfer to determine the specific heat capacity of a solid block.

CONTENT FOCUS

This task is designed to assess students' understanding of density both conceptually and mathematically, as well as their understanding of heat transfer. It is intended to be used during Key Concept 1.2, after students have completed Lesson 1.5: Heat Transfer.

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUT

- Practice Performance Task: Determining Properties of an Unknown Substance

MATERIALS

- calculator
- equation sheet

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings
▪ 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.

Learning Objectives	Essential Knowledge
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** 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.
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.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.
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.

SUPPORTING STUDENTS

BEFORE THE TASK

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

- Students might need a refresher on calculations involving density and specific heat capacity. Prior to the task, you could give the students some sample problems to work on with a partner.
- A common mistake students make is leaving off the negative sign on the specific heat calculations for the substance that loses heat energy, so you can lead a quick refresher on sign conventions.
- Students may have built a density column in middle school. You can ask students to recall how they constructed the column and why the liquids separated into layers.
- You can also consider having students draw particle diagrams for different states of matter and/or substances that have different densities.

DURING THE TASK

Because this is a practice performance task, you could choose to have students engage in the task differently from how they might engage in a conventional assessment. You may want to use an implementation strategy such as the following:

- Students could work in pairs to complete the task. It is not recommended for students to work in small groups. There is ample work and enough opportunity for discussion for two students, but in a group of more than two students there may not be quite enough work for everyone to meaningfully engage in the task.
- You could chunk the task into parts 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 what changes, if any, they could make to their responses to craft a more complete response.
- Have students complete the task individually. Then distribute the scoring guidelines to students to have them score their own tasks or score the response of a classmate. Finally, have students reflect on their work and make recommendations to themselves about how they could improve their performance next time.

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. Students should understand that converting their score into a percentage does not provide a good measure of how they performed on the task.

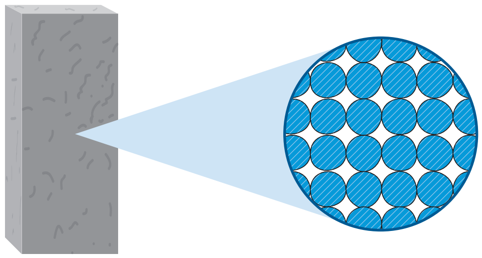
You may also want to build on this task to give students additional practice in justifying claims. After students have completed the task, provide them with the following data table and ask them to make an evidence-based claim about the identity of the unknown material. The data in the task was taken using a sample of brass, but students could reasonably defend either copper or brass based on the data. You could also ask them what other kinds of evidence they could use to strengthen their claim.

Material	Density (g/mL)	Specific Heat Capacity $\left(\frac{J}{g{\bullet}°C}\right)$
Aluminum	2.7	0.900
Brass	8.5	0.380
Copper	8.9	0.386
Iron/Steel	7.8	0.450
Lead	11.3	0.130
Tin	7.3	0.210
Zinc	7.1	0.387

SCORING GUIDELINES

There are 14 possible points for this performance task.

Part (a)

Sample Solutions	Points Possible
	**2 points maximum** 1 point for consistent size of particles 1 point for orderly arrangement consistent with the sample being a solid
Targeted Feedback for Student Responses	
Refer students back to Lesson 1.2, in which they built a model of a solid using magnetic marbles to show the orderly arrangement of particles in a solid.	

TEACHER NOTES AND REFLECTIONS

Part (b)

Sample Solutions	Points Possible
The list of substances ordered by increasing density is: Liquid A, the solid sample, Liquid B. The solid floats in Liquid B, so Liquid B is more dense than the solid. The solid sinks in Liquid A, so the solid is more dense than Liquid A.	**2 points maximum** 1 point for correct order 1 point for correct justification
Targeted Feedback for Student Responses	
Ask students to consider why ice cubes float in liquid water and have them compare the densities of ice and water.	

TEACHER NOTES AND REFLECTIONS

Part (c)

Sample Solutions	Points Possible
Liquid A: 12.2 mL Liquid B: 8.0 mL	**2 points maximum** 1 point for each volume, with the correct precision *Scoring note:* Accept all reasonable values for volume.

Targeted Feedback for Student Responses
Remind students that they should always estimate the last digit of any measurement. In this case, that means reading between the markings on the graduated cylinder. Since the markings are in 1 mL increments, the estimated digit is in the tenths place.

TEACHER NOTES AND REFLECTIONS

Part (d)

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

$D = \frac{m}{V}$

change in volume $= 12.2\ \text{mL} - 7.0\ \text{mL}$
$= 5.2\ \text{mL}$

$D = \frac{42.13\ \text{g}}{5.2\ \text{mL}}$

$D = 8.1\ \text{g/mL}$

</td><td>

3 points maximum

1 point for the correct change in volume for Liquid A

1 point for using the formula for density

1 point for answer

Scoring notes:

- Students do not have to explicitly show the calculation for the change in volume. Any reasonable value for volume should be accepted since students must estimate their measurement of the final volume.
- If students use the incorrect volume in the density formula, they can still earn the points for using the formula and their answer, but they should not earn the point for calculation of volume change.
- No points are assigned for correct significant figures.

</td></tr>
<tr><th colspan="2">Targeted Feedback for Student Responses</th></tr>
<tr><td colspan="2">If students used Liquid B, ask them how they determined the volume of the block since some of it was in the liquid and some was out of the liquid. Lead students to the conclusion that they do not have enough information to determine the density of the block using the information from the graduated cylinder containing Liquid B.</td></tr>
</table>

TEACHER NOTES AND REFLECTIONS

Part (e)

Sample Solutions	Points Possible
$q = mc\Delta T$ $q_{H_2O} = (62.00\text{ g})\left(4.18\ \frac{\text{J}}{\text{g}\bullet{}^\circ\text{C}}\right)(26.0^\circ\text{C} - 23.2^\circ\text{C})$ $q_{H_2O} = 730\text{ J}$	**2 points maximum** 1 point for correct ΔT 1 point for correct calculation of heat energy gained by the water *Scoring notes:* ▪ Students do not have to explicitly show the calculation of the temperature change of the water. ▪ If students use the incorrect value for ΔT, they can still earn the calculation point if they used the equation correctly. ▪ No points are assigned for correct significant figures.
Targeted Feedback for Student Responses	
Remind students that ΔT is the final temperature minus the initial temperature. Since this question asked about the energy gained by water, they should use the mass of the water and the temperature change of the water.	

TEACHER NOTES AND REFLECTIONS

Part (f)

Sample Solutions	Points Possible
$q_{block} = mc\Delta T$ $-730\ J = (42.13\ g)(c)(26.0°C - 75.0°C)$ $c = 0.35 \frac{J}{g \bullet °C}$	**3 points maximum** 1 point for correct ΔT 1 point for recognizing that the heat the water gained was the heat lost by the block 1 point for the correct calculation of the specific heat capacity of the block *Scoring notes:* ▪ Students do not have to explicitly show the calculation of the temperature change of the block. ▪ If a student calculated the incorrect value for the energy gained by the water in part (e) above, follow their mistake in this part of the question (i.e., a correct calculation based on an incorrect value should not be penalized here). ▪ No points are assigned for correct significant figures.
Targeted Feedback for Student Responses	
We must assume that the energy the water gained was from the block, so the answer from part (e) is the energy change for the block. The value is negative here since the block transferred energy to the water. The mass and temperature change used in the equation should be those of the block.	

TEACHER NOTES AND REFLECTIONS

UNIT 1

LESSON 1.6

Phase Diagrams – What's So Dry About Dry Ice?

OVERVIEW

LESSON DESCRIPTION

Part 1: Observing Water Ice and Dry Ice from a Particulate Perspective

In the first part of this lesson, students observe and compare water ice and dry ice undergoing changes of state. Students draw on their prior knowledge of states of matter to create particle diagrams and provide explanations of what they observe.

Part 2: Interpreting Phase Diagrams of Water and Carbon Dioxide

In this part of the lesson, students are introduced to phase diagrams for water and carbon dioxide. They are asked to use the phase diagrams to predict phase transitions and to support the observations they made in Part 1 of the lesson.

Part 3: Boiling and Subliming Dry Ice

In this part of the lesson, students apply their understanding of phase diagrams from Part 2 to analyze a demonstration of an infrequently observed phenomenon: the melting of dry ice. This demonstration gives students a chance to see liquid carbon dioxide and to use their interpretation of the phase diagram to explain the phenomenon. Students also consider how water and carbon dioxide interact to make the cloud or "smoke" that is seen above carbon dioxide as it sublimes.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 1.6.A: Water and Dry Ice
- 1.6.B: Phase Diagrams of Water and Carbon Dioxide
- 1.6.C: Boiling and Subliming Dry Ice

MATERIALS

- dry ice
- heavy gloves or tongs
- hammer
- mortar and pestle
- transparent plastic cup
- scissors
- pliers or clamp
- water
- plastic sandwich bag
- wide-bore plastic transfer pipette
- goggles

CONTENT FOCUS

In this lesson students explore the relationship between temperature, pressure, and states of matter and how this information is displayed on a phase diagram. Water and carbon dioxide were chosen as the materials for study in this lesson because students are familiar with the behavior of water but not as familiar with the behavior of carbon dioxide. This lesson also reinforces students' prior understanding of the different states of matter both on a particle level as well as on a macroscopic level. Students use particle diagrams throughout the lesson to connect macroscopic observations to what is occurring at the particle scale.

The lesson is designed so that students use their observations of dry ice and water ice to help them interpret phase diagrams and to understand phase transitions, including those that take place in conditions other than typical room temperature and pressure.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Solids, liquids, and gases have different properties as a result of the motion of particles and the interactions among them.	
Learning Objectives	**Essential Knowledge**
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** The transitions between solid, liquid, and gas can be represented with heating and cooling curves and phase diagrams. **d.** Phase diagrams give information about a pure substance at a specific temperature and pressure, including phase transitions.

SETUP AND PREPARATION NOTES

Dry ice can be purchased at many grocery stores and some ice cream stores.

SAFETY NOTES

- All general safety guidelines should be followed.
- Dry ice must be handled using heavy gloves or tongs. It will cause severe burns if it comes in contact with bare or unprotected skin. Always wear goggles when handling dry ice. When breaking the dry ice into smaller pieces with a hammer, cover the dry ice with a towel to keep the pieces in one place, or leave it in an open bag to contain the pieces. Do not store dry ice in an airtight container. A plastic foam cooler is sufficient for holding the dry ice.
- During the demonstration in Part 3, if you put too much dry ice into the pipette, you will very likely cause it to explode. A plastic cup rather than a glass beaker should be used to hold the water because of this possibility. Everyone (including you) should wear goggles during this demonstration since there is a risk of the pipette exploding.

PART 1: OBSERVING WATER ICE AND DRY ICE FROM A PARTICULATE PERSPECTIVE

In the first part of this lesson, students observe and compare water ice and dry ice undergoing changes of state. Students draw on their prior knowledge of states of matter to create particle diagrams and provide explanations of what they observe.

- In order to gauge students' prior knowledge about dry ice, show some images of dry ice such as the one below. Ask the class what the substance is and why it is producing the white "smoke" shown in the images. If students are unable to identify the substance, tell them it is dry ice. Explain that during this lesson they will learn why it produces the smoke.

Jeff J Daly / Alamy Stock Photo

- Explain that dry ice is simply solid carbon dioxide and that it is useful because it can actually keep food frozen, while regular ice can just keep things cool (similar to the difference between a freezer and a refrigerator).
- In preparation for making comparisons between water ice and dry ice, students will create particle diagrams to review what they know about the three phases of water. Ask students to find **Handout 1.6.A: Water and Dry Ice** and respond to question 1, which presents a picture of a partially filled bottle of ice water. Students provide a particle diagram for each phase of water in the picture.

Guiding Student Thinking

The particle diagrams should be a review for students, but some may not realize that there is water vapor present in the bottle, so you may need to prompt them to draw water particles in the air at the top of the bottle. If students draw nitrogen or other components of the air in the bottle, you can offer them praise for being thorough. Then let them know that in this lesson we'll focus mainly on water, and eventually, carbon dioxide.

- Ask students to share their particle diagrams with a partner. Students should discuss similarities and differences and then make any revisions they think are necessary to their models. In particular, ask students to make sure all three states are shown and to look at the arrangement and organization of the particles in all three states.
- The next step of the lesson is designed to get students to start thinking about the differences between water ice and dry ice, in terms of phase transitions and the behavior of each substance. Place a small drop of water and a small piece of dry ice in one or more locations in the classroom (such as on a desk), so everyone can see. To help ensure that the water droplet and dry ice sample take about the same amount of time to evaporate, you may want to use warm water. Remind students that dry ice is simply solid carbon dioxide and draw an analogy to regular ice being solid water. Students will observe that, over time, each sample evaporates (or sublimes).

  As students are observing the water drop and dry ice, they will draw particle diagrams to represent this situation, as directed in question 2 of the handout. At this point, the focus of the lesson is on what is happening to the water particles that make up the droplet and the carbon dioxide particles that make up the dry ice. So, as question 2 indicates, students are to show the arrangement of water particles in the water drop and just above the water drop (circles 1 and 2), and the arrangement of carbon dioxide particles in the dry ice and just above the dry ice (circles 3 and 4).

> **Classroom Ideas**
> You may do this on individual desks or in front of the classroom. If you have a document camera, you may use it to show the demonstration more easily.

- As you circulate around the room and look at students' drawings, remind students which particles to focus on for each circle. Also point out that throughout this lesson, we will use circles to represent water particles and squares to represent carbon dioxide particles. You may want students to check their particle diagrams with a partner, similar to what they did with their particle diagrams for water.

Guiding Student Thinking

If students add water particles above the dry ice, remind them that we are only drawing the carbon dioxide now and will return to the interaction between the water in the air and the carbon dioxide at the end of the lesson. If students ask about the liquid phase of carbon dioxide or attempt to show liquid carbon dioxide in their drawings, use that as an opportunity to question them about when or where they saw liquid carbon dioxide, but postpone extended discussion until after students have had a chance to study the phase diagram of carbon dioxide.

You can also ask students to think-pair-share with a partner to discuss their thoughts about the following part of question 2:

- What's similar about the process shown in circles 1 and 2 versus that shown in 3 and 4? What's different?

- Next, tell students you are going to put a small sample of dry ice in a sandwich bag, remove the air, and seal it. Ask students to predict what they think will happen, based on what they have observed about carbon dioxide so far. Ask for a few volunteers to share their predictions.
- After students have shared predictions, in a location where everyone can see you, perform the demonstration: place a small sample of dry ice in a sandwich bag, squeeze the air out, and seal the bag. The bag should begin to fill with gas.

  Ask students to explain this process at the particle level and use drawings to support their argument; this is in response to question 3 on the handout. As you circulate while students work on their drawings, you can use the following questions to prompt individuals who may be struggling:

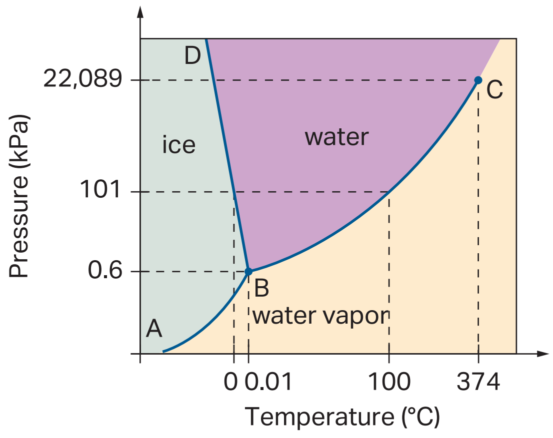
  - What causes a balloon to expand when you blow it up with air?
  - What are you putting in a balloon when you blow it up?
  - Where does the "stuff" that causes the bag to expand come from?
  - What happens to the particles of carbon dioxide that leads to them filling the bag?

PART 2: INTERPRETING PHASE DIAGRAMS OF WATER AND CARBON DIOXIDE

In this part of the lesson, students are introduced to phase diagrams for water and carbon dioxide. They are asked to use the phase diagrams to predict phase transitions and to support the observations they made in Part 1 of the lesson.

- To introduce students to phase diagrams, show students a phase diagram such as the one on the next page. Give students time to just observe the phase diagram before asking them to analyze it. If your students are not familiar with kPa as a pressure unit, take this opportunity to explain that pressure is measured in a variety of units and that atmospheric pressure at sea level is 101 kPa.

PHASE DIAGRAM OF WATER



Support students in analyzing the graph by asking the following questions:

- What do you observe about the graph?

  Listen for students to point out the axis labels and the indications of the states of matter in different regions. Students may also notice that the axes are not scaled in a traditional way.

- What do you think the purpose of this graph is?

  To show the state the state of matter for water at various temperatures and pressures.

- Identify the phase of water at −10°C and 0.6 kPa.

  solid

- Identify the phase of water at 120°C and 10.0 kPa.

  gas

- What do you think happens along the line between B and D?

  The line B to D represents the transitions between solid and liquid, or melting and freezing.

- What do think happens along the line between B and C?

  The line B to C represents the transitions between liquid and gas, or boiling and condensation.

- What happens to solid water if you increase the temperature at low pressures?

  The solid transitions directly to a gas, in a process called sublimation.

- Now is a good time to introduce the various terms for phase changes. Depending on how you are displaying the phase diagram to the class, consider asking students to draw arrows on it or to suggest where they would draw them to represent the various transitions. (The definitions of triple point and critical point are not used in this course and so do not need to be included in your instruction.)
- Next, let students apply what they've learned so far about phase diagrams. Ask them to work with a partner to analyze the phase diagrams on **Handout 1.6.B: Phase Diagrams of Water and Carbon Dioxide** and to answer the accompanying questions.
    - As you circulate around the room during this time, encourage students to mark up their phase diagrams using arrows for the various transitions in order to better visualize the transformations that occur. Check their progress in answering the questions to be sure they are interpreting the phase diagrams correctly.
    - When students get to question 4, you will most likely need to help them with the term *sublimation* if you haven't already introduced it. Have students refer back to their observations of the dry ice on the table to help them visualize the process.
    - The last question (question 6) is an opportunity to connect phase transitions to the strengths of intermolecular interactions. The goal here is to use the observation that water melts and boils at higher temperatures to infer the relative strength of the interactions. Connecting this to the nature of the interactions (i.e., hydrogen bonding versus London dispersion forces) will not be covered until Unit 2 of the course.

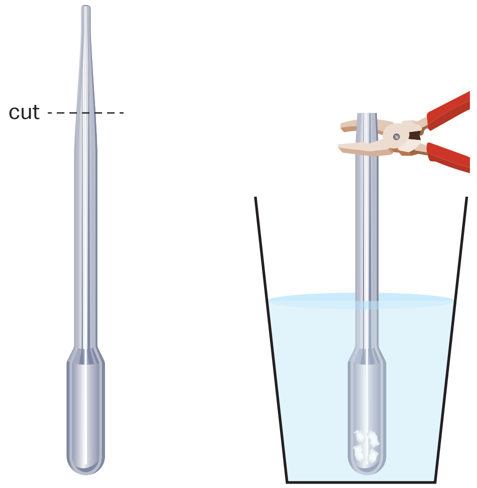
PART 3: BOILING AND SUBLIMING DRY ICE

In this part of the lesson, students apply their understanding of phase diagrams from Part 2 to analyze a demonstration of an infrequently observed phenomenon: the melting of dry ice. After examining the phase diagram and demonstrations earlier in the lesson, students most likely have some ideas about why we call dry ice "dry." This demonstration gives students a chance to see liquid carbon dioxide and use their interpretation of the phase diagram to explain the phenomenon. Students also consider how water and carbon dioxide interact to make the cloud or "smoke" that is seen above carbon dioxide as it sublimes.

- Follow the steps below to demonstrate the melting of carbon dioxide. The picture may help you visualize the procedure. You may need to repeat the procedure several times for students to be able to see the liquid.

UNIT 1

1. Cut the tip off a wide-bore plastic transfer pipette.
2. Fill a plastic cup with tap water.
3. Use a mortar and pestle to grind some of the dry ice into small pieces or a powder.
4. Slide a small amount of the ground dry ice (or several small pieces) down through the stem of the pipette into the bulb.
5. Using pliers, clamp the tip of the pipette closed and lower the pipette until the bulb is submerged in the water.



6. As the solid sublimes and the pressure inside the pipette increases, the dry ice will begin to melt. It is a clear, colorless liquid.
7. As soon as you detect liquid, release the pliers and the solid CO_2 should re-form.

   Notes:

   - If you do not see liquid, you may have to fold over the pipette before clamping it with pliers to prevent gas from escaping.
   - If you put too little dry ice in the pipette, the pressure will not increase sufficiently to melt the CO_2.
   - If you put too much dry ice in the pipette, you will very likely cause the pipette to explode. A plastic cup rather than a glass beaker should be used to hold the water because of this possibility.

Classroom Ideas

If you don't have a good way for all students to be able to observe the demonstration, you can show part of the video "The Behavior of Atoms—Phases of Matter and the Properties of Gases," at **https://www.learner.org/series/chemistry-challenges-and-solutions/the-behavior-of-atoms-phases-of-matter-and-the-properties-of-gases/**. A similar demonstration takes place from 6 minutes to a little past 8 minutes.

- Have students use their observations of this demonstration to complete **Handout 1.6.C: Boiling and Subliming Dry Ice**. Some suggestions for supporting students as you are circulating around the room are as follows:
  - For question 1, parts (a) and (b), make sure that students observed that the dry ice became liquid when the pipette was sealed and went back to solid when the seal was removed. Part (c) of question 1 asks students to use the phase diagram of carbon dioxide to explain these observations.

- Remind students of the question on the previous handout in which they considered the pressure required for dry ice at room temperature to melt. Also make sure students realize that the pressure in the pipette increased when it was sealed. To guide students to this realization, you may want to ask why it was important to use pliers to seal the pipette. It may also be useful to draw analogies to the dry ice bag in Part 1. You can ask what would happen if you put a large amount of dry ice in a bag; help students conclude that it could burst from the pressure generated by carbon dioxide gas.
- Question 2 returns to the question we asked at the beginning of class: What makes the "smoke" produced by dry ice? Students are now ready to answer this question based on what they have learned and observed in this lesson.

  When students get to this question, you might want to ask them to discuss with a neighbor. Encourage them to use the phase diagrams of both water and carbon dioxide to explain the phenomenon. Once students have had a chance to discuss with a neighbor, they can go ahead and write their explanation and draw particle diagrams that support their explanation.

- After students have had a chance to craft their response to question 2, lead a whole-class discussion about it. During the discussion, try to elicit the following information from students:
  - Carbon dioxide gas is clear and colorless. Otherwise, we would see it in the air around us all the time.
  - Dry ice sublimes at −78.5°C, and this means the vapor produced is initially at −78.5°C.
  - The carbon dioxide vapor is cold enough to freeze the water vapor that is in the air.
  - This leads to very small ice crystals which appear as the white cloud.
- Following the classroom discussion, have students revise their written explanation and particulate drawings as needed. As you circulate the room, look for the following:
  - Ensure that students' written explanations are consistent with the points listed above.
  - The particulate drawing of the solid dry ice should show carbon dioxide particles packed closely together.
  - The particulate drawing of the region above the dry ice should show carbon dioxide particles that are spread out and well separated, along with small, closely packed clusters of water particles.

ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

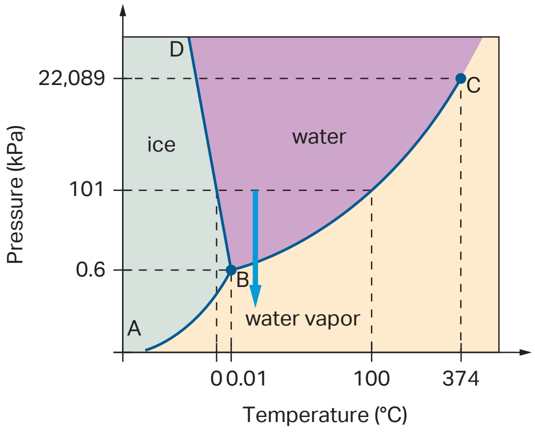
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 1.6.A: Water and Dry Ice

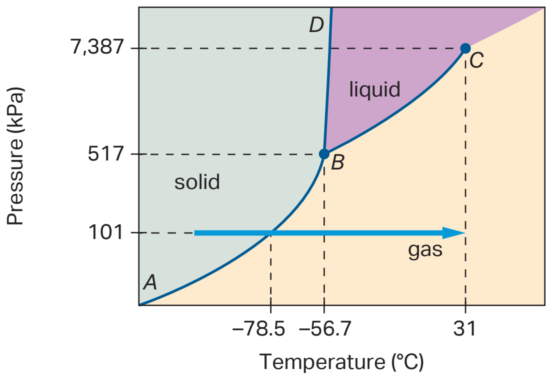
1. Student answers should provide accurate particulate representations of all three phrases of matter for water: the ice, the water, and the water vapor in the air.
2. The diagram and student response should indicate that the water particles went from the liquid phase (circle 1) to the gas phase (circle 2), and that the carbon dioxide particles went from the solid phase (circle 4) to the gas phase (circle 3).
3. The bag expanded over time. The solid carbon dioxide in the bag turned into a gas and filled the bag. The number of carbon dioxide particles remained the same.

Handout 1.6.B: Phase Diagrams of Water and Carbon Dioxide

1. (a) Water is a liquid under these conditions, and carbon dioxide is a gas.
   (b) Yes. In a room at a comfortable temperature, water is a liquid and carbon dioxide is a gas.
2. (a) 0°C
   (b) 100°C
   (c) i. Water will freeze at a higher temperature than standard conditions.
   ii. Water will boil at a lower temperature than standard conditions.
3. Sample response: The water would boil. I drew an arrow on the phase diagram to show the path corresponding to a decrease in pressure at 25°C. The water will boil when the pressure crosses the line separating the liquid and gas phase.



4. (a) Sample response: The carbon dioxide goes directly from the solid to the gas phase, through a process known as sublimation. Gaseous carbon dioxide filled the bag. I drew an arrow on the phase diagram to show the path corresponding to warming solid carbon dioxide at the pressure in the room (101 kPa).



(b) The pressure would have to be greater than 517 kPa, five times greater than atmospheric pressure.

5. At room temperature and pressure, it turns directly from a solid to a gas, with no liquid, so it's "dry."

6. Because carbon dioxide becomes a gas at a temperature far below the boiling point of water, the attractions among carbon dioxide particles must be weaker than those among water particles.

Handout 1.6.C: Boiling and Subliming Dry Ice

1. (a) The dry ice appears to become a liquid.

   (b) The dry ice goes back to being a solid.

   (c) When the pipette is sealed, the pressure and temperature are such that the carbon dioxide sublimes, creating a gas. The gas causes the pressure in the pipette to increase. According to the phase diagram, the solid carbon dioxide will melt instead of sublime at high pressure. Since the carbon dioxide melted, the pressure inside the pipette must have been at least 517 kPa. When the pipette is unsealed, the pressure drops and the carbon dioxide goes back to being solid.

2. (a) As the dry ice sublimes, it produces carbon dioxide vapor, which is clear. However, the carbon dioxide vapor is very cold (−78.5°C), which causes water vapor in the air to freeze and become ice. The ice particles are so small they appear as smoke.

   (b) The particulate drawing of the region above the dry ice should show carbon dioxide particles that are spread out and well separated, along with small, closely packed clusters of water particles.

UNIT 1

LESSON 1.7

Investigating Heating Curves

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Heating Curves
Students examine a heating curve for an unknown substance and then compare and contrast heating curves and phase diagrams.

Part 2: Heat of Fusion of Ice Lab
Students read a short passage about how the energy transferred as water freezes can be used to protect orange groves from freezing temperatures, and then experimentally determine the heat of fusion of ice.

Part 3: Heat of Vaporization of Water Demonstration
Students determine the amount of energy gained by one sample of water as another sample is vaporized. Students then use this information to calculate the heat of vaporization of water.

CONTENT FOCUS

This lesson introduces students to heating curves. Students are asked to use their knowledge of phase diagrams to sketch heating curves for various substances, including carbon dioxide. They also examine energy changes that can be deduced from heating curves. Students use knowledge gained in previous lessons to determine energy changes when the temperature of a substance changes.

To connect energy and phase changes to the real world, students read a short passage that describes how the energy transfer during phase changes of water can be used to protect crops. Students then experimentally

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~135 minutes

HANDOUTS

- 1.7.A: Heating Curves
- 1.7.B: How Do You Heat an Orange Grove?
- 1.7.C: Heat of Fusion Lab and Heat of Vaporization Demonstration

MATERIALS

For each group:

- goggles
- plastic foam cups
- water
- thermometer
- ice
- stirring rod
- slotted spoon

Additional materials for demonstration:

- distilled water
- beakers
- hot plate
- goggles

determine the heat of fusion and heat of vaporization of water and connect those values back to the heating curve for water.

This lesson guides students to start thinking about why different substances have different values for heat of fusion and heat of vaporization as an introduction to intermolecular forces, which they will explore in more depth in Unit 2.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SAFETY NOTES

All general safety guidelines should be followed. Students should wear goggles.

PART 1: INTRODUCTION TO HEATING CURVES

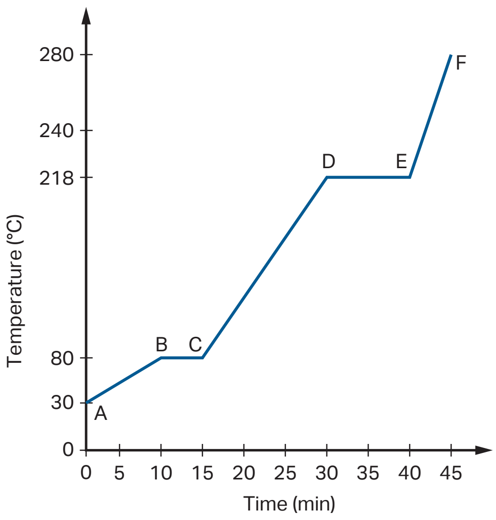
Students examine a heating curve for an unknown substance and then compare and contrast heating curves and phase diagrams.

- Direct students' attention to the short scenario, table, and graph at the top of **Handout 1.7.A: Heating Curves**. These pertain to a student heating an unknown substance and collecting and graphing the data.

A student heats 100 g of an unknown solid substance at 1.0 atm (101 kPa). Every minute, they record the temperature of the substance and their observations. The student then summarizes the data in a table and a graph, shown below.

Time (min)	Observations
0–10	The substance remains a solid and temperature increases approximately 5 degrees per minute.
11–15	The solid slowly becomes a liquid and the temperature remains the same.
16–30	The substance remains a liquid and temperature increases approximately 10 degrees per minute.
31–40	The liquid slowly becomes a gas and the temperature remains the same.
41–45	The substance remains a gas and temperature increases approximately 15 degrees per minute.

HEATING CURVE OF AN UNKNOWN SUBSTANCE



Handout 1.7.A

Give students time to review the information and ask them specifically what they notice about the graph. You can orient students to the graph by letting them know it's an example of a kind of graph called a heating curve, but you don't need to explain what a heating curve is yet.

- Ask a few students to share what they observed about the graph. Listen for responses such as comments about the axis labels and the observation that the temperature changes during some intervals on the graph and not during others.

Building on the discussion of these shared observations, guide students to develop a description of the purpose of a heating curve. A possible description is that a heating curve shows how the temperature of a substance changes over time as heat is added (or removed, for a cooling curve).

- To have students start thinking about the energy changes represented in this heating curve, support them in making connections back to the lab on specific heat capacity in Lesson 1.5. You can use questions such as the following to guide the discussion:
    - In the specific heat capacity lab, how did you determine the amount of energy gained by the room temperature water from the hot metal?

      We calculated it based on the specific heat capacity of water, the temperature change of the water, and the mass of the water. We used $q = mc\Delta T$.
    - How do you think you could determine the energy change between C and D on the heating curve?

      By using the mass of the substance that was heated, the specific heat capacity of the substance, and the change in temperature.
    - Could you use the same process to determine the energy change between B and C on the heating curve?

      No, because there is no temperature change. Using $q = mc\Delta T$ would lead to an energy change of zero.
    - Do you think the energy change from B to C is actually zero?

      No. The substance was still being heated, so it gained energy.
    - What is happening to the substance from B to C? How do you know?

      It is melting. The observations in the table indicate that it changes from a solid to a liquid.
    - Where do you think the energy that is added between 11 and 15 minutes goes?

      It goes to overcoming the attraction between particles, separating them, as they move from being a solid to being a liquid.
- When students are comfortable reading the heating curve, ask them to work with a partner to answer questions 1–8 on their handout. These questions are designed to give students practice interpreting heating curves.

Meeting Learners' Needs

If students need a little more help drawing conclusions about the purposes of a heating curve, show them some heating curves for other substances. They can note the similarities between them and identify the common elements they share.

UNIT 1

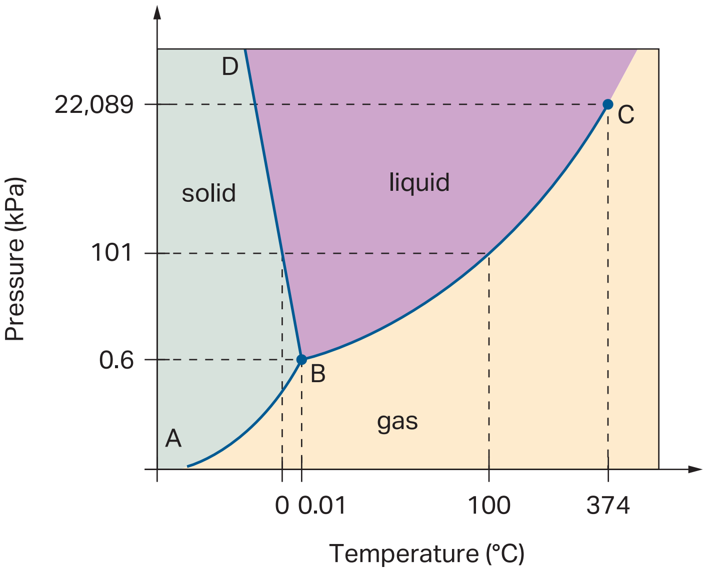
- You can use the following questions to guide student thinking as they work:
  - If the unknown sample is at its coldest temperature, will the particles be close together or far apart?

    Close together.
  - If kinetic energy is responsible for the motion of the particles, what can you do to make the particles move faster?

    Increase the temperature (temperature measures the average kinetic energy of the system).
  - Will the kinetic and potential energy both change at the same time on the graph at any line segment? When do they each change?

    No, kinetic energy increases when temperature increases, and potential energy changes when the phase changes.
  - If the substance is a gas, are the particles arranged in a pattern?

    No, solids are patterned, and gases are spread out.
- Once students have successfully completed the first section of the handout, bring them back together as a whole group. Now, to help students make connections between phase diagrams and heating curves, show students an unlabeled phase diagram that does **not** correspond to the unknown substance in the handout (which happens to be napthalene). You can use the phase diagram for water, with the identifying labels removed, as shown below.



- Lead a class discussion about the relationship between this phase diagram and the heating curve for the unknown substance on the handout. Use questions such as the following to guide the discussion:
  - Do you think this could be the phase diagram for the unknown substance (the one represented in the heating curve)? Why or why not?

    No. At 101 kPa, there is not a phase change at either 80°C or 218°C. (After this discussion, if you like, you can let students know the identity of the unknown substance: naphthalene.)
  - How are the phase diagram and heating curve different?

    The axes for a phase diagram are pressure and temperature, whereas the axes for the heating curve are temperature and time. The heating curve is only valid at a given pressure while the phase diagram shows what state of matter a substance will be in at different temperatures and pressures. Heating curves show how a system changes over time as energy is transferred into the system. Phase diagrams do not give the same kind of insight about energy changes.
  - How are the phase diagram and heating curve similar?

    You can figure out the state of matter for a substance from both.
  - A heating curve shows only one boiling temperature whereas the phase diagram shows a variety of temperatures where there is a transition between liquid and vapor. Why do you think that is?

    The boiling point depends on the external pressure. The heating curve is only valid for a given pressure. If you drew the heating curve for a substance at a pressure other than atmospheric pressure, the boiling point would be at a different temperature.
  - Some packaged foods, such as cake mixes, have high altitude cooking directions. Why do you think that is?

    At higher altitudes, the atmospheric pressure is less and water boils at a lower temperature. This lower boiling temperature means it takes longer for food to cook.

In the next portion of this lesson, students will work in pairs and groups to develop responses to questions 9 through 11 on the handout. The handout guides students through the following general procedure for each question:

1. Students first work with a partner to sketch a heating curve based on a phase diagram.
2. Each student pair forms a peer-critique group with another pair. Each pair explains the decisions they made in sketching their heating curve.

3. After students have discussed and compared their heating curves, they can make revisions as needed to their sketches. Students will also record what revisions they made and why they made them.

You may want to review these steps with students before they begin working.

Instructional Rationale

The structure of working first with a partner and then getting feedback allows students time to process their thoughts. The conversation with another group allows students to see other approaches and consider things they may not have initially. Also, the process of peer critique and revision mirrors the processes that scientists use to develop ideas.

- Direct students to work in pairs and groups as instructed to complete question 9, which asks students to sketch what they think the heating curve for water at standard pressure (101 kPa) will look like. Encourage students to use the phase diagram of water as they work.
- Next, let students see how accurate their predicted graphs were by comparing them with real data. A great way to do this is by showing a time-lapse video of the melting and boiling of water, with the accompanying heating curve. You can find teacher-created videos like this on video-sharing sites such as YouTube.

  After the video, ask students to discuss the following questions with their peer-critique group from earlier.
  - What parts of the graph did you correctly predict?
  - What parts were different and surprised you?

Meeting Learners' Needs

If you think your students would benefit from practicing their lab skills, you can have them collect and graph the data rather than watching the video.

After groups have had time to discuss, ask a few groups to share their responses.

Guiding Student Thinking

Some videos found online may have rough data as the ice begins to melt. If students remark on this, use the opportunity to show the video again, this time asking students to carefully observe the placement of the temperature probe and how the ice melts. You could use this opportunity to have them brainstorm how this demonstration could be improved in order to have data that is more linear as the water heats up.

- Now that students have developed a heating curve for a substance they are familiar with, they will extend their thinking by drawing the heating curves for carbon dioxide at two different pressures (101 kPa and 7,387 kPa). Direct students to complete question 10 on the handout. You may want to remind students again of the procedure to follow for working in pairs and then groups.
- As students work, circulate around the room to make sure they are using the phase diagram appropriately and determining what the phase changes are at each pressure indicated.
- After students have had a chance to revise their heating curves, lead a whole class discussion about the differences in the two heating curves.
  - How are the phase diagrams for carbon dioxide different at 101 kPa and 7,387 kPa?

    At 101 kPa, there is only one phase change (sublimation). At 7,387 kPa, there are two phase changes (melting and boiling).
  - What would you observe if you heated solid carbon dioxide from a very low temperature at 101 kPa?

    It would turn from a solid directly to a vapor, which is what we saw in a previous demonstration when a piece of dry ice was placed on the desk.
  - What would you observe if you heated solid carbon dioxide from a very low temperature at 7,387 kPa?

    It would turn from a solid to a liquid, and then eventually to a gas. This is similar to what we saw with the dry ice in the closed pipette in a previous demonstration.
  - What happens to the average speed of the particles during a phase change?

    Since the temperature is constant, the kinetic energy isn't changing, so the speed of the particles isn't changing.
- Explain to students that cooling curves are also useful and ask them to predict what a cooling curve is. Once the class has reached consensus on what a cooling curve is, direct them to work on question 11, which involves sketching the cooling curve for water as it condenses from a gas to a liquid and then freezes. Students are also asked to label the phase of matter for each phase change and to label the temperature at which each phase change occurs.

Guiding Student Thinking

Students sometimes do not realize that freezing occurs at the same temperature as melting and that condensing occurs at the same temperature as boiling. Probe for this understanding as students are creating their cooling curves.

PART 2: HEAT OF FUSION OF ICE LAB

In this part of the lesson, students read a short passage about how the energy transferred as water freezes can be used to protect orange groves from freezing temperatures. Students then experimentally determine the heat of fusion of ice.

- To connect the heat of fusion of ice to the real world, ask students to read the *Orlando Sentinel* article in **Handout 1.7.B: How Do You Heat an Orange Grove?** This is a relatively short text written in a casual style. Depending on your students' needs, you may want to preview some of the vocabulary words together before they start reading. Encourage students to use reading strategies such as marking the text as they read.
- After students have read the passage, ask them to complete the three sentences on their handout to summarize what they learned during their reading. Call on a few students to share their sentences with the whole class as a way to debrief the reading. The sentence starters and sample responses are provided below for reference.

1. Farmers spray their orange trees with water during a freeze because

   Sample response: as water freezes, it releases heat.

2. Farmers spray their orange trees with water during a freeze, but

   Sample response: this solution generally only works for air temperatures above −8 degrees Celsius.

3. Farmers spray their oranges with water during a freeze so

   Sample response: the heat released by the freezing water will keep the trees warm.

Handout 1.7.B

- Next, students will collect data to experimentally determine the heat of fusion of ice. Explain to students that the purpose of the lab is to determine the energy needed to melt ice, or the heat of fusion (ΔH_{fus}). Tell students that we will measure this value in joules/gram. You can also explain that this value involves the opposite of the process they read about in the passage about orange groves, with the ice melting instead of freezing.

- Before students start on the lab, it might be helpful to lead a discussion about calculations they will need to do. The following questions can be used to guide the discussion.
  - What is the equation we used to determine the specific heat capacity of a metal?
    $q = mc\Delta T$
  - If you cooled 85.0 g of water from 55.0°C to 2.0°C, what amount of heat would be lost? The specific heat capacity of water is 4.18 J/(g • °C).
    $q = mc\Delta T$
    $q = (85.0\ \text{g})\left(4.18\dfrac{\text{J}}{\text{g}\bullet{}^\circ\text{C}}\right)(2.0^\circ\text{C} - 55.0^\circ\text{C})$
    $q = -18{,}800\ \text{J}$
  - What does the negative indicate on the previous answer?
    It indicates that energy was transferred from the water to the surroundings.
  - A cup of warm water weighs 100.0 g. You add some ice to it and after the ice melts in the cup, the cup of water weighs 143.0 g. What mass of ice melted?
    $143.0\ \text{g} - 100.0\ \text{g} = 43.0\ \text{g}$
  - If a student determined that it took 19,750 J of energy to melt the ice, what is the student's experimental value for the heat of fusion of ice in joules/gram?
    $\Delta H_{\text{fus}} = \dfrac{19{,}750\ \text{J}}{43.0\ \text{g}} = 459\ \text{J/g}$
- Allow students to begin working on the lab described in the first part of **Handout 1.7.C: Heat of Fusion Lab and Heat of Vaporization Demonstration**. During the lab, students will add ice to warm water in nested foam cups and wait for some of the ice to melt. They will then use the mass of the water, the temperature change of the water, and the mass of ice that melted to determine the heat of fusion of ice.

  As students are working, circulate to monitor their progress and probe for understanding. When students remove the ice from water, make sure they are not also removing a significant amount of water from the cup.
- After students complete the Analysis section for the lab, you may want to lead a whole-class debrief of the lab, which could include a discussion of the percent error and what the significance of their error is. You can use questions such as the following the guide the discussion:
  - What assumptions did we make about energy transfer during the lab?
  - What are the problems with those assumptions?

- Why is temperature constant during a phase change?
- Where does the "sweat" on a cold glass come from? How is this similar to the "cloud" that you saw when dry ice sublimed on the table?
- Why do farmers sometimes spray their orange groves with water?
- Another student did the lab with the same procedure that you did but stopped adding ice when their water cooled down to only 15°C, instead of adding more ice until the water reached a temperature close to 0°C. Would this procedure change have made the final calculated ΔH_{fus} larger or smaller in magnitude, or resulted in no change? Justify your response.

PART 3: HEAT OF VAPORIZATION OF WATER DEMONSTRATION

In the last part of the lesson, students determine the amount of energy gained by one sample of water as another sample is vaporized. Students then use this information to calculate the heat of vaporization of water.

- Before the demonstration, introduce the concept of heat of vaporization. You can do this by asking students to state what they think it is, based on what they learned in the previous part of the lesson about heat of fusion and their understanding of phase changes. As needed, support students in arriving at an accurate description of heat of vaporization.
- Direct students' attention to the second half of their handout, which supports this demonstration. Then perform the demonstration for the class using the following steps:
  1. Add 5 mL of distilled water to one beaker and 100 mL of distilled water to another beaker. Place both beakers on a hot plate.
  2. Turn the hot plate to a medium setting and begin heating.
  3. When the 5 mL of water just starts to boil, measure and record the initial temperature of the 100 mL of water. Students should record this value in their data table.
  4. When the 5 mL of water has completely vaporized, measure and record the final temperature of the 100 mL of water. Students should record this value in their data table.
- Explain to students that in this demonstration we assume that both beakers are identical and that the hot plate distributes heat evenly to both beakers. Therefore, we know that the heat energy gained by both beakers is identical. From this, guide students to the conclusion that we can use the temperature change of the 100 mL sample of water to calculate the heat energy absorbed by both samples of water.
- Ask students to work with a partner to complete the Analysis section for the handout. As they work, circulate to monitor their progress. You may need to ensure that students

understand that the energy change for both samples was the same, but that in the 5 mL sample, the energy went to vaporizing the water instead of simply heating it up.

- To close this lesson, bring the class together and show them the following data table.

	Heat of Vaporization	Heat of Fusion
Water	2,260 J/g	334 J/g
Carbon dioxide	364 J/g	205 J/g
Propane	558 J/g	80 J/g

Meeting Learners' Needs

If you find that some students are struggling with the calculations, you might want to remind them that the density of water is 1 g/mL, and they can easily convert the volume of water to the mass of water to use the specific heat equation in determining the energy absorbed by the water.

- Ask students to identify trends in the data and give possible explanations. Questions such as the following might be useful:
  - What patterns do you notice?

    For all three substances, the heat of vaporization is larger.
  - Why do you think water has a much higher value for heat of vaporization than carbon dioxide or propane?

    There must be something about water that causes it to require more energy to separate into a gas when compared to both carbon dioxide and propane. Something may hold water particles together more strongly than the other two substances.
  - Why do you think the heat of vaporization is greater than the heat of fusion for all three substances?

    It takes more energy to separate particles from a liquid to a gas than it does from a solid to a liquid because particles are being moved even farther apart so their attractions need to broken even more.

Instructional Rationale

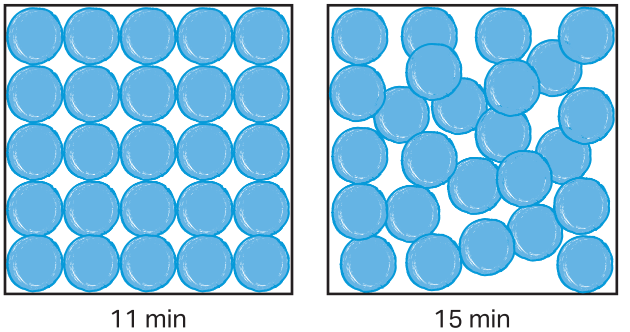
Students will study intermolecular forces in more depth in Unit 2. The purpose of these questions is to get students to start thinking about "stickiness" between particles. Focus your questions on which substances are more "sticky" or held together more strongly than others. You can return to the experiences and data from this lesson to spark a discussion about intermolecular forces in Unit 2.

ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

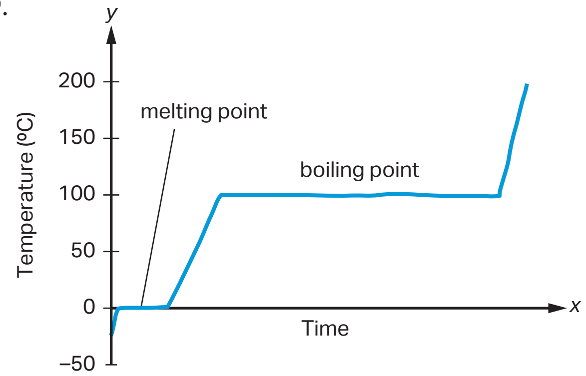
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 1.7.A: Heating Curves

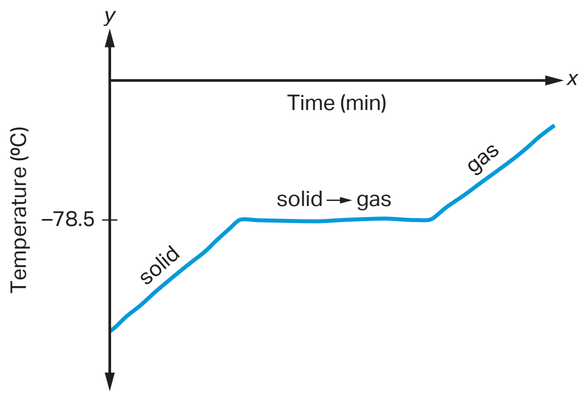
1. A to B: solid, B to C: solid and liquid, C to D: liquid, D to E: liquid and gas, E to F: gas
2. (a) Kinetic energy increases.
   (b) Kinetic energy remains the same.
   (c) Kinetic energy increases.
   (d) Kinetic energy remains the same.
   (e) Kinetic energy increases.
3. (a) Potential energy remains the same.
   (b) Potential energy increases.
   (c) Potential energy remains the same.
   (d) Potential energy increases.
   (e) Potential energy remains the same.
4. (a) 80°C
   (b) 218°C
5. The forces of attraction among particles decrease in strength.
6. The energy that is added goes to overcoming the attractive forces between the particles to separate them as they become either a liquid or a vapor.
7. It takes more energy to separate the particles as they transition from liquid to gas than it does to separate them when the transition is from solid to liquid.
8. 

11 min 15 min

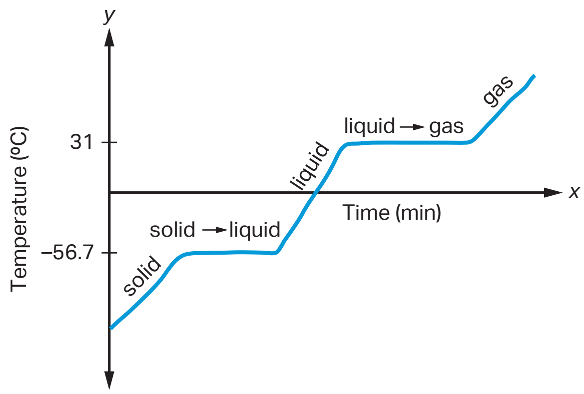
9.



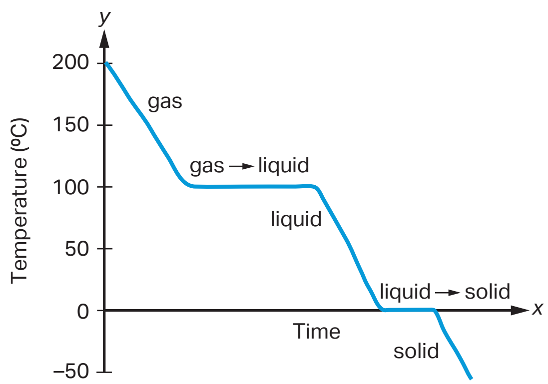
10. 101 kPa



7,387 kPa



11.



Handout 1.7.B: How Do You Heat an Orange Grove?

Sample responses are provided in the lesson.

Handout 1.7.C: Heat of Fusion Lab and Heat of Vaporization Demonstration

Heat of Fusion Data

Student answers will vary. Sample data are provided below for reference.

Mass of nested foam cups	25.0 g
Mass of nested foam cups and water	105.0 g
Mass of warm water	80.0 g
Starting temperature of warm water	24.0°C
Final temperature of melted ice and water mixture	0.0°C
Final mass of nested cups, water, and melted ice	129.0 g

Heat of Fusion Analysis

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

1. $0°C - 24.0°C = -24.0°C$
2. $q = mc\Delta T$

   $q = (80.0\text{ g})\left(4.18\frac{\text{J}}{\text{g}\bullet°\text{C}}\right)(-24.0°\text{C})$

   $q = -8{,}030\text{ J}$
3. Not all of the energy that the warm water lost went to melting the ice. Some of it went to the surroundings.
4. $129.0\text{ g} - 105.0\text{ g} = 24.0\text{ g}$
5. $\Delta H_{\text{fus}} = \frac{8{,}030\text{ J}}{24.0\text{ g}} = 335\text{ J/g}$
6. $\text{percent error} = \frac{|334\text{ J/g} - 335\text{ J/g}|}{334\text{ J/g}} \times 100$

   $\text{percent error} = 0.299\%$

7. The energy to melt the ice is lost by the drink, causing the drink and glass to become cooler. The cooler glass "sweats" due to water particles in the air slowing down and condensing on the surface of the glass.
8. It should not affect the results since the change in temperature would be reduced. The heat lost calculated would be lower as well. The mass of the melted ice would be less. The smaller heat loss divided by the smaller mass will be proportionate to the heat of fusion.

Heat of Vaporization Data

Student answers will vary. Sample data are provided below for reference.

Initial temperature of the 100 mL water sample (when the 5 mL sample started to boil)	25.0°C
Final temperature of the 100 mL water sample (when the 5 mL sample was completely vaporized)	54.0°C

Heat of Vaporization Analysis

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

1. $q = mc\Delta T$

   $$q = (100.0\text{ g})\left(4.18\frac{\text{J}}{\text{g}\bullet{}^\circ\text{C}}\right)(54.0^\circ\text{C} - 25.0^\circ\text{C})$$

   $q = 12{,}100\text{ J}$

2. $q = 12{,}100\text{ J}$

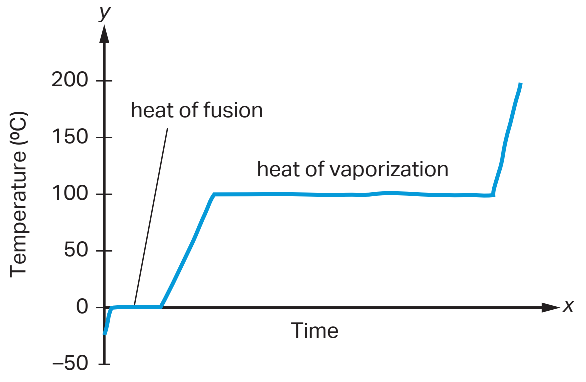
3. $$\Delta H_{vap} = \frac{12{,}100\text{ J}}{5.0\text{ g}} = 2{,}400\text{ J/g}$$

4. $$\text{percent error} = \frac{|2{,}260\text{ J/g} - 2{,}400\text{ J/g}|}{2{,}260\text{ J/g}} \times 100$$

   percent error = 6.2%

5. Sample response: The heat of vaporization of water is almost seven times more than the heat of fusion of water. It must take much more energy to separate the particles to create a gas than it does to create a liquid.

6.



7. The value of the heat of vaporization of water is higher. Water has an increased "stickiness" that causes it to require more energy to separate into a gas when compared to carbon dioxide.

8. Sample response: The heat of vaporization is always greater than the heat of fusion. I think that is probably true for most substances because it takes more energy to separate the particles in order for a substance to turn from a liquid to a gas than for changing from a solid to a liquid.

LESSON 1.8

Launch Lesson – Introduction to Properties of Gases

OVERVIEW

LESSON DESCRIPTION

Part 1: Cupping – Harmless Fad or Sound Science?
Students learn about the concept of pressure through a reading on cupping, a form of traditional medicine, from *ChemMatters*.

Part 2: There's No Such Thing as Suction
Students form small groups and observe changes in pressure by making a hard-boiled egg drop into a glass bottle.

CONTENT FOCUS

This lesson is intended to lead students into several days of investigation of gas properties including temperature, volume, and pressure. Students begin to build their understanding of pressure and how it relates to other observable properties of gases through a reading and investigation. The purpose of this lesson is to help students build a conceptual understanding of gas variables before studying those variables quantitatively in future lessons.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 1.8.A: Cupping – Harmless Fad or Sound Science?
- 1.8.B: There's No Such Thing as Suction

MATERIALS

For each group:

- glass bottles with wide mouths (500 mL Erlenmeyer flasks, glass milk bottles)
- hard-boiled eggs
- matches or a lighter
- strips of paper
- effervescent antacid tablets (optional)
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Observable properties of gases can be measured experimentally and explained using an understanding of particle motion.	
Learning Objectives	**Essential Knowledge**
1.3.A.1 Create and/or evaluate models that illustrate how a gas exerts pressure.	**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.

SETUP AND PREPARATION NOTES

- Check for egg allergies as you are planning this lesson so you can make appropriate modifications if needed.
- You will need a lot of hard-boiled eggs so students can try multiple times. You could ask for donations of bottles or have each student group be responsible for bringing four hard-boiled eggs and two glass bottles.
- You can also use water balloons instead of boiled eggs. You will need to experiment with the size of the balloon so it will fit into the bottles you use.
- Depending on the size of your eggs and the bottle opening, you may find it helpful to grease the mouth of the bottle with a little vegetable oil to help the egg slide in.
- Anything that increases the pressure inside the bottle should work to get the egg out so you can reuse bottles (see the Extending the Lesson box at the end of this lesson for several methods that you can use). The egg can also be removed by using something sharp (such as a butter knife) to break it into pieces so it can be dumped out.
- The investigation could also be done as a demo if gathering materials presents a challenge.

SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear goggles.
- Make appropriate modifications if you have students who are allergic to eggs.

PART 1: CUPPING – HARMLESS FAD OR SOUND SCIENCE?

Students learn about the concept of pressure through a reading on cupping, a form of traditional medicine, from *ChemMatters*.

- Since students may not be familiar with cupping, you may want to begin the lesson by showing a video of the use of cupping by athletes, which can be found on video-sharing sites such as YouTube.
- After students watch the video and begin to read **Handout 1.8.A: Cupping – Harmless Fad or Sound Science?**, you might want to make use of metacognitive markers to aid them in active reading. You could have students underline any content they feel is important, put an asterisk next to content they feel is review or something they already know, and use a question mark for any content they still don't understand.
- As students finish reading, have them form groups of four and discuss what they just read. You could have them identify one phrase for each metacognitive marker, or assign one person in the group a section to summarize if the discussion does not begin naturally.

  Some important aspects of the article that students should pick up on during the discussion include:

  - Air, a mixture of gases, exists inside the cup.
  - Heating the air in the cup increases the pressure.
  - Pressure comes from collisions of the air particles with each other and the cup.
  - When the heat source is removed and the cup is placed on the skin, the particles cool down, lowering the pressure.
  - The skin gets drawn into the cup as pressure decreases.
- If the discussion is slow, you can prompt students with these questions:
  - What is inside the cup?
  - What does holding the flame near the cup do?
  - What is pressure?

Meeting Learners' Needs

If students are having difficulty, you could demonstrate reading the first few paragraphs together as a class using metacognitive markers. Another option could be to break into groups before reading and assign a section to each group member to read aloud.

PART 2: THERE'S NO SUCH THING AS SUCTION

In this part of the lesson, students demonstrate how pressure changes occur using the egg-in-a-bottle investigation. This involves lighting a strip of paper on fire and dropping it into a glass bottle. A hard-boiled egg is then placed in the mouth of the bottle, and as the flame goes out the egg will drop into the bottle. After this demonstration and the reading from Part 1, students should have a basic understanding of how pressure changes and what results from those changes, so that they can construct an explanation of how the egg "fell" into the bottle.

- Have students work in pairs on **Handout 1.8.B: There's No Such Thing as Suction**. Circulate around the room and provide guidance if needed as students work.
- Once students have completed the handout, use think-pair-share to allow them to construct ideas, then revise the ideas as they talk with peers. Give them a couple of minutes to construct their explanation of why the egg fell into the bottle, and then another few minutes to share with a partner. Finally, have each pair of students join another pair and give the groups about 5 minutes to finalize their explanations.

Classroom Ideas

You could have students turn in summaries of their explanations by group, or have them present on large whiteboards to the class.

- Ask for a few groups to share their explanations. Encourage them to use their particle diagrams in their explanations.

Guiding Student Thinking

Since this is an introductory lesson, student explanations may not be accurate yet. Look for opportunities to ask guiding questions to spark curiosity among the students as you go further into the unit.

- Students will want to say the egg "got sucked into" the bottle. As groups share their explanations, use these questions to steer students away from the idea of suction:
  - When did the egg fall into the bottle?

    When the paper stopped burning.
  - What did the flame do to the air particles in the bottle?

    Heated them up, made them move more.

- What about the air particles outside of the bottle?

  They stay at the same pressure.

Extending the Lesson

You can extend the lesson by challenging your students to come up with a way to get the egg out of the bottle: anything that increases the pressure inside the bottle should work. A few options are:

1. Flip the bottle/flask upside down and run hot water over the base. The egg should pop out (this is the reverse of what students did to get the egg into the bottle).
2. Add water and some effervescent antacid tablets to the bottle/flask and invert. The pressure created by the gas generated will force the egg out.

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 1.8.B: There's No Such Thing as Suction

Analysis

Particle Diagram 1 should show equal pressure inside and outside the container, indicated by the same amount of space between particles inside and outside.

Particle Diagram 2 should should show lower pressure inside the container compared to outside; this is indicated by particles being spaced farther apart inside the container than outside.

Particle Diagram 3 should show equal pressure again.

LESSON 1.9

Exploring and Measuring Gas Properties Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploding Hair Spray Can
Students watch a video clip of a news story about a can of hair spray that exploded after being left in a hot car and discuss possible explanations for why this happened.

Part 2: Collecting and Graphing Data to Create Models of Gas Laws
Students perform several lab procedures in which they measure the effects of varying one property of a gas on its pressure. Students collect data for the relationship between pressure and volume, pressure and amount of gas, pressure and temperature, and volume and temperature.

Part 3: Relationships Between Gas Properties – Discussion of Lab Results
Students engage in a whole-class discussion in which they discuss their results and come to a consensus on explanations and models for each phenomenon.

CONTENT FOCUS

The goal of this laboratory lesson is for students to be able to understand the qualitative and quantitative relationships between pressure, temperature, volume, and amount of a gas. The lesson is designed for students to collect data and use it to create multiple representations of gas behavior.

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~135 minutes

HANDOUTS

- 1.9.A: Exploring and Measuring Gas Properties – Pressure and Volume
- 1.9.B: Exploring and Measuring Gas Properties – Pressure and Amount of Gas
- 1.9.C: Exploring and Measuring Gas Properties – Pressure and Temperature
- 1.9.D: Exploring and Measuring Gas Properties – Volume and Temperature

MATERIALS

For each group:

- data collection probes and software (e.g., Vernier, Pasco)
  - temperature probe (or thermometer)
  - pressure sensor
- water
- ice

UNIT 1

With their prior knowledge from this unit that the temperature of a gas is a measure of particle motion and that the pressure exerted by a gas is the result of collisions between gas particles and the walls of the container in which they are enclosed, students are well equipped to draft explanations and particulate models of the phenomena they are investigating.

Students also graph their data in order to derive mathematical models to represent each gas law. For example, by the end of the lesson students should not only be able to explain that increasing the temperature of a gas leads to an increase in its pressure, but also that the absolute temperature and pressure of a gas are directly proportional.

- rock salt
- hot plate
- hot mitts
- syringe
- Erlenmeyer flask
- beaker
- one-hole stopper (the one that comes with the pressure sensor will work)
- computers/tablets with access to the Charles's Law simulation available at **https://teachchemistry.org/classroom-resources/the-gas-laws-simulation**
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Observable properties of gases can be measured experimentally and explained using an understanding of particle motion.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- Consider bringing in an aerosol can of some kind to show students the "Contents Under Pressure" or similar label at the beginning of Part 1 of the lesson.
- This laboratory lesson is designed for students to gain experience collecting and interpreting data quantitatively. Generic instructions are included in the student materials and will need to be modified based on your data collection devices. Regardless of the device, students should enter isolated data points rather than time-based collection (i.e., "events with entry" for Vernier devices or "manual entry" for PASCO devices).

SAFETY NOTES

- All general safety guidelines should be followed.
- Before students begin working on the handouts in Part 2, show them how to use the pressure sensors and syringes and take appropriate precautions.
- Students should wear goggles.

PART 1: EXPLODING HAIR SPRAY CAN

Students watch a video clip of a news story about a can of hair spray that exploded after being left in a hot car and discuss possible explanations for why this happened. This part of the lesson is meant to elicit prior student experience with temperature and pressure of gases before they engage in data collection.

- To begin, ask students if any of them have ever left a can of something in a hot car for a long period of time and what happened. If no student has had this experience, ask why they think it may be a bad idea to do so. Listen for students to say things like "It will explode" or "The pressure will build up too much." It is not necessary to get into the detailed explanation for the phenomenon yet. Instead, encourage and affirm their choice of language for the explanation.
- Once students have had the opportunity to respond, show a video clip of an exploding can of hair spray. One option is a video from the news site KGW.com, available here: **https://www.kgw.com/article/news/local/vancouver/hairspray-can-explodes-in-hot-car-smashes-windshield/442721427**. You can also find videos like this on video sharing sites such as YouTube.
- Next, explain to students that they are going to perform several investigations with gases in order to understand this and other phenomena more deeply. Lead a discussion to have students come up with properties they think should be investigated and how they are related. Some questions to consider asking include:
    - What changed about the can?

      The temperature or the pressure.
    - How do you think temperature affects pressure?

      Higher temperature causes the pressure to increase. Ask students to defend their answers, but do not provide full explanations at this time.

PART 2: COLLECTING AND GRAPHING DATA TO CREATE MODELS OF GAS LAWS

Student groups perform three lab procedures and one simulation in which they measure the effects of varying one property of a gas on another property and collect data for the relationships between pressure and volume, pressure and amount of gas, pressure and temperature, and volume and temperature.

- Introduce this part of the lesson by explaining to students that they will be collecting data to determine the relationships between pressure, temperature, volume, and amount of gas. Before students begin data collection, it is valuable to have them consider the design of the experiments and to predict what they think the relationships will be. You can use a sequence of questions like the following to guide the discussion:

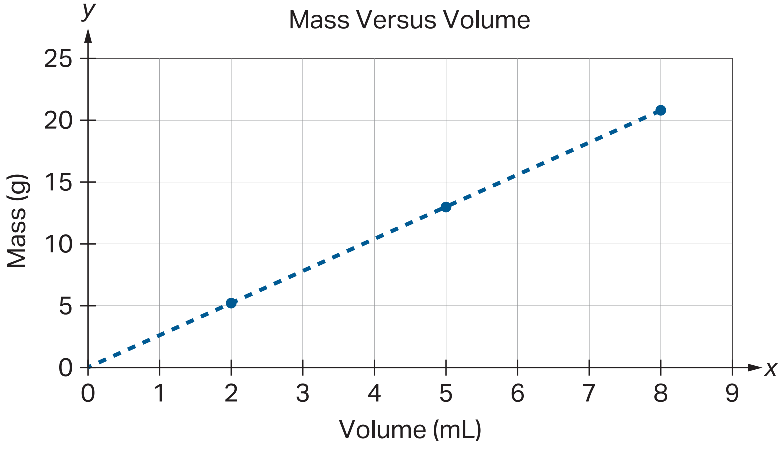
- The variables we can manipulate for gases include pressure, temperature, volume, and amount of gas. If we want to determine the relationship between the pressure and volume of a gas, which variables should we hold constant?
- As the volume of a container is decreased, what do you think will happen to the pressure exerted by the gas? Explain your prediction.
- If we want to determine the relationship between the pressure and amount of gas, which variables (pressure, temperature, volume, or amount of gas) should we hold constant?
- As the number of gas particles in a container are increased, what do you think will happen to the pressure exerted by that gas? Explain your prediction.
- If we want to determine the relationship between the pressure and temperature of a gas, which variables (pressure, temperature, volume, or amount of gas) should we hold constant?
- As the temperature of a gas is increased, what do you think will happen to the pressure exerted by that gas? Explain your prediction.
- If we want to determine the relationship between the volume and temperature of a gas, which variables (pressure, temperature, volume, or amount of gas) should we hold constant?
- As the temperature of a gas is increased, what do you think will happen to the volume occupied by that gas? Explain your prediction.

Classroom Ideas
You can ask students to think-pair-share with a partner before responding to the questions.

Guiding Student Thinking

The difference between volume and amount of gas may not be evident to students. Remind them that gases can compress or expand to fill a container, so how much space a gas takes up is different than the amount of gas. Ask them to think about amount of gas as how many particles of gas there are in the sample.

- Explain to students that their goal is to develop both a conceptual and mathematical understanding of the relationships between the gas variables. One part of that is using data they have graphed to write an equation. It is likely that this is a new process for students, so it could be helpful to walk them through the process using an equation they are familiar with, such as the one for density. To do this, show them a graph of mass versus volume; an example is given here.



- When looking at this graph, students should be able to identify it as a linear relationship and recognize that we can use $y = mx + b$ to write an equation that describes this relationship.
- Explain to students that you can substitute the variables plotted on the *x*- and *y*-axes to get the equation for this specific line. Since the *y*-axis variable is mass, it is helpful to also change the slope variable to another letter, such as *k*. The equation can be written as $m = kV + b$.
- Next, you can point out that since the *y*-intercept is 0, the equation can be simplified to $m = kV$. Since the slope in this case represents density, we can rewrite the equation as $m = DV$ or the more familiar $D = \frac{m}{V}$.
- Now that students have seen how to use data to write a familiar equation, explain that they will go through a similar process to determine the equations that can be used to describe the relationships between gas variables. These will be equations they are not already familiar with.
- Before students begin working on the handouts, show them how to use the pressure sensors and syringes and take appropriate precautions.

Classroom Ideas
You can have lab groups complete all procedures at one bench or set up the lab as stations.

Pressure and Volume

- As students work through **Handout 1.9.A: Exploring and Measuring Gas Properties – Pressure and Volume**, they will introduce a set amount of gas into a syringe attached to the pressure sensor and move the plunger in the syringe to vary the volume.

Pressure and Amount of Gas

- The key point for students to remember for data collection when working on **Handout 1.9.B: Exploring and Measuring Gas Properties – Pressure and Amount of Gas** is that all readings must be taken at the same volume, but with different amounts of gas. In other words, they should manipulate only one variable at a time. To accomplish this, students will draw different amounts of gas into the syringe, but once the syringe is connected to the pressure sensor, they will move the plunger to adjust the volume to 5.0 mL. You may need to demonstrate this process for the students before they complete this part of the lab.

Guiding Student Thinking

This lab procedure involves a very critical hypothesis: equal volumes of gas at the same temperature and pressure contain equal numbers of gas particles. This was the hypothesis first proposed by Amedeo Avogadro in 1811 that laid the foundation for the atomic molecular theory. You can choose to mention this explicitly now or during the class discussion after the lab. However, during the lab make sure to emphasize that in this part students are concerned with the *number* of gas particles represented by “units” and not the volume those particles occupy. This can be a bit difficult for students since they are using a syringe marked in milliliters.

Pressure and Temperature

- As students work through **Handout 1.9.C: Exploring and Measuring Gas Properties – Pressure and Temperature**, make sure they keep a thumb on the stopper when measuring higher temperatures to prevent the stopper from popping out.
- Encourage students to take as many data points as possible over as wide a range of temperatures as possible. The fit line can be used to estimate absolute zero, and the wider the range of temperatures used, the more accurate the estimate will be.

Volume and Temperature

- As students work on **Handout 1.9.D: Exploring and Measuring Gas Properties – Volume and Temperature**, circulate around the room and provide guidance if needed.

Instructional Rationale

The goal is for students to construct their own understanding of these proportional relationships from data, rather than memorizing a set of equations with no underlying conceptual understanding. A simulation is used here instead of a lab procedure because most common lab procedures for illustrating this relationship provide inconsistent results and are procedurally challenging.

PART 3: RELATIONSHIPS BETWEEN GAS PROPERTIES – DISCUSSION OF LAB RESULTS

Students engage in a whole-class discussion in which they share their responses to the analysis questions for each handout and come to a consensus on explanations and models for each phenomenon.

- It may be helpful during the discussion to have a simulation of a particle view of a gas projected to help students visualize the particle view. One option is the "Gas Properties" simulation from PhET: **https://phet.colorado.edu/en/simulation/gas-properties**.

Pressure and Volume

- The following questions can be used to guide the discussion of the Analysis section in **Handout 1.9.A: Exploring and Measuring Gas Properties – Pressure and Volume**.
    - Describe the relationship between pressure and volume at constant temperature and amount of gas.

      Students might not use the word *inverse*, but listen for descriptions that include the idea that as volume increases, pressure decreases.

    - Use a particulate description to explain the relationship between pressure and volume.

      Decreasing the volume of the container would lead to more collisions between gas particles and the walls of the container because the particles have less space in which to move around, and will therefore contact the walls more frequently. More collisions mean more pressure.

- Explain how your particle diagrams show differences in pressure and volume. Did anyone else represent these differences another way?

  Possible ways to represent pressure in a particle diagram include particles touching the walls of the container or arrows showing particles rebounding off the walls.

  Students are likely to come up with different ways of representing this. Ask them to defend their representations and discuss which method or methods do the best job of illustrating the concept.

- Once you are confident that students have a conceptual understanding of the qualitative relationship between pressure and volume, you can then discuss the quantitative relationship. Having a sample graph of student data on the board or projected will make it easier to discuss the relationships.
- Students may not see the reason for graphing P versus $1/V$. Explain that since the original data did not produce a linear relationship, we are manipulating the data to see if a linear fit is possible. This will make it easier to write an equation for the relationship.
- To lead students to an understanding of the equation of the line they wrote, the following questions might be helpful:
  - What did we have to plot to get a linear relationship between pressure and volume?

    Pressure and 1/volume

  - What is the generic equation for a line?

    $y = mx + b$

  - What is on the y-axis for our data set?

    Pressure

  - What is on the x-axis for our data set?

    1/volume

  - How can we rewrite the equation for a line to be specific for this data set?

    $P = m\left(\frac{1}{V}\right) + b$

  - What is the y-intercept for our data set? Why is that the case?

    Zero. If gas doesn't take up any space, it won't exert any pressure either.

- How could we simplify our equation?

  Since the y-intercept is zero, the equation simplifies to $P = m\left(\frac{1}{V}\right)$, which can be rearranged to give $PV = m$.

- How can we mathematically describe the relationship between pressure and volume at constant temperature and amount of gas?

  If the pressure doubles, the volume will decrease by half.

Guiding Student Thinking

If students give a less quantitative response, such as "As the pressure increases, the volume decreases," encourage them to reexamine their data and make some quantitative statements.

- What does *inversely proportional* mean?

  Inversely proportional is the math term used to describe the relationship explained in the previous question. In this case, if the volume doubles, the pressure decreases by half.

Guiding Student Thinking

Students may struggle with defining *inversely proportional*. If so, ask them some simple questions such as, "If the volume of the container is doubled, what will happen to the pressure of the gas?" Listen for students who say things like "It will decrease." Have them explain why in terms of particle motion and collisions with the walls of the container. Then challenge them by asking, "The pressure will decrease—do we know by how much?"

Pressure and Amount of Gas

The following questions can be used to guide the discussion of the Analysis section in **Handout 1.9.B: Exploring and Measuring Gas Properties – Pressure and Amount of Gas**.

- How is amount of gas different from volume? How did you vary the amount of gas in the experiment but keep the volume the same?

  Amount of gas is how many gas particles are present in a sample. Volume is how much space the gas occupies. For a given sample of gas, the amount is a constant, but the volume can change based on the container the gas is in. To vary the amount of gas, we drew different amounts of the gas into the syringe. To keep the volume the same, we always adjusted the volume of the syringe to 5 mL once it was attached to the pressure sensor.

- Describe the relationship between pressure and amount of gas at constant volume and temperature.

  Students might not use the term *directly proportional*, but listen for descriptions that include the idea that as the amount of gas increases, the pressure of the gas also increases.

- Use a particulate description to explain the relationship between pressure and amount of gas.

  As you increase the amount of a gas in a rigid container, there will be more collisions of gas particles with the walls of the container, increasing the pressure.

- Explain how your particle diagrams show differences in pressure and amount of gas. Did anyone else represent these differences another way?

  Possible ways to represent pressure in a particle diagram include particles touching the walls of the container or arrows showing particles rebounding off the walls. Different diagrams should show different amounts of particles and different numbers of collisions.

  Students are likely to come up with different ways of representing this. Ask them to defend their representations and discuss which method or methods do the best job of illustrating the concept.

- Once you are confident that your students have a conceptual understanding of the qualitative relationship between pressure and amount of gas, you can then discuss the quantitative relationship. Having a sample graph of student data on the board or projected will make it easier to discuss the relationships.
- To lead students to an understanding of the equation of the line they wrote, the following questions might be helpful:
  - What did we have to plot to get a linear relationship between pressure and amount of gas?

    Pressure and amount of gas

  - What is on the y-axis for our data set?

    Pressure

  - What is on the x-axis for our data set?

    Amount of gas

  - How can we rewrite the equation for a line to be specific for this data set?

    $P = mN + b$

- What is the y-intercept for our data set? Why is this the case?

  Zero. If there is no gas, there can be no pressure.

- How could we simplify our equation?

  Since the y-intercept is zero, the equation simplifies to $P = mN$, which can be rearranged to give $\frac{P}{N} = m$ (a constant).

- How can we mathematically describe the relationship between pressure and amount of gas at constant temperature and volume?

  If the amount of gas doubles, the pressure will also double.

- What does *directly proportional* mean?

  As one amount increases, the other amount increases by the same amount.

Guiding Student Thinking

Students may struggle with what *directly proportional* means and how it is different from *linear*. Give them simple examples, such as asking them, "If the number of particles of gas in the container is doubled, what will happen to the pressure of the gas?" Listen for students who say things like "It will increase." Have them explain why in terms of particle motion and collisions with the walls of the container. Then, challenge them by asking, "The pressure will increase—do we know by how much?" After seeing the equation, some students should say some variant of "The pressure will double." You can also have student data available to show them that as the number of particles doubles, the pressure is doubled (with some lab error).

Pressure and Temperature

The following questions can be used to guide the discussion of the Analysis section in **Handout 1.9.C: Exploring and Measuring Gas Properties – Pressure and Temperature**.

- Describe the relationship between pressure and temperature at constant volume and amount of gas.

  As the temperature of the gas increases, the pressure of the gas also increases.

- Use a particulate description to explain the relationship between pressure and temperature.

  Temperature is a measure of kinetic energy. As the temperature increases, the particles of the gas move faster, which leads to more collisions with the walls of the container, increasing the pressure.

  - Explain how your particle diagrams show differences in pressure and temperature. Did anyone else represent these differences another way?

    Possible ways to represent pressure in a particle diagram include particles touching the walls of the container or arrows showing particles rebounding off the walls.

    Possible ways to represent temperature in a particle diagram include showing arrows of different lengths to represent different particle speeds.

    Students are likely to come up with different ways of representing this. Ask them to defend their representations and discuss which method or methods do the best job of illustrating the concept.

- Once you are confident that your students have a conceptual understanding of the qualitative relationship between pressure and temperature, you can then discuss the quantitative relationship. Having a sample graph of student data on the board or projected will make it easier to discuss the relationships.
- To lead students to an understanding of the equation of the line they wrote, the following questions might be helpful:
  - What did we have to plot to get a linear relationship between pressure and temperature?

    Pressure and temperature

  - What is on the *y*-axis for our data set?

    Pressure

  - What is on the *x*-axis for our data set?

    Temperature

  - How can we rewrite the equation for a line to be specific for this data set?

    $P = mT + b$

  - Why isn't the *y*-intercept zero?

    The *y*-intercept isn't zero because our temperature data is in degrees Celsius. 0°C isn't absolute zero; therefore pressure will still be exerted at the temperature since the gas particles are still moving. If we converted the temperature to Kelvin, the intercept would then be 0 because at 0 K there is no molecular motion and therefore no collisions and no pressure.

- How can we mathematically describe the relationship between pressure and absolute temperature at constant volume and amount of gas?

  Pressure and temperature are directly proportional. If we double the absolute temperature of a sample of gas, the pressure will also double.

Meeting Learners' Needs

As an extra challenge for your students, you might have them calculate a theoretical value for absolute zero in Celsius from their graph.

Guiding Student Thinking

If you choose to not derive the Kelvin temperature scale here, the key takeaway for students to understand is that pressure is directly proportional to the Kelvin temperature, not the Celsius temperature. Therefore, we will use the Kelvin scale in gas calculations from now on.

Volume and Temperature

The following questions can be used to guide the discussion of the Analysis section in **Handout 1.9.D: Exploring and Measuring Gas Properties – Volume and Temperature**.

- Describe the relationship between volume and temperature at constant pressure and amount of gas.

  As the temperature of the gas increases, the volume also increases.

- Use a particulate description to explain the relationship between volume and temperature.

  Temperature is a measure of kinetic energy. As the temperature increases, the particles of the gas move faster. This faster movement leads to more collisions with the walls of the container. If the container is flexible, as it is in the simulation, the collisions will cause the container to expand. Once the pressure in the container equalizes, the piston will stop moving.

- Explain how your particle diagrams show differences in volume and temperature. Did anyone else represent these differences another way?

  Possible ways to represent volume in a particle diagram include showing containers of different sizes.

  Possible ways to represent temperature in a particle diagram include showing arrows of different lengths to represent different particle speeds.

Students are likely to come up with different ways of representing this. Ask them to defend their representations and discuss which method or methods do the best job of illustrating the concept.

- Once you are confident that your students have a conceptual understanding of the qualitative relationship between volume and temperature, you can then discuss the quantitative relationship. Having a sample graph of student data on the board or projected will make it easier to discuss the relationships.
- To lead students to an understanding of the equation of the line they wrote, the following questions might be helpful:
  - What did we have to plot to get a linear relationship between volume and temperature?

    Volume and temperature
  - What is on the y-axis for our data set?

    Volume
  - What is on the x-axis for our data set?

    Temperature
  - How can we rewrite the equation for a line to be specific for this data set?

    $V = mT + b$
  - What is the y-intercept? Why is this the case?

    The y-intercept is 0 because we measured the temperature in Kelvin. At 0 K, all molecular motion stops, so the volume of the gas would be zero.
  - How could we simplify our equation?

    Since the y-intercept is zero, the equation simplifies to $V = mT$, which can be rearranged to give $\frac{V}{T} = m$.
  - How can we mathematically describe the relationship between volume and temperature at constant pressure and amount of gas?

    Volume and temperature are directly proportional. If we double the absolute temperature of a sample of gas, the volume will also double.

Meeting Learners' Needs

You may need to illustrate for students how to move from the equations they developed in this lab to the proportions used to solve problems. For example, you might need to show them how to set up $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ or $P_1V_1 = P_2V_2$ explicitly and explain that it is just a proportion based on the fact that the ratio of P to T or the product of P and V for a given gas is a constant.

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 1.9.A: Exploring and Measuring Gas Properties – Pressure and Volume

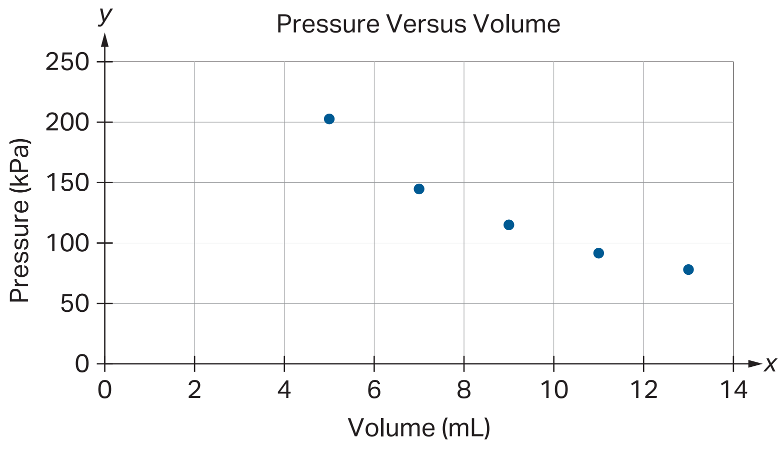
Pressure and Volume Data

Student responses will vary. Sample data are provided for reference.

Volume (mL)	Pressure (kPa)
5.0	204.0
7.0	145.7
9.0	113.3
11.0	92.7
13.0	78.5

Pressure and Volume Analysis

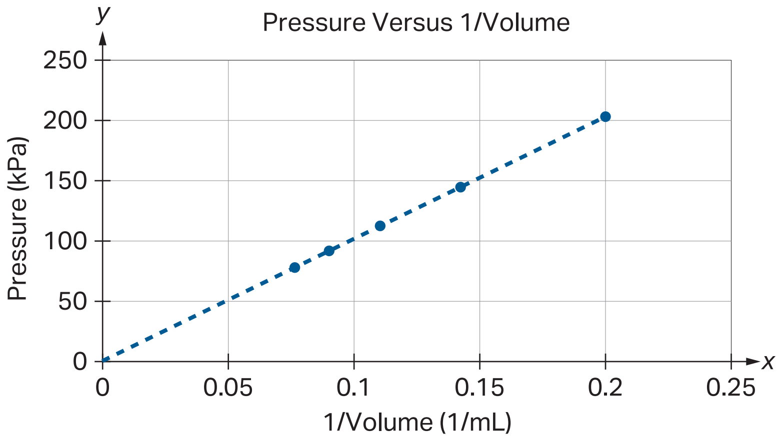
1. (a) Student responses will vary. This graph is based on sample data.



(b) As volume increases, pressure decreases.

(c) No, it is not a linear relationship because the rate of change is not constant.

2. (a)



(b) Yes, it is a linear relationship because the rate of change is constant.

3. Line is shown in graph above.

$$P = m\left(\frac{1}{V}\right) + b$$

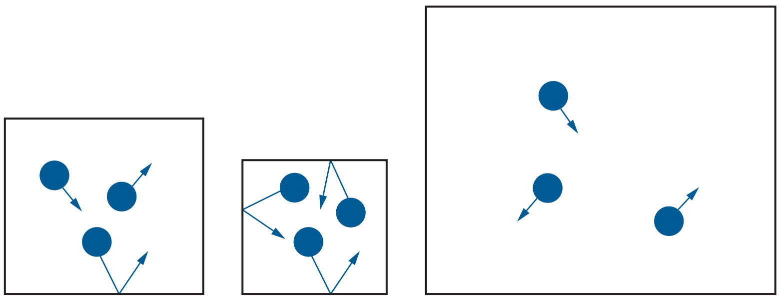
or

$PV = m$ (a constant)

4. They are inversely proportional. A plot of P versus $1/V$ is linear, meaning that as the volume doubles, the pressure will decrease by half.

5. "$PV =$ a constant" is true at any point on the graph, so if one set of conditions equals the constant, another set of conditions should also equal the constant. Setting those sets of conditions equal to one another (instead of the constant) results in $PV(\text{old}) = PV(\text{new})$ or $P_1V_1 = P_2V_2$.

6.



7. Each diagram shows the same number of gas particles. When the volume of the container is decreased, the pressure increases because the number of collisions between gas particles and the walls of the container increases. When the volume of the container is increased, the pressure decreases because the number of collisions between gas particles and the walls of the container decreases.

Handout 1.9.B: Exploring and Measuring Gas Properties – Pressure and Amount of Gas

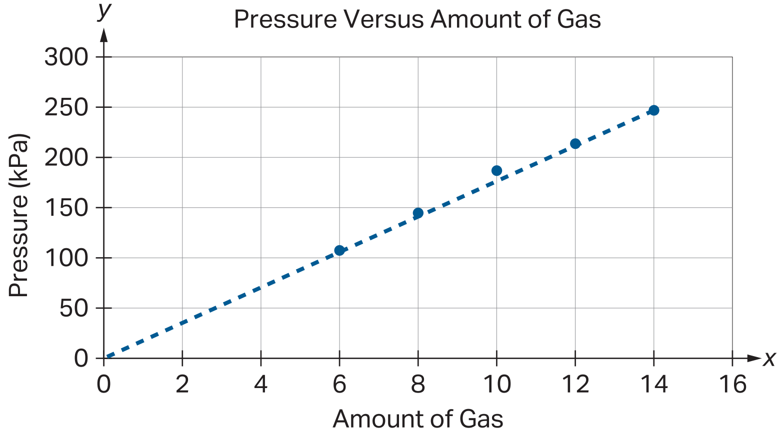
Pressure and Amount of Gas Data

Student responses will vary. Sample data are provided for reference.

Units of Gas	Pressure (kPa)
6.0	108.2
8.0	146.6
10.0	188.2
12.0	215.5
14.0	248.7

Pressure and Amount of Gas Analysis

1. Student responses will vary. This graph is based on sample data.



2. (a) As the number of particles increases, the pressure increases.

   (b) Yes. If the amount of gas doubles, the pressure also doubles.

3. Line is shown in graph above.

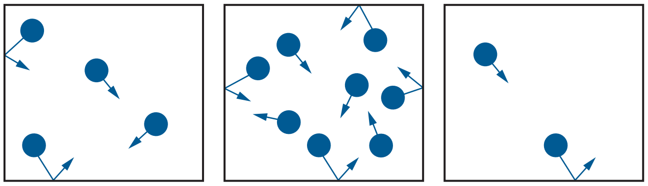
   $P = mN + b$

   or

   $\frac{P}{N} = m$ (a constant)

4. Pressure and amount of gas are directly proportional as demonstrated by a plot of pressure versus amount of gas being linear. As the amount of gas doubles, the pressure also doubles.
5. Answers will vary. Sample responses:

   The value of the y-intercept, b, for this data is 0 because the y-axis has pressure values which should be 0 when $x = 0$.

   The number of particles is represented on the x-axis, so we can conclude from the graph that when there are zero particles, there is no pressure.
6. 
7. More gas particles increase the pressure because the number of collisions between gas particles and the walls of the container will increase. Removing gas particles will decrease the pressure because the number of collisions between gas particles and the walls of the container will decrease.

Handout 1.9.C: Exploring and Measuring Gas Properties – Pressure and Temperature

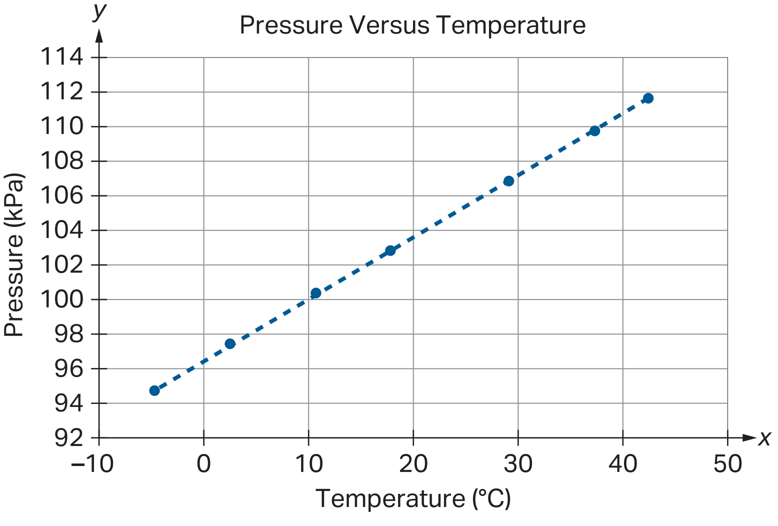
Pressure and Temperature Data

Student responses will vary. Sample data are provided for reference.

Temperature (°C)	Pressure (kPa)
−4.7	94.8
2.5	97.5
10.7	100.4
17.8	102.9
29.1	106.9
37.3	109.8
42.4	111.7

Pressure and Temperature Analysis

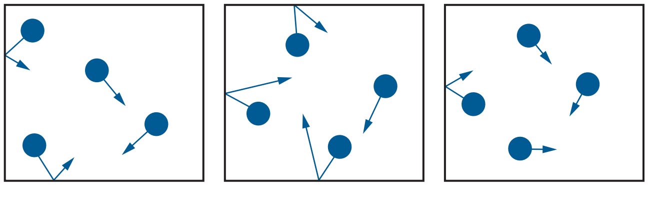
1. Student responses will vary. This graph is based on sample data.



2. Pressure and temperature are directly proportional. As the temperature of the gas increases, the pressure of the gas also increases.

3. $P = mT + b$

4. Disagree; the *y*-intercept should not be 0 since temperature data collected is in Celsius. The lowest Celsius reading in this experiment is not absolute zero; therefore, pressure should be exerted at this temperature. If the temperature actually reached 0 Kelvin, the intercept would then be 0 because at 0 K there is no molecular motion and therefore no collisions and no pressure.

5. 

6. As the temperature is increased, the pressure exerted by the gas increases because the gas particles move faster and collide with the walls of the container with greater frequency and with greater force (represented by longer arrows). As the temperature is reduced, the pressure exerted by the gas decreases because the particles move more slowly and collide with the walls of the container less frequently and with less force (represented by shorter arrows).

7. Sample response: As the gas in the hair spray can was heated, the particles of gas gained thermal energy and moved faster. This caused them to collide with the sides of the can with more frequency and force. At a certain point the bottom of the can failed and the gas particles escaped, causing the can to shoot "like a rocket" through the window of the car.

Handout 1.9.D: Exploring and Measuring Gas Properties – Volume and Temperature

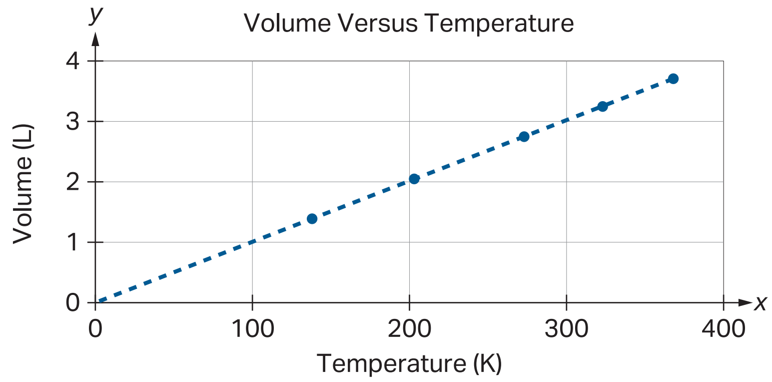
Volume and Temperature Data

Student responses will vary. Sample data are provided for reference.

Temperature (K)	Volume (L)
138	1.39
203	2.05
273	2.75
323	3.25
368	3.71

Volume and Temperature Analysis

1. Student responses will vary. This graph is based on sample data.



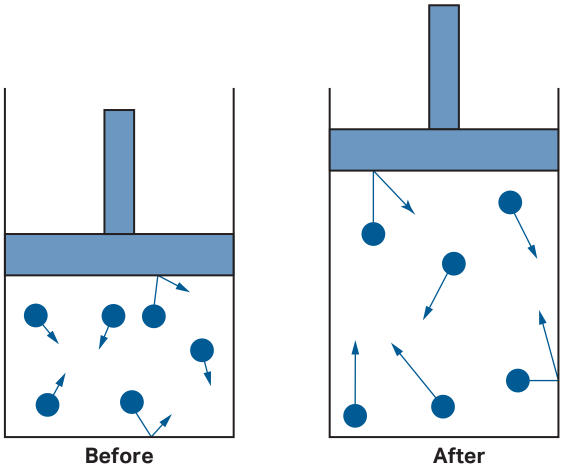
2. $V = mT + b$

or

$$\frac{V}{T} = m \text{ (a constant)}$$

3. Volume and temperature are directly proportional as demonstrated by a plot of volume versus temperature being linear. As the temperature of the gas doubles, the volume also doubles.

4.



5. If the temperature doubles, the volume will also double, so the volume will be 4.0 L.

6. (a) The pressure inside the container must be greater than the pressure of the environment in order for the collisions of the particles with the container to cause the piston to rise.

   (b) Once the piston stops moving, the pressure inside the container must equal the pressure outside it. The collisions of particles with the inside of the piston and the outside of the piston are balanced so it no longer moves.

Unit 1

Performance Task

UNIT 1

PERFORMANCE TASK

Cooling an Alcohol

OVERVIEW

DESCRIPTION

In this performance task, students use a cooling curve, a phase diagram, and pressure and temperature data of ethanol to answer several questions related to phase changes and relationships between gas variables.

CONTENT FOCUS

This task is designed to have students apply their knowledge of heating and cooling curves, phase diagrams, and gas laws to a novel situation—the cooling and condensing of an alcohol—using a substance that was most likely not studied during the unit. It is intended to be used at the end of Unit 1 because it draws on concepts from across the unit. Having students work with heating curves and phase diagrams for an unfamiliar substance is an effective way to assess student learning because it requires the student to draw conclusions based solely on the data and known general principles, rather than intuition or prior experience with the substance.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 1 Performance Task: Cooling an Alcohol

MATERIALS

- calculator
- equation sheet

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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** 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.
1.2.C.1 Explain the relationship between changes in states of matter and the attractions among particles.	**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.
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** 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.

UNIT 1

SCORING GUIDELINES

There are 17 possible points for this performance task.

Question 1(a)

Sample Solutions	Points Possible
350–360 K During a phase change, the temperature of the substance remains constant. According to the graph, the temperature is constant for several minutes at 350–360 K.	**2 points maximum** 1 point for a correct answer 1 point for justification *Scoring note:* If a student uses the phase diagram instead of the cooling curve, they should receive full credit as long as they say they assumed the experiment was done at standard pressure and that they determined that the phase change happened at 351 K.

Targeted Feedback for Student Responses
Prompt students to think about what happens at the particle level that causes temperature to remain constant during a phase change.

TEACHER NOTES AND REFLECTIONS

Question 1(b)

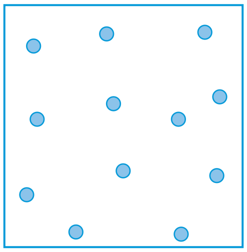
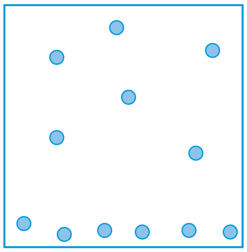
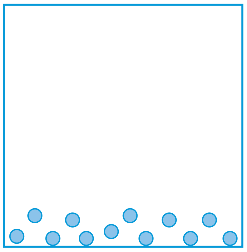
Sample Solutions	Points Possible
Disagree. While the average kinetic energy (or speed or velocity) of the particles at 500 K is higher than the average at 400 K, the kinetic energy of individual particles varies significantly at any temperature. Thus, the slowest-moving particles at 500 K would be moving slower than the fastest-moving particles at 400 K.	**1 point maximum** 1 point for a correct choice and justification

Targeted Feedback for Student Responses
Students may have the misconception that at a given temperature all particles have the same kinetic energy and therefore the same velocity. In reality, the temperature is related to the average kinetic energy. Some particles will move faster than average and some will move slower than average, so some faster-moving particles in the 400 K sample could be moving faster than some slower-moving particles in the 500 K sample.

TEACHER NOTES AND REFLECTIONS

UNIT 1

Question 1(c)

Sample Solutions	Points Possible
Alcohol Sample at 3 Minutes  Alcohol Sample at 12 Minutes  Alcohol Sample at 17 Minutes 	**3 points maximum** 1 point for the same size and same number of particles in each particle diagram 2 points for correct particle arrangement in each container, reflecting a transition from gas to liquid *Scoring notes:* • For the particle diagram at 12 minutes, as long as the student shows particles in both phases, the number in each phase is not important, provided the total number of particles stays the same. • For the particle diagram at 17 minutes, a student could still draw some particles in the vapor phase, provided there are fewer particles in the vapor phase than there are in the particle diagram for 12 minutes. • If students draw 1 or 2 particle diagrams correctly, they should receive 1 point.

Targeted Feedback for Student Responses
Changing the temperature does not change the size or number of particles. Changing the temperature simply changes how fast the particles move. In this case, there is also a phase transition, so at 3 minutes, the alcohol is a gas, and at 17 minutes, the alcohol is a liquid.

TEACHER NOTES AND REFLECTIONS

Question 1(d)

Sample Solutions	Points Possible
$q = \Delta H_{vap} m$ $q = \left(841\ \frac{J}{g}\right)(10.0\ g)$ $q = 8{,}410\ J$	**2 points maximum** 1 point for selecting the ΔH_{vap} value for the alcohol 1 point for a correct answer *Scoring note*: If students select the incorrect heat of vaporization value, they can still earn the second point for a correct calculation using the incorrect value. No credit should be awarded if students select either heat of fusion value.

Targeted Feedback for Student Responses
If students used the value of heat of vaporization for water instead of the alcohol, encourage them to closely observe the data table and select the relevant information. Students may think that the value for vaporization is only used for the liquid to gas transition, so you may need to remind them that the magnitude is the same for the gas to liquid transition.

TEACHER NOTES AND REFLECTIONS

Question 1(e)

Sample Solutions	Points Possible
Energy must have been released by the alcohol as it changed phase because liquid particles have less average potential energy than gas particles of the same substance. The energy was released as heat.	**1 point maximum** 1 point for a correct answer and explanation
Targeted Feedback for Student Responses	
Remind students about the difference between *endothermic* and *exothermic* and ask them to consider what happens at the particle level during phase transitions.	

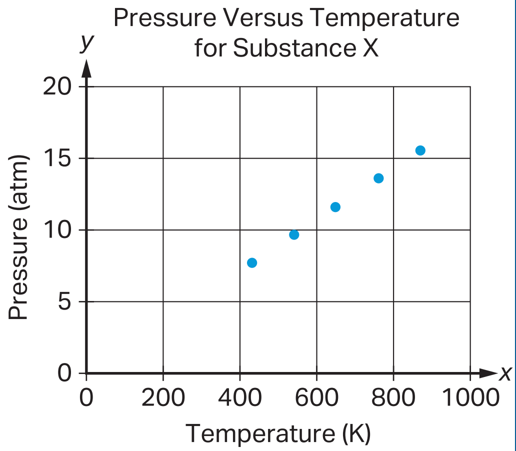
TEACHER NOTES AND REFLECTIONS

Question 1(f)

Sample Solutions	Points Possible
Water particles have stronger interactions with each other than do particles of the alcohol. Heat of vaporization is the amount of energy required to overcome the interactions between particles to separate them from one other; because more energy is required to vaporize a gram of water than a gram of the alcohol, water particles must have stronger interactions.	**1 point maximum** 1 point for a correct answer and explanation
Targeted Feedback for Student Responses	
Again, ask students to consider what must happen at the particle level during a phase change. It requires energy to separate particles. If some particles are "stickier" it will take more energy to overcome those attractions.	

TEACHER NOTES AND REFLECTIONS

Question 2(a)

Sample Solutions	Points Possible
	**3 points maximum** 1 point for scaling each axis evenly 1 point for a title and labels on both axes 1 point for plotting points correctly *Scoring note*: If students connect the points, do not award the point for plotting points correctly. If students draw a fit line, they should receive the point for plotting points correctly.

Targeted Feedback for Student Responses
Students have likely been learning the expectations for graphing since elementary school. Remind them of those parameters and give them ample opportunity to practice.

TEACHER NOTES AND REFLECTIONS

Question 2(b)

Sample Solutions	Points Possible
The graph demonstrates a direct relationship. As temperature increases, pressure increases proportionally.	**1 point maximum** 1 point for a correct choice with explanation

Targeted Feedback for Student Responses
Students likely learned the relationship as *direct variation* in math class, so it may be helpful to use that language. Prompt them for what they learned about relationships with direct variation in math. They will likely say that the ratio of the quantities is constant, as they are in this example. You can also ask students to sketch what an inverse linear relationship looks like.

TEACHER NOTES AND REFLECTIONS

Question 2(c)

Sample Solutions	Points Possible
Pressure is the sum of the force of all the collisions the particles have with the container walls relative to the surface area of the container walls. When the temperature of the gas is higher, the gas particles have higher kinetic energy on average than they do at lower temperatures. Thus, at higher temperatures, the particles will have more frequent and, on average, more forceful collisions with the walls. When the volume and thus the surface area of the container remain unchanged (as is the case here), more force exerted by the particles equals greater pressure.	**1 point maximum** 1 point for a correct explanation
Targeted Feedback for Student Responses	
Remind students that temperature is a measure of average kinetic energy and to consider what this means at the particle level. Then ask them to think about what pressure measures and to connect this to kinetic energy.	

TEACHER NOTES AND REFLECTIONS

Question 2(d)

Sample Solutions	Points Possible
$\frac{P_1}{T_1} = \frac{P_2}{T_2}$ $\frac{15.55 \text{ atm}}{873 \text{ K}} = \frac{P_2}{1{,}135 \text{ K}}$ $P_2 = 20.2 \text{ atm}$	**2 points maximum** 1 point for showing work 1 point for correct answer *Scoring notes:* ▪ Note that this answer is based on choosing the first data point in the table. Selection of any of the other data points for P_1 and T_1 is acceptable and will lead to the same numerical answer. ▪ Students do not have to use the equation to earn the points. They could use an understanding of proportional reasoning to arrive at the answer.

Targeted Feedback for Student Responses
Students may struggle with the algebraic manipulation. Encourage students to use their conceptual understanding of the relationship between pressure and temperature as well as proportional reasoning to see if the answer makes sense. If it doesn't, they likely made an algebra mistake. You could ask students questions such as "At constant volume, what happens to the pressure as temperature increases?" or "If the temperature went up by a factor of about 1.5, by how much would you expect the pressure to change?"

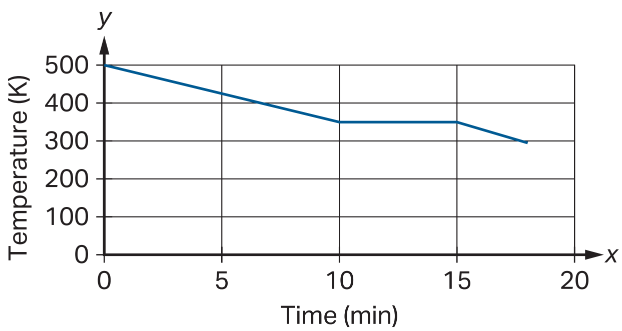
TEACHER NOTES AND REFLECTIONS

Cooling an Alcohol

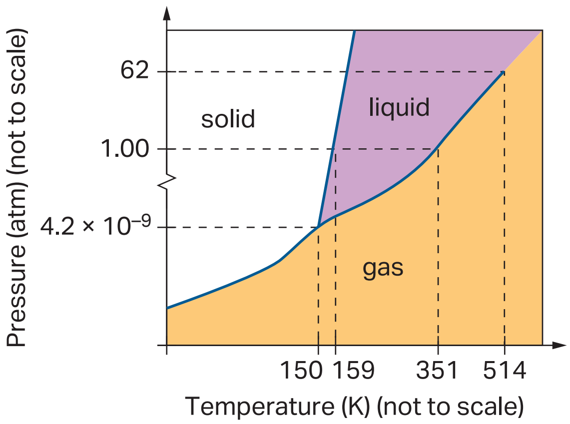
PERFORMANCE TASK

1. In an experiment, a closed container holds a 10.0 g sample of an alcohol. The container is cooled at a constant rate. The sample's temperature is recorded each minute. A graph of the data is below. A phase diagram for the alcohol is also shown.

COOLING CURVE FOR AN ALCOHOL



PHASE DIAGRAM OF AN ALCOHOL



(a) At about what temperature does the sample change phase? Justify your answer based on the cooling curve shown above.

(b) A student states, "When the alcohol sample was at a temperature of 500 K, all the particles were moving faster than any of the particles were moving at 400 K." Do you agree or disagree with this student's statement? Justify your answer.

PERFORMANCE TASK

(c) In the boxes below, draw three particle diagrams representing the sample of alcohol cooling in the experiment described above. The diagrams should represent the sample at 3 minutes, 12 minutes, and 17 minutes.

Use the phase diagram and cooling curve above to help you draw the diagrams.

ALCOHOL SAMPLE AT 3 MINUTES	ALCOHOL SAMPLE AT 12 MINUTES	ALCOHOL SAMPLE AT 17 MINUTES

(d) How much energy was transferred during the phase change shown on the cooling curve above? Use the phase diagram and table of values below to help you answer the question.

	Water	Alcohol
Heat of Vaporization, H_{vap} (J/g)	2,260	841
Heat of Fusion, H_{fus} (J/g)	334	109
Specific Heat Capacity of the Liquid, *c* (J/g•K)	4.18	2.46

(e) During the phase change process, was energy absorbed or released by the alcohol? Explain.

(f) What can you conclude about the strength of the interactions between water particles compared to the strength of the interactions between particles of the alcohol? Use information from the table of values in part (d) above to justify your answer.

PERFORMANCE TASK

2. In a different experiment, the pressure and temperature inside a container holding a different alcohol were monitored each minute. The container volume and the amount of gas did not change during cooling. The temperature and pressure data appear in the table below.

Temperature (K)	Pressure (atm)
873	15.55
764	13.61
651	11.60
543	9.67
433	7.71

(a) Graph the pressure–temperature data on the grid below. Be sure to label and scale your axes appropriately and give your graph a title. Start your x-axis at 0 K.

(b) Does the graph demonstrate a direct relationship, an inverse relationship, or no relationship between temperature and pressure when the alcohol is in the gas phase? Explain your choice.

(c) Provide a particle-level explanation for the relationship between pressure and temperature when the alcohol is in the gas phase.

(d) Predict the pressure that would be observed if the container was at a temperature of 1,135 K.

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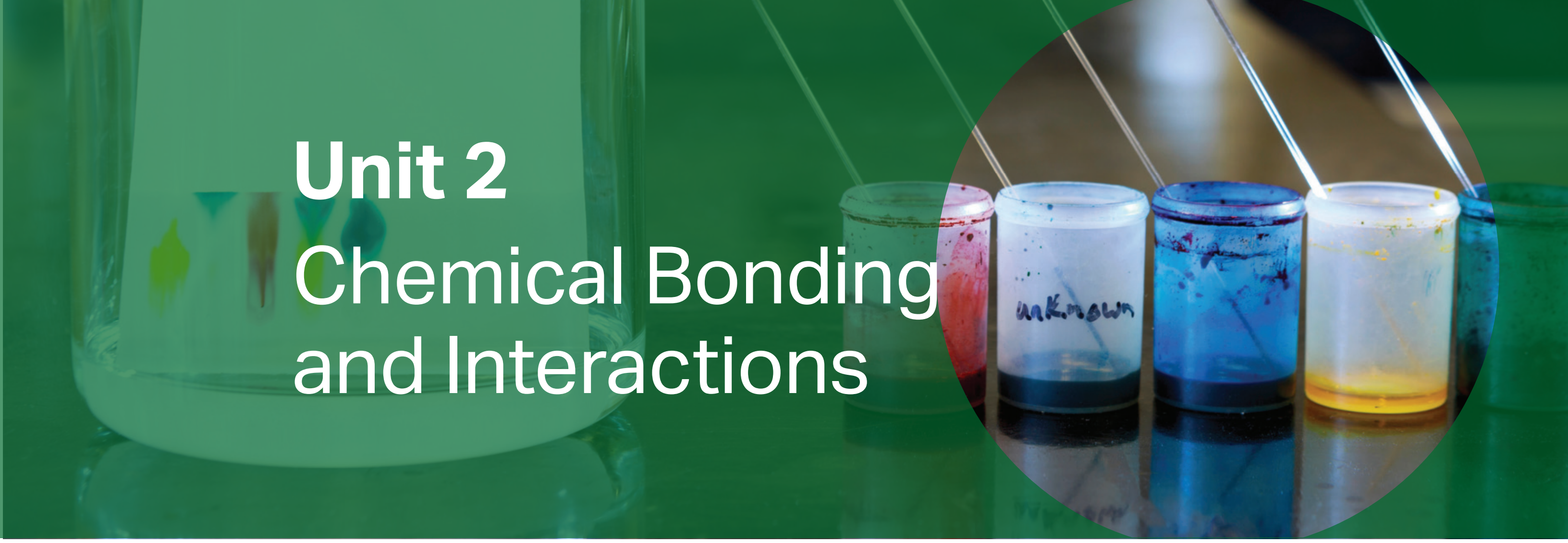
Unit 2



Unit 2
Chemical Bonding and Interactions

Overview

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 deepen 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 will 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

This unit focuses on the following enduring understandings:

- 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 2

KEY CONCEPTS

This unit focuses on the following key concepts:

- 2.1: Classification and Interactions of Matter
- 2.2: Molecular Structure and Properties
- 2.3: Covalent and Ionic Bonding

UNIT RESOURCES

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

Lessons for Key Concept 2.1: Classification and Interactions of Matter				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.1: Launch Lesson – Mixing and Unmixing	2.1.B.1, 2.1.B.2	2.1.B.a, 2.1.B.b	~105 minutes	Attention to Modeling
2.2: Atoms, Molecules, and Particles	2.1.A.1, 2.1.A.2	2.1.A.a, 2.1.A.b, 2.1.A.c	~45 minutes	Attention to Modeling
2.3: Chromatography Lab – Who Forged the Hall Pass?	2.1.B.1, 2.1.B.2	2.1.B.a, 2.1.B.b	~60 minutes	Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing
2.4: Partial Pressure	2.1.B.1, 2.1.C.1	2.1.B.a, 2.1.C.a, 2.1.C.b	~45 minutes	Emphasis on Analytical Reading and Writing, Strategic Use of Mathematics

2.5: Distillation and Electrolysis Lab	2.1.D.1	2.1.D.a, 2.1.D.b	~90 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing
All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.				

Lessons for Key Concept 2.2: Molecular Structure and Properties				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.6: Launch Lesson – Comparing Methane and Butane	2.2.A.1, 2.2.A.2, 2.2.B.1	2.2.A.a, 2.2.A.b, 2.2.A.c, 2.2.B	~45 minutes	Attention to Modeling
2.7: Exploring Intermolecular Forces	2.2.A.1, 2.2.A.2, 2.2.B.1	2.2.A.a, 2.2.A.b, 2.2.A.c, 2.2.B	~90 minutes	Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing
2.8: Evaporation and Intermolecular Forces Lab	2.2.A.1, 2.2.A.2, 2.2.B.1	2.2.A.a, 2.2.A.b, 2.2.A.c, 2.2.B	~60 minutes	Strategic Use of Mathematics, Attention to Modeling
Learning Checkpoint 1: Key Concepts 2.1 and 2.2 (~45 minutes)				
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts 2.1 and 2.2 (Learning Objectives 2.2.A.1–2.2.C.1). For sample items and learning checkpoint details, visit Pre-AP Classroom.				

UNIT 2

Lessons for Key Concept 2.2: Molecular Structure and Properties *(continued)*				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.9: Molecular Geometry	2.2.D.1, 2.2.E.1	2.2.D.a, 2.2.E	~60 minutes	Attention to Modeling
2.10: Spicy Chemistry – The Flavors of Isomers	2.2.D.1, 2.2.D.2, 2.2.E.1	2.2.D.a, 2.2.D.b, 2.2.E	~45 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling
2.11: Solubility and Laundry Detergents Lab	2.2.A.2, 2.2.B.1, 2.2.F.1, 2.2.G.1	2.2.A.a, 2.2.A.b, 2.2.A.c, 2.2.B, 2.2.F, 2.2.G	~90 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling

The following Key Concept 2.2 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: 2.2.C.1
- Essential Knowledge Statements: 2.2.C.a, 2.2.C.b

Practice Performance Task for Unit 2 (~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 2.3: Covalent and Ionic Bonding				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.12: Classifying Solids Lab	2.3.A.1, 2.3.B.1	2.3.A, 2.3.B.a, 2.3.B.b	~45 minutes	Attention to Modeling
2.13: The Structure of Ionic Compounds	2.3.C.1, 2.3.D.1	2.3.C.a, 2.3.C.b, 2.3.C.c, 2.3.D	~90 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing
	All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.			

Learning Checkpoint 2: Key Concepts 2.2 and 2.3 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts 2.2 (Learning Objectives 2.2.D.1–2.2.G.1) and 2.3. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 2 (~45 minutes)
This performance task assesses learning objectives and essential knowledge statements from the entire unit.

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LESSON 2.1

Launch Lesson – Mixing and Unmixing

OVERVIEW

LESSON DESCRIPTION

Part 1: Describing and Defining Types of Mixtures

Students predict and observe what happens when you mix water with sugar, water with sand, and sugar with sand. The goal is to get students thinking about what exactly it means for a substance to be a mixture. The examples include both homogeneous and heterogeneous mixtures to provide a context for thinking about the length scale over which two samples are mixed.

Part 2: Observing Filtration and Evaporation

Students observe what happens when a mixture of water and sand and a mixture of water and sugar are evaporated or passed through filter paper. The goal of this portion of the lesson is to have students observe and describe two methods of unmixing: filtration and evaporation. This experience lays the groundwork for Part 3, in which students draw conclusions about how each method works.

Part 3: Unmixing Sugar and Sand

Students use what they observed about filtration and evaporation in Part 2 to design a way to separate a mixture of sugar and sand. They then develop particulate representations for the filtration and vaporization processes and use those representations to draw conclusions about the substances involved.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~105 minutes

HANDOUTS

- 2.1.A: Mixing and Unmixing
- 2.1.B: Unmixing Sugar and Sand
- 2.1.C: Particle Diagrams for Filtration and Evaporation

MATERIALS

For each group and for class demonstration:

- beakers
- flasks
- sugar
- sand
- tap water
- hot plate
- funnel
- filter paper
- pencils or markers with three different colors (blue, red, and green) (1 set per student, not needed for demonstration)
- goggles

UNIT 2

CONTENT FOCUS

In Unit 1, students used particulate models of matter to reason about the phases of matter, the energy involved in phase transitions, and the properties of gases. Now, in Unit 2, students consider the makeup of the particles of matter and how the structure of a particle influences its interaction with other particles.

This launch lesson extends the particulate reasoning of Unit 1 to a particle view of mixtures and the distinction between homogeneous and heterogeneous mixtures. This lesson also gives students experience and practice with topics they will encounter later in this unit, including dissolution, evaporation, and the use of differences in particulate interactions to separate mixtures. This lesson focuses on filtration and evaporation as ways to separate mixtures; students learn about distillation and chromatography in lessons later in this unit.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

To expedite the demonstration in Part 2, you may want to start the evaporation process as students are working on their definitions in Part 1 of the lesson.

SAFETY NOTES

All general safety guidelines should be followed.

PART 1: DESCRIBING AND DEFINING TYPES OF MIXTURES

Students predict and observe what happens when you mix water with sugar, water with sand, and sugar with sand. The goal is to get students thinking about what exactly it means for a substance to be a mixture. The examples include both homogeneous and heterogeneous mixtures to provide a context for thinking about the length scale over which two samples are mixed.

- To begin, ask students to work with a partner to predict which of the following pairs of substances will mix: water and sugar, water and sand, and sugar and sand. Students can record their predictions in the second column in the table at the top of **Handout 2.1.A: Mixing and Unmixing**, shown below for reference.

Substances Being Mixed	My Predictions: Will they mix?	My Observations: What do I observe in the beaker?	My Conclusions: Did they mix? Was my prediction correct?
sugar and water			
sand and water			
sugar and sand			

Handout 2.1.A

Invite students to share their predictions. Highlight instances where students disagree; this will likely be the case for predictions about mixing sugar and sand. Have students defend and explain their reasoning, but don't evaluate their predictions or answer their questions about what it means to be a mixture just yet.

- Now students will have the opportunity to evaluate their predictions. Make the three mixtures, one at a time, in small beakers as a demonstration for the class. Be sure to stir them well. Ask students to make observations of each mixture and discuss with their partners whether they think their observations support their predictions. Students can record their responses and conclusions in the appropriate columns of the handout.

  Again, after student pairs have completed this step, invite students to share their responses with the class, but don't provide your own evaluation. Be sure to discuss the outcomes of any predictions that the students disagreed about.

Guiding Student Thinking

Making and evaluating predictions about mixing substances requires students to define what it means for two substances to mix. Allow students to wrestle with uncertainty about their definition and how to evaluate their observations. This exercise helps motivate the need to consider the length scale of a mixture in the discussion later on.

- To help students begin to synthesize their thoughts about what it means for substances to mix, engage the class in the following thought experiment. Allow students time to discuss their responses to each question with a partner before examining the question as a class. During this thought experiment, have the three beakers from the demonstration available as a visual reference for students.
    - Think about the beaker of sand and water. Suppose you took several teaspoon-sized samples from the beaker. Would each sample of the mixture look different or the same? What if you did this for the other two beakers?

      For the sand/water mixture, teaspoon-sized samples would look different. Some would be mostly or only water, and some would be mostly or only sand. But for the other two beakers, teaspoon-size samples would look the same.
    - Now think about the beaker of sand and sugar. How small would samples of this mixture need to be to look different from one another? The size of a thimble? A water drop? Even smaller? What about for the mixture of sugar and water?

      For the sand and sugar mixture, you need samples as small as one grain of sand or sugar for the samples to look different. For the sugar and water mixture, we can't see samples small enough to distinguish between them.
    - Is the sugar still present in the sugar and water mixture, even though you can't see it? How could you verify this?

      Yes, the sugar is still there, dissolved in the water. I could taste the mixture to see if it was sweet.
    - Suppose you took smaller and smaller samples of the sugar and water mixture—too small to even see. If you tasted these tiny samples, do you think at some point the samples would taste different?

      Even though the sugar mixes in the water, the identities of the sugar and of the water do not change. So, a one-molecule sample of sugar would taste different from a one-molecule sample of water (assuming your tongue could taste a single molecule).

- Use the demonstrations and thought experiments conducted so far in this lesson as a launching point for a whole-class discussion on what it means for two substances to form a mixture. The goal of the discussion is to guide student thinking toward the connection between mixing and the length scale over which you are considering the substance as being mixed.

  In this discussion, introduce the term *length scale* to students. Emphasize that sugar and sand appear to be mixed on the length scale of a spoonful, but not on the length scale of single grains. Meanwhile, the sugar and water are mixed on the length scales of both a spoonful and a single grain of sugar. The length scale at which sugar and water are no longer mixed is that of single molecules.

Instructional Rationale

The discussion of the length scale of mixing is important in this lesson not only because it is relevant to distinguishing between heterogeneous and homogeneous mixtures, but also because it sets students up to understand what happens in filtration. In Part 3, students will draw particle diagrams to explain why sugar passes through a filter while sand is trapped.

- Lead the discussion toward its conclusion by introducing the terms *homogeneous mixture* and *heterogeneous mixture*. Explain the meaning of the prefixes *homo-* ("same") and *hetero-* ("other" or "different"). Then ask students to work in pairs to classify each of the three mixtures as either homogeneous or heterogeneous, based on what they think the terms mean. Also have them to try to write definitions of each term.
- After each group has had time to work, facilitate a class discussion that leads to a consensus for the classifications of the three mixtures and the definitions of homogeneous and heterogeneous. Reasonable definitions would include the idea that if taking a small sample always gives you the same proportions of its constituent substances, it is a homogeneous mixture, and that if taking a small sample sometimes gives you different proportions, it is a heterogeneous mixture.

Guiding Student Thinking

Emphasize that the distinction between homogeneous and heterogeneous for the same mixture may change depending on the length scale you are working with. But for sugar in water, any sample that you could see would be the same, so this mixture is homogeneous down to very small sizes. For water and sand, you may want to consider making a distinction between a layer of water on top of the sand and mud.

- Wrap up the conversation by having students identify some everyday examples of heterogeneous and homogeneous mixtures. You can also offer some common ones for discussion (e.g., air, metal alloys used in coins such as dimes and nickels, ice water, carbonated soda) if students are struggling to generate their own.

PART 2: OBSERVING FILTRATION AND EVAPORATION

Students observe what happens when a mixture of water and sand and a mixture of water and sugar are evaporated or passed through filter paper. The goal of this portion of the lesson is to have students observe and describe two methods of unmixing: filtration and evaporation. This experience lays the groundwork for Part 3, in which students draw conclusions about how each method works.

- Perform the following simple demonstrations in front of the class so that all students can see. To expedite these demonstrations, you may want to start the evaporation process as students are working on their definitions in Part 1 of the lesson.

Evaporation

1. Place a small sample of the water and sugar mixture into a beaker. Heat the beaker on a hot plate.
2. Repeat step 1 with the water and sand mixture.
3. Leave both beakers heating on the hot plate until the water boils away. Have students examine the contents of each beaker.

Filtration

1. Pass a small sample of the water and sugar mixture through a filter and collect the filtrate in a flask.
2. Repeat step 1 with the water and sand mixture.
3. Have students observe the contents of each flask.

- Ask students to record what they observed during the demonstrations in the space provided in the table at the bottom of **Handout 2.1.A: Mixing and Unmixing**. As you circulate around the room, ensure that students notice the following: (1) both the sugar and the sand are left behind when the water boils away, and (2) the sugar passes through the filter along with the water, but the sand does not. Also, ensure that students realize that the sugar retains its identity when dissolved in water by asking them how they could verify this.

PART 3: UNMIXING SUGAR AND SAND

This portion of the lesson asks students to use what they observed about filtration and evaporation in Part 2 to design a way to separate a mixture of sugar and sand. Second, it asks students to develop particulate representations for the filtration and evaporization processes and to use those representations to draw conclusions about the substances involved.

- Ask students to work in small groups to write a procedure for separating a mixture of sugar and sand, using **Handout 2.1.B: Unmixing Sugar and Sand** as a guide. Show students what materials are available for their use. These should be the same materials you used in the demonstration earlier: flasks, beakers, water, funnels, hot plates, and filter paper (along with a sand and sugar mixture). Students can record the steps of their procedure and the materials they will use on their handout. Let students know it is important to write the procedure in a manner that would allow others to easily execute the required steps.
- As you circulate around the room while students are developing their procedures, guide students toward a logical process. Although students may come up with a variety of procedures, a standard approach (and one that will be referenced later in the lesson) is as follows: (1) add water to the mixture of sugar and sand, (2) filter the resulting mixture to separate out the sand, and then (3) evaporate the water from the remaining mixture to separate out the sugar. Encourage students to use relatively small amounts of the substances in their procedures so the filtering and boiling go quickly.
- You will likely want to review their procedures before allowing students to proceed. As you review the procedures, focus primarily on safety and the validity of the overall approach, not on fixing smaller flaws. Students will learn from the experience of carrying out their own procedure and encountering any flaws in their designs.

Instructional Rationale

This part of the lesson is intended to give students practice with both creating an experimental procedure and recording the procedure in a systematic manner. This will be helpful later in the course when students carry out experiments that require more complicated experimental designs and data analysis.

- Have students carry out their procedures and then answer the analysis questions on the handout to evaluate the effectiveness of their procedures.

- Next, to help students develop and demonstrate their knowledge about what happens at the particle level in filtration and evaporation, have them work in groups to complete questions 1 and 2 on **Handout 2.1.C: Particle Diagrams for Filtration and Evaporation**. Both questions involve creating particle diagrams. As you circulate around the room checking progress, look for the following elements in the particle diagrams for each question:

Question 1: Filtration

- Sugar is drawn in both the upper and lower panel while sand is drawn only in the upper panel. This is to ensure that students understand that they are trying to explain why sugar passes through the filter paper but sand does not.
- The sugar is drawn as individual particles whose size allows them to pass through the pores in the filter.
- The sand is drawn in a manner that makes it clear that a grain of sand, which is made up of constituent particles, cannot fit through the pores. Point out that it may be useful for students to consider how the small filter-paper particles lead to pores that are much larger than the particles.
- Inclusion of water particles is useful, but it may be best to prompt students to include these only after their drawing meets the above criteria. Including water is useful to help them realize that although we sometimes only draw the substances we are investigating, there is always a background of a large number of water particles in solutions. The substances of interest are like submarines moving through the sea.

Question 2: Evaporation

- The liquid in the beaker contains both water and sugar particles.
- The vapor contains only water particles.
- Optionally, the diagram may contain some indication that water particles are leaving the solution and entering the vapor phase. This can be shown, for example, using arrows.

- Once groups have drawn their particle diagrams, partner pairs of groups together. Each group should then compare drawings and get feedback from their partner group, using the process outlined in question 3 on the handout.

Classroom Ideas

If you are concerned with group size when combining groups, you could allow each group to pick one person to be a roving “spy” who looks at the work of other groups and then reports back to their group.

Instructional Rationale

There is much to consider when completing these particle diagrams, so there is a chance that not all groups will include all elements. Having each group review the work of another group might give them a perspective they did not originally consider.

- After groups have received feedback, allow them time to revise their diagrams based on that feedback. In response to question 4, they should also describe the revisions they made.
- After students have finished revising their particle diagrams, close the lesson with a class discussion. Base your discussion questions on what you learned about students' thinking by looking at their particle diagrams. Now is also a good time to have students begin to consider interactions between particles, since that is a focus of this unit. As a result of the discussion, students should be able to:
  - Connect their drawings to the distinction between homogeneous and heterogeneous mixtures. Here, the relevant scale for distinguishing homogeneous from heterogeneous solutions is the size of the pores. Emphasize that:
    - You can't use a paper filter to separate sugar from water. The dissolved sugar and water mixture is homogeneous on the scale of the filter's pores.
    - You can use a paper filter to separate sand from a mixture of sugar and water. The sand and sugar-water mixture is heterogeneous on the scale of the filter's pores.
  - Connect their drawings to the interactions between particles by asking questions such as: Why do the particles in sand grains stay together? Why don't the sugar particles do this? This will encourage students to think about attractions between particles and help them begin to realize that something must be different about the particles for the attractions to be different. The discussion may be fairly simple at this point, using the observation that grains of sand do not dissolve to infer that the interactions between particles in sand itself must be much stronger than those between sand and water particles.

ASSESS AND REFLECT ON THE LESSON

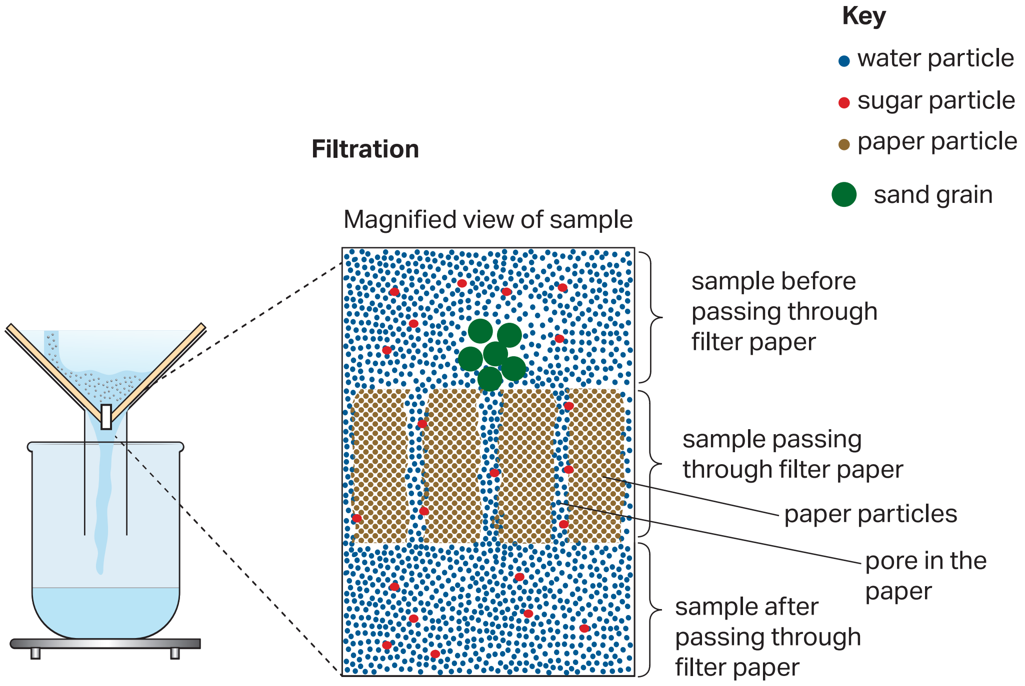
HANDOUT ANSWERS AND GUIDANCE

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

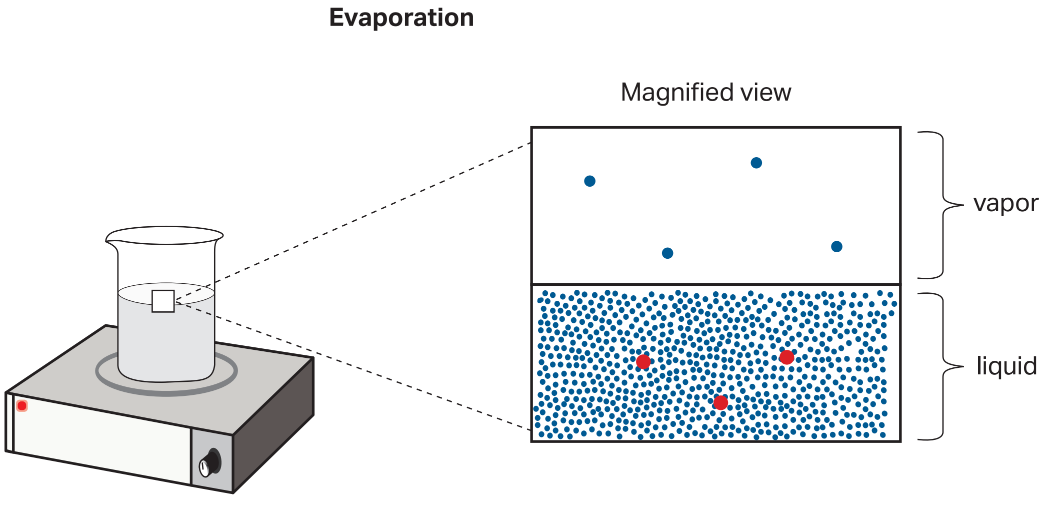
Handout 2.1.C: Particle Diagrams for Filtration and Evaporation

Sample responses for question 1 and 2 are provided below. For questions 3 and 4, answers will vary but should be consistent with the sample diagrams shown here.

1.



2.



LESSON 2.2

Atoms, Molecules, and Particles

OVERVIEW

LESSON DESCRIPTION

Part 1: Molecules as Particles
Students identify connections between the particle diagrams they worked with in Unit 1 and representations of the atomic structure within those particles. They accomplish this by engaging in a series of card sorts involving three kinds of representations of butane molecules.

Part 2: The Many Ways to Represent Molecules
Students are introduced to the many ways chemists represent molecules. An important takeaway from this part of the lesson is that each of these representations has benefits and limitations, and that different representations are suited for different kinds of tasks. Students are guided toward this understanding as they work with a set of cards showing a variety of different molecular representations of butane.

Part 3: Breaking Interactions Between Molecules and Between Atoms Within Molecules
Students are introduced to intermolecular versus intramolecular interactions and reason about the interactions that are broken in physical versus chemical processes. In this part of the lesson, students work with a set of cards in which both a phase change and a chemical reaction are represented.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUT

- 2.2: Atoms, Molecules, and Particles – Card Sets (one of each card set per student group, with all cards cut out)

CONTENT FOCUS

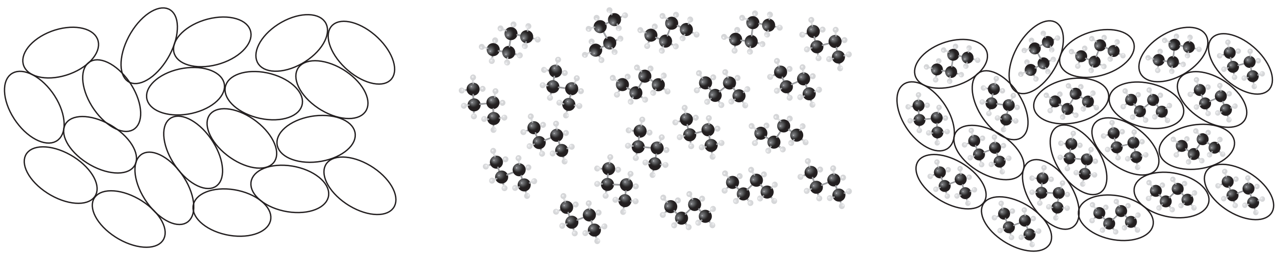
In Unit 1, the generic term *particle* was used instead of *atom* or *molecule*. In Unit 2, these particles start to have structure. This lesson is intended to help students begin to make the distinction between atoms and molecules and to understand how the term *particle* can be used to describe both. Students learned about phase changes in Unit 1 and this lesson gives them the chance to review what phase changes look like at the molecular level and how they are different from chemical changes. This lesson also introduces students to a variety of ways to represent molecules, which will be useful to return to later in the unit as students learn about Lewis diagrams and molecular geometry.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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.

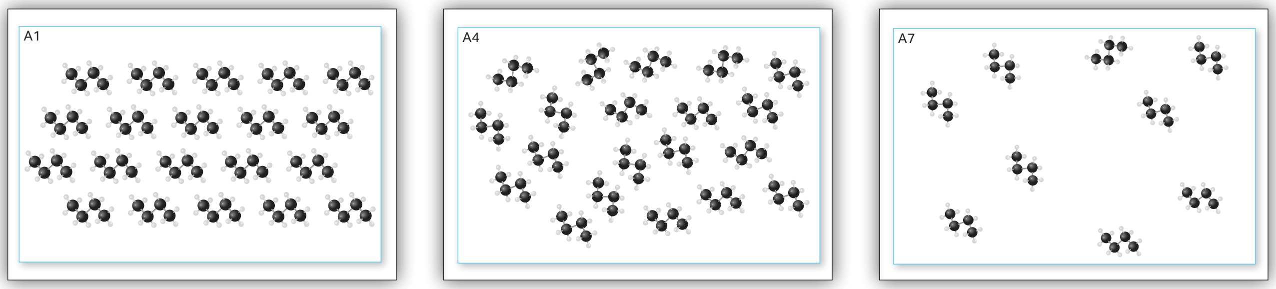
PART 1: MOLECULES AS PARTICLES

This portion of the lesson helps students connect the kinds of particle diagrams they worked with in Unit 1 to representations of the atomic structure within those particles. They accomplish this by engaging in a series of card sorts involving three kinds of representations of butane molecules. An example of each kind of representation is shown below. One kind (on the left) shows each molecule as a single particle, an approach students are familiar with from Unit 1; one kind (center) shows all the atoms in each molecule; and one kind (right) shows both representations used together.



The cards use these different representations to depict collections of butane molecules in the solid, liquid, and gas phases. (For cards, see Card Set A on **Handout 2.2: Atoms, Molecules, and Particles – Card Sets**.)

- Ask students to work in small groups and give each group the three "all atoms shown" cards for butane (A1, A4, and A7).



Handout 2.2

Ask students how many particles are shown on each card. After a few minutes of group work, students will likely begin to observe that there are different answers depending on what they choose to count as a single particle. At this point, bring the class together for a brief discussion about how to interpret the word *particle*. One way is to consider each small sphere to be a particle. Another way is to count the number of total structures, where each "structure" is a set of small spheres connected by sticks. At this point, do not use the words *atom*, *molecule*, *bond*, *intermolecular*, *intramolecular*, etc.

- Once students are comfortable with these two distinct notions of a particle, introduce them to the following chemical terms by being very specific about the representations on their cards:

sphere	=	atom
stick between spheres	=	bond
set of spheres connected by sticks	=	molecule

Instructional Rationale

This approach is designed to have students come to the essential distinction between atoms and molecules on their own, with the words *atom* and *molecule* being introduced only after they have made the distinction themselves.

- Ask each group to determine the number of atoms and the number of molecules on each card. (There are 20 molecules on each solid and liquid phase card and 9 on the gas phase card. There are 14 atoms in butane, C_4H_{10}, which gives 280 atoms for each solid and liquid phase card and 126 for the gas phase card.)

  As you circulate around the room while groups are working on this question, guide students to an approach in which they multiply the number of molecules by the number of atoms per molecule. You might want to offer the following supports:

  - If students decide to count all individual atoms, let them do this long enough to realize it is tedious. This will help make them open to considering more efficient ways to count atoms.
  - Ask students if the number of atoms in each of the molecules is the same.
  - Use simpler cases as examples to get students thinking in this way. For example, ask, "If each molecule had 2 atoms and you had 3 molecules, how many atoms would you have?"

- Once groups have arrived at their answers, give a short explanation of how the number of atoms can be determined from proportional reasoning and mathematical expressions of this type:

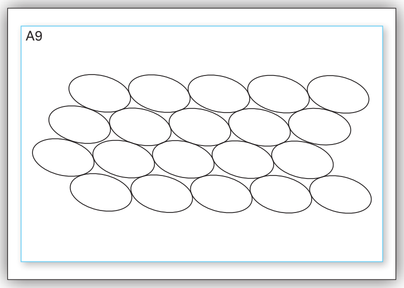
$$20 \text{ molecules} \times \left(\frac{14 \text{ atoms}}{1 \text{ molecule}}\right) = 280 \text{ atoms}$$

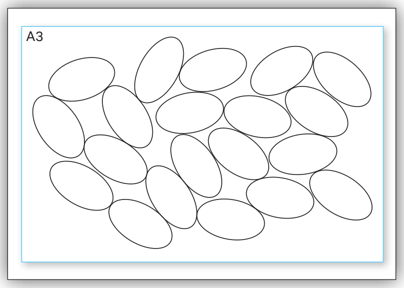
$$9 \text{ molecules} \times \left(\frac{14 \text{ atoms}}{1 \text{ molecule}}\right) = 126 \text{ atoms}$$

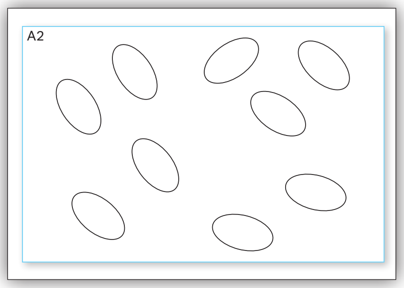
Guiding Student Thinking

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.

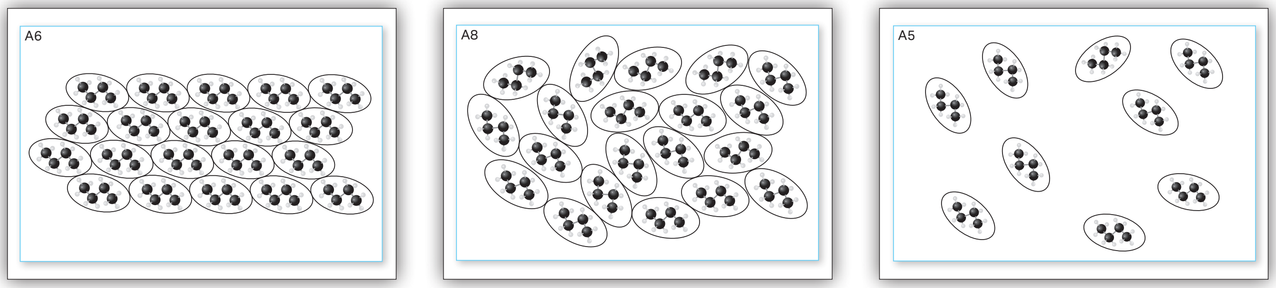
- Once students have made their connections, give each group the set of three cards showing both representations (A6, A8, and A5).

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.

Tell them that the cards represent butane in the solid, liquid, and gas phases, and ask them to identify the phases.

A6 = solid; A8 = liquid; A5 = gas



Handout 2.2

PART 2: THE MANY WAYS TO REPRESENT MOLECULES

This portion of the lesson exposes students to some of the many ways chemists represent molecules. An important takeaway from this part of the lesson is that each of these representations has benefits and limitations, and that different representations are suited for different kinds of tasks. Students are guided toward this understanding by working with a set of cards showing a variety of different molecular representations of butane. (For cards, see Card Set B on **Handout 2.2: Atoms, Molecules, and Particles – Card Sets**.)

- Give each student group one complete set of cut-out cards from Part B of the handout. Students will recognize the butane molecule on card B1 from the previous part of the lesson. Let students know that each card in the set is a different representation of a butane molecule.
- Ask students to group the cards by type of representation. Because "type of representation" is a vague notion, students may do this sorting in many different ways.

Instructional Rationale

The benefit of starting with this task is that it encourages students to look at the cards carefully and try to make sense out of what is shown. When looking at students' arrangements, avoid suggesting that there are correct and incorrect answers. Instead, simply point out similarities or differences between cards that you believe students may not have noticed and encourage students to explain their reasoning.

- After groups have had time to sort their cards, ask them to join with another group to compare their arrangements. Each group should explain their reasoning for sorting the cards the way they did.
- Once groups have shared their arrangements, allow them time to revise their arrangements based on their discussion with the other group.
- Have a few groups share their arrangements and rationales. Emphasize that there is not one correct grouping. Rather, focus on the features students used for grouping and identify similarities and differences. For example, students might create one group with models that show the three-dimensional structure of butane, one with models that show the bonds, but not the three-dimensional structure, and another with models that just show the number of each type of atom. Other groups might separate the models into those that show the atoms as spheres and those that use the symbols for each element.

Instructional Rationale

It is not important for students to be able to name the various representations they examine in this part of the lesson. The focus here is on exposing students to the many ways it is possible to represent the same information. Students will be exposed to these representations throughout the course and should be comfortable obtaining information about compounds from them. You can revisit these representations later in this unit when students learn about Lewis diagrams and molecular geometry.

- To help students begin to develop an understanding of why chemists have so many different ways to represent the same information, pose each of the following questions to the students and have them work with their group to answer them. You can have each group write a response on a small whiteboard and then call on a few groups to share their responses.
  - Which representation(s) would be most useful if you just wanted to count the number of each type of atom (C versus H) in the molecule?

    Use this question as a means to discuss the way these atoms are shown in the various representations. The molecular formula C_4H_{10} is easiest to extract this information from. Emphasize that sometimes all we care about is the total number of each type of atom, which is why the molecular formula is a common representation. C_4H_{10} also provides an opportunity to review the meaning of the "4" and "10" in this molecular formula.

- Which representation(s) would be most useful if you wanted to count the number of each type of bond (C-H versus C-C) in the molecule?

  Butane has 3 C-C bonds and 10 C-H bonds. Both the three-dimensional and two-dimensional structures have this information, but the two-dimensional structures probably make it easier to count. This information is not shown in the molecular formulas.

- Which representation(s) would be most useful if you wanted to convey the three-dimensional arrangement of atoms in a molecule?

  Each of the three-dimensional structures has this information but shows it in different ways. You can use this opportunity to introduce the purpose of wedge and dash representations.

PART 3: BREAKING INTERACTIONS BETWEEN MOLECULES AND BETWEEN ATOMS WITHIN MOLECULES

In this portion of the lesson, students consider the differences between intermolecular and intramolecular interactions. The main takeaway from this part of the lesson is that breaking intermolecular attractions is a physical change, so molecules retain their identities in physical transformations such as melting and boiling. By contrast, greater energies are generally required to break the interactions between atoms within a molecule. These breaks occur only in chemical transformations such as combustion. Therefore, the definition of *molecule* is closely tied to the large difference in these energies.

In this part of the lesson, students work with a set of cards in which both a phase change and a chemical reaction are represented. Again, butane is the molecule represented on all cards. (For cards, see Card Set C on **Handout 2.2: Atoms, Molecules, and Particles – Card Sets**.)

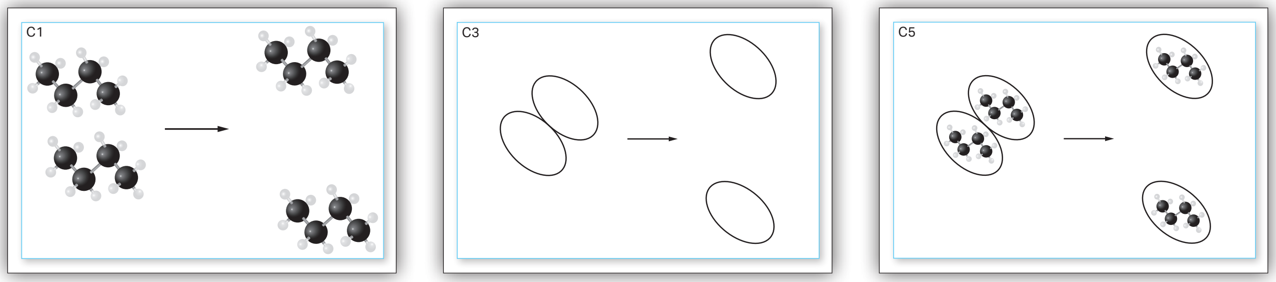
- Give each student group one complete set of cut-out cards from Part C of the handout. Explain to students that some of the cards represent a phase change involving butane, and some of the cards represent a chemical reaction involving butane. Ask groups to sort the cards into two groups, according to the type of change shown on the card. As students are working, you can support them by doing the following:
  - Initially focus their attention on the relationships between the cards. Three of the cards represent a situation in which interactions **between** molecules are broken. The other three cards represent a situation in which interactions **within** a molecule are broken.

UNIT 2

- Ensure that students understand what is depicted in each card—i.e., breaking of a C-C bond versus breaking of the interactions between two butane molecules.

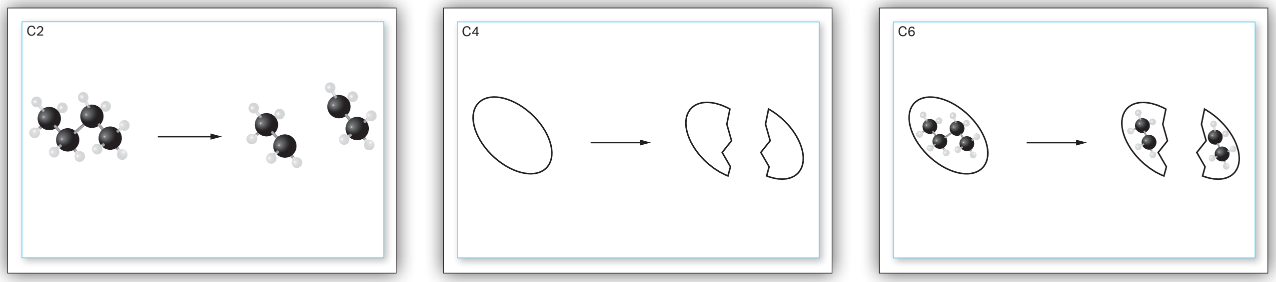
- After students have sorted their cards, introduce the terms *intermolecular* (between molecules) and *intramolecular* (within a molecule). Ask student groups to label their cards as representing a change that overcomes either intermolecular or intramolecular attractions. As students are working, circulate around the room and support groups in arriving at the correct sorting and labeling. The cards, grouped by the type of change shown, are shown below for reference.

Interactions between molecules (intermolecular) are broken:



Handout 2.2

Interactions within a molecule (intramolecular) are broken:



Handout 2.2

- Explain to students that it generally takes more energy to break a bond between atoms in a molecule, such as a C-C bond, than it does to overcome intermolecular attractions. You can use the following values as the approximate quantities of energy required for each of those changes:
  - Breaking the interaction between two butane molecules takes 4 kJ/mol.
  - Breaking a C-C bond within a butane molecule takes 400 kJ/mol.

Guiding Student Thinking

This may be the first time students have heard the word *mole* used in a chemistry context. Encourage students to not focus on the term *mole*, but rather on the relative differences in the energy required for each type of change. You can explain that *mole* just refers to the number of butane molecules; for the same amount of butane, it takes about 100 times more energy to break a C-C bond than it does to overcome intermolecular attractions between two butane molecules.

- Lead a classroom discussion focusing on intermolecular and intramolecular interactions, using questions such as the following:
  - Which of the cards show what happens when butane boils?

    C1, C3, and C5, because the cards represent butane before and after the phase change. In all three cases, there are 2 butane molecules present before and after the change.
  - What types of interactions are broken when butane boils?

    Intermolecular ("between molecules") attractions are broken when a substance boils.
  - Why do you think it takes more energy to overcome intramolecular ("within molecules") forces than intermolecular forces?

    To overcome intermolecular forces, all that must happen is for there to be enough energy to separate molecules from one another. To overcome intramolecular forces, bonds between atoms must be broken.
  - Where does the energy required to break the interactions between butane molecules come from when butane boils?

    The energy likely comes from an external heat source.
  - What processes can you think of in which the C-C bond of butane may break?

    It would have to be a chemical change, such as the burning of butane in a kitchen torch.

Instructional Rationale

The goal here is to get students to connect the diagrams in Part 1 of the lesson (which show butane in the solid, liquid, and gas phases) to the definition of a molecule. The combination of cards showing all atoms, single particles, and both representations provides a tool to help students make these connections. When substances melt or boil, the interactions between the molecules break but the bonds between the atoms in the molecule do not, so the molecules retain their identity. In Unit 1, we represented molecules as single particles because the structure of the molecule did not change in the phase transitions studied. Students will learn more details about both intermolecular and intramolecular forces later in this unit. The last part of this lesson serves as an introduction for students.

UNIT 2

LESSON 2.3

Chromatography Lab – Who Forged the Hall Pass?

OVERVIEW

LESSON DESCRIPTION

Part 1: Chromatography Technique

Students are guided through the use of paper chromatography in order to learn the technique they will need for Part 2 of the lesson. Students learn about chromatography's applications as well as retention factors, polarity differences, physical changes and intermolecular forces of attraction, and the difference between mixtures and pure substances.

Part 2: Chromatography Investigation

Students identify which pen was used to write a forged hall pass using the chromatography technique developed in Part 1. Then they write an evidence-based justification for their claim of which pen was used.

CONTENT FOCUS

The first part of the chromatography lab allows students to build on their understanding of mixtures from Lesson 2.1 and to demonstrate their knowledge of proper experimental procedures, how to avoid common errors, and how to record and analyze the data. Students analyze the chromatography data they collect to identify the differences between pure substances and mixtures. The retention factors are used as a quantitative measure to discuss relative attraction between solutes and solvents. The data are also used to explain whether the changes observed are physical or chemical.

AREAS OF FOCUS

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

SUGGESTED TIMING

~60 minutes

HANDOUT

- 2.3: Chromatography Lab – Who Forged the Hall Pass?

MATERIALS

For each student group:

- chromatography paper (filter paper or coffee filters may be used instead)
- pencil
- ruler
- red and black dye or food coloring (one should be a mixture and one should be a pure substance)
- beaker
- toothpicks
- distilled water

In Part 2 of this lesson, students demonstrate and refine their chromatography skills and apply them to a new situation. They use retention factors to compare the samples and as evidence to support their claims.

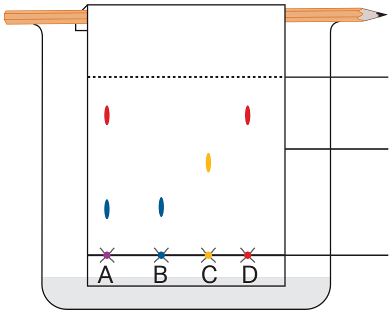
- access to four "suspect" pens or markers with black ink, labeled 1–4 (these can be shared by all groups)
- samples of forged hall passes written with one of the distinguishable black pens
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- Toothpicks are useful for transferring food coloring or dye to the chromatography paper.
- Students could work in groups of 2 or 3, depending on available equipment.
- Depending on your supplies, you may need students to stabilize their chromatography paper in the beaker. They could tape the top of the paper to a pencil and lay the pencil across the top of the beaker, for example. A sample setup is shown on the following page.



For Part 1:

- You can use any two colors of food coloring or dye, although red and black work well and are recommended in this lesson. Use one that is a mixture and one that is not so students can observe different results. Consider having different groups use different dyes so students can see a variety of results.

For Part 2:

- If your school doesn't use hall passes, feel free to modify the scenario to something that makes more sense for your students. A scenario involving any kind of anonymous handwritten document will work. You can create your own version of Part 2 of the handout that reflects the scenario you are using.
- You will need to experiment with different black pens or markers to find four that give different results on chromatography paper. It often works best to use a washable black marker that separates into multiple colors as the match and additional washable markers of different compositions as well as a permanent marker (that will not travel up the paper) for the other suspects. Some examples of markers you might use include:
  - black washable Crayola marker (as the match)
  - black Sharpie marker
  - black Mr. Sketch scented marker
  - black overhead transparency marker
- To prepare "samples" of the forged hall pass for students to analyze, use the marker you've selected and write on strips of chromatography paper. To make this activity accessible for students, it is helpful for the samples to be similar to the other chromatography strips used in this lab, with minimal markings at just one end of the strip. (It is less important for the samples to actually resemble a hall pass.)

SAFETY NOTES

All general safety guidelines should be followed.

PART 1: CHROMATOGRAPHY TECHNIQUE

Students are guided through the use of paper chromatography in order to learn the technique they will use in Part 2 of the lesson. Students learn about the uses of chromatography, retention factors, polarity differences, physical changes and intermolecular forces of attraction, and the difference between mixtures and pure substances.

- Begin the lesson by having the students silently read the background information about chromatography in the Introduction section of **Handout 2.3: Chromatography Lab – Who Forged the Hall Pass?** and/or by having one or more students volunteer to read the text to the class. Ask students to use annotation techniques as they read, such as identifying any terms they are unfamiliar with, and help them use context clues to determine the meaning of the words. Be sure to highlight the real-world application of chromatography.

Meeting Learners' Needs

Students likely encountered the words *solvent* and *solute* in middle school. So, even if they struggle with exact definitions of these terms, this is a great opportunity for students to work together and determine meaning from context.

- Have students work with a partner to complete the pre-lab questions. This could be done as a think-pair-share. It is not essential that students have the correct prediction in the pre-lab; however, it is essential that they have some reasoning for their prediction.

Guiding Student Thinking

Students may think that black is a pure color based on the "absence of color" or other misconceptions. This prediction is a wonderful place to gain insights into the students' prior knowledge to drive future discussions.

- As a way to orient students generally to the procedure they will use in Part 1 of the handout while keeping them engaged, lead a "tool talk." In this tool talk, discuss how chromatography is used in the chemistry field and some common mistakes people make such as labeling the paper in pen or allowing the sample to bleed into the water. Since it might be hard for students to envision how a dye separates, you could also show them examples of chromatograms so they can see what their results might look like.

UNIT 2

- Allow student groups to conduct the Part 1 procedure and begin to answer the questions with their lab group. You can use questions such as those below to help teams as they work.
    - Water is polar and "like" solvents dissolve "like" solutes. What does that imply about the colors as they travel up the paper?

      Polar colors travel farthest since they are more attracted to the polar water as it travels up the paper.

    - Chemical changes change substances into new substances with new properties. Do you have any evidence of a chemical change?

      No, therefore the change must be physical. The products are still dyes/food color, just separated.

    - Chemical changes alter the structure and bonds between particles while physical changes only alter the particle placements. Does chromatography change the bonds within the particles or the forces between particles?

      Chromatography changes the forces between particles because the particles are only separating.

- Once the entire class has completed the Part 1 procedure and questions, you may choose to have teams individually discuss their answers with you, or you can have a class discussion to ensure that all students understand the concepts addressed in this part of the lab. These concepts are:
    - The most polar solute will dissolve best in the water and travel up the paper the farthest.
    - The retention factor is a value from 0 to 1 that shows how well the solute dissolved in the solvent and traveled up the paper.
    - Chromatography involves physical changes that occur as parts of a mixture are physically separated. No chemical changes occur.
    - Chromatography results in changes in intermolecular forces rather than in bonds, since it involves physical changes, not chemical changes.
- Check the answer to question 5 of Part 1 to ensure that the students use appropriate evidence that is relevant to their claim and highlight Rf values as part of their justification. This is a setup for Part 2.

Instructional Rationale

Many students probably do not have prior experience with chromatography. The "tool talk" and guided procedure in Part 1 are designed to ensure the students have the proper foundation to conduct an inquiry later. Without that foundation, the mistakes that students make can cause anxiety or can result in obtaining data that leads to misconceptions.

PART 2: CHROMATOGRAPHY INVESTIGATION

In this part of the lesson, students identify which pen was used for a forged hall pass using chromatography techniques developed in Part 1.

- Orient students to their goal in this part of the lab by having them read the section titled Your Mission at the top of Part 2 of the handout. You may want to invite a student volunteer to read it aloud.

YOUR MISSION

A forged hall pass was identified at your school and the principal needs your help. She is backlogged with work and hopes your knowledge of chemistry can be put to use. Four students are suspected of forging the pass, and their pens have been confiscated. To protect their identities, we'll refer to these students simply as Suspects 1, 2, 3, and 4. Determine which student's pen, if any of them, was used to write the forged pass.

Handout 2.3

When talking about the mission with the class, ask students how chromatography can help solve this mystery. Be sure students grasp the connection: chromatography can be used to identify substances—such as the ink from the suspect pen—based on how they separate.

Explain that students will carry out their mission by designing and implementing a procedure based on what they learned in Part 1 of the lab. Highlight the fact that they will receive only one sample of the pass to use in their investigation, so they have only one chance to collect the data. Students can use any of the materials from Part 1 in their procedure.

- Instruct teams to determine what materials they will use, to develop their step-by-step procedures, and to design a data table. Let students know you must approve the teams' procedures and data tables before they can begin data collection. Ensure that each team will be measuring Rf values and following a logical procedure.

- Once teams have received your approval and have access to the necessary materials, they can implement their procedure and complete the Claim and Evidence section of the handout.
- After students have finished the lab, have teams report their claim, evidence, and reasoning. Each group can write their claim and evidence on a whiteboard or large piece of paper to share with the whole class. (If it's not clear by this point which ink was used in the hall pass, you can reveal this information to the class.)
- Once all groups have shared, identify trends in the students' work, mentioning common strengths and weaknesses. Lead a discussion about how students could strengthen their statements based on these trends, and then allow groups time to revise their statements.

EXTENDING THE LESSON

Ask students to come up with a way to separate the insoluble ink used in Part 2. If the ink is insoluble in water, what change could be made to the procedure to determine if that ink is a mixture or a pure substance? If time and materials are available, allow the teams to try to separate the permanent ink in other solvents. Each team can have different solvents or combinations of solvents and compare their results in a brief class presentation.

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 2.3: Chromatography Lab – Who Forged the Hall Pass?

Introduction

Pre-Lab Questions

1. Pencil marks will not be affected by the water. Pen will bleed and may also separate, contaminating the data.
2. Predictions and reasoning will vary.

Part 1

Data

Answers will vary. Sample data are provided below for reference.

Color	Streak or Spot?	Colors, Bottom to Top	Distance Traveled by Solute(s)	Distance Traveled by Solvent Front	Rf Value for Each Color Observed
Red	Spot	Red	4.8 cm	8.0 cm	0.6
Black	Streak	Red, yellow, blue	4.8 cm, 5.6 cm, 7.2 cm	8.0 cm	0.6, 0.7, 0.9

Analysis

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

1. Blue was the most polar because it traveled the farthest up the paper with the water, which is polar. It has the highest Rf value.
2. The separation of the colors was a physical change because the components of the mixture have not changed composition. The colors can be mixed back together.
3. The bonds are not changed because the compositions of the dyes have not changed. The intermolecular forces are weakened or broken to allow the colors to separate and travel at different Rf values.

4. Red is a pure dye and black is a mixture.
5. The red dye only had one component and remained red, with only one Rf value. The black dye had red, yellow, and blue colors with three Rf values, showing it is a physical mixture of those colors.

Part 2: Chromatography Investigation

Materials

Student answers will vary. Sample response: hall pass sample, ink samples, pencil, ruler, chromatography paper, beaker, water, toothpicks, tape

Procedure

Student answers will vary.

1. Mark one strip of chromatography paper with the pen or marker for each suspect. Obtain a sample of the hall pass.
2. Mark start and finish lines on all the papers.
3. Place each paper in a beaker that contains a small amount of water. Ensure the ink sample is above the water line.
4. Allow the water to travel up the papers.
5. Measure the Rf values of each solute and make observations of the papers.

Data

Student answers will vary. Sample data are provided below for reference.

Pen	Colors, Bottom to Top	Distance Traveled by Solute(s)	Distance Traveled by Solvent Front	Rf Value for Each Color Observed
Suspect 1	black	0 cm	8.0 cm	0
Suspect 2	black	1.6 cm	8.0 cm	0.2
Suspect 3	red, yellow, blue	3.2 cm, 4.8 cm, 6.4 cm	8.0 cm	0.4, 0.6, 0.8
Suspect 4	red, yellow, green, blue	3.2 cm, 4.8 cm, 5.6 cm, 6.4 cm	8.0 cm	0.4, 0.6, 0.7, 0.8
Hall Pass	red, yellow, blue	3.2 cm, 4.8 cm, 6.4 cm	8.0 cm	0.4, 0.6, 0.8

Claim and Evidence

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

1. Suspect 3 forged the hall pass.
2. The evidence shows that the suspect's pen produces the same three colors with the same Rf values as the forged hall pass on the chromatography paper. All other suspects' pens had different colors and different Rf values.
3. When chromatography is used, the water separates the components of a mixture based on their polarity and solubility. Rf values are determined for each color of the mixture, based on the ratio of the distance the color has traveled up the paper to the distance the water has traveled. When Rf values of two samples match, that means the samples have the same components.

UNIT 2

LESSON 2.4

Partial Pressure

OVERVIEW

LESSON DESCRIPTION

Part 1: Analytical Reading

Students read a pair of passages about the composition of air at different altitudes in order to learn about partial pressure. The first passage pertains to the context of sports teams in Denver and a relationship between high altitude and home-field advantage.

Part 2: Individual and Partner Questions

Students first answer conceptual and mathematical questions about the reading individually and then discuss their answers with a partner and revise.

Part 3: Whole-Class Discussion

Students participate in a whole-class discussion of the reading and questions.

AREAS OF FOCUS

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

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 2.4.A: The Chemistry of Air and Altitude
- 2.4.B: The Chemistry of Air and Altitude – Check Your Understanding

CONTENT FOCUS

This lesson introduces students to the concept of partial pressure and how it is related to the composition of a mixture of gases. In order to engage students and help them connect chemical ideas to their own lives and experiences, the lesson uses the context of variation in air pressure at various altitudes and the effect this has on athletic performance. It is structured as a reading and writing task in order to expand students' abilities to decode, understand, summarize, and analyze texts about chemical concepts and models. Students also connect the new information about mixtures of gases to what they learned about the kinetic molecular theory in Unit 1. Additionally, the lesson develops written and oral argumentation skills, including appropriate selection of relevant evidence and use of reasoning to link evidence and claims logically.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
2.1.B.1 Create and/or evaluate models of mixtures.	**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.
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.

UNIT 2

FORMATIVE ASSESSMENT GOAL

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

1. Commercial scuba divers use tanks filled with a mixture of gases known as Trimix on very long, deep dives. Trimix is composed of 70 percent nitrogen, 10 percent oxygen, and 20 percent helium. The total pressure of Trimix inside a certain tank at the beginning of a dive is 118.4 atm.
   (a) What is the partial pressure of oxygen in the tank?
   (b) Recall that the total pressure of air at sea level is about 1 atm, and that air is 20.9 percent oxygen. How does the partial pressure of oxygen in the tank compare to the partial pressure of oxygen in air?
2. Heliox is a mixture of gases and is used in medicine to help people with breathing problems such as severe asthma. A typical Heliox mixture contains He at a partial pressure of 0.75 atm and O_2 at a partial pressure of 0.35 atm.
   (a) What is the total pressure of the Heliox mixture?
   (b) What fraction of the molecules in Heliox are helium?
   (c) Draw a particulate representation of Heliox that contains 10 particles.

PART 1: ANALYTICAL READING

In the first part of this lesson, students read a pair of passages about the composition of air at different altitudes in order to learn about partial pressure. The first passage pertains to the context of sports teams in Denver and a relationship between high altitude and home-field advantage.

- To begin, direct students to **Handout 2.4.A: The Chemistry of Air and Altitude** and ask them to read the passages.
- Encourage students to take notes and annotate the text in order to identify key ideas as well as any questions or uncertainties they may have.
- Before students answer the Check Your Understanding questions in the next part of the lesson, it can be helpful to assess their level of understanding of the concepts in the text. You can use questions such as the following to gauge their understanding:
  - What is partial pressure?
  - How is the partial pressure of a gas in a mixture determined?
  - Why might some athletes train at high altitudes?

Meeting Learners' Needs

If some students find the reading difficult, encourage them to try annotating the text with the following symbols:

- ? (for text that raises a question)
- ! (for text that states something new or exciting)
- * (for text that they would like to share or discuss)
- Underlining (for text that represents a key idea or important detail)

PART 2: INDIVIDUAL AND PARTNER QUESTIONS

Students first individually answer a series of text-dependent questions and then discuss their answers with a partner before revising them. The question types include reading comprehension, argumentation, and application of chemistry content, including the kinetic molecular theory and Dalton's law of partial pressures.

- Have students find **Handout 2.4.B: The Chemistry of Air and Altitude – Check Your Understanding** and instruct them to answer each question on their own, in the "My first answer, thinking on my own" box. As students answer the questions, have them look back at **Handout 2.4.A** and highlight text that is relevant to each question and number their selection so that they can refer to it in the discussion with their partner later.
- After students have had time to individually answer the questions, ask them to work in pairs to share their answers. If the two students in a pair have any answers

that differ, they should discuss those answers as needed to attempt to come to a consensus. Each student should then record their new answer in the "My revised answer after discussing it with my partner" box.

Guiding Student Thinking

The peer review and discussion of responses in this part of the lesson gives you valuable insight into student thinking. It is important to closely monitor student discussion so you can correct any potential misconceptions or student challenges regarding partial pressure.

- Consider the following as you support students in working through this part of the lesson:
  - Question 1: The mathematical relationship is described in words in the passage and then expressed as an equation at the end of it. Help students connect these two representations so they can solve the problem. You could use the oxygen example in the text. Students may also need a refresher on the relationship between percentages and decimal fractions. It may be helpful to explicitly ask students if they recall this relationship while they are working on the question, and guide them to recall that they differ by a factor of 100.
  - Question 2: Encourage students to think about what they learned about temperature, pressure, and the kinetic molecular theory in Unit 1.
  - Question 5: For part (b), students may want to use proportional reasoning instead of the formula to arrive at the answer. That is an acceptable approach, but you could also ask the students to find the answer using both methods to ensure that they understand how to use the formula.
  - Question 7: Students may find it confusing that carbon dioxide and argon are not represented in the model. Ask them to think in terms of percentages. If you're only drawing 10 particles, each particle is 10 percent of the mixture, so any gas that is less than 10 percent of air would not be represented. You could

Meeting Learners' Needs

If you have students who work at very different paces, you may want to assign pairs to start the partner discussion/revision on different questions—so some pairs will start at question 1, others with question 2, etc. This strategy ensures that at least some pairs will have answered each question before the whole-class discussion, even if all students aren't able to get to all questions.

consider asking the students how many particles they would have to draw before carbon dioxide and argon would be shown. This question also provides a good opportunity to discuss the limitations of models.

- As you circulate during the pair discussion/revision time, make note of which pairs have strong responses to each question so you can call on those students during the whole-class discussion, if needed. You can also look for groups who used different evidence in their response to each question so the class can see there may be multiple correct approaches.

PART 3: WHOLE-CLASS DISCUSSION

This final part of the lesson involves a whole-class discussion to summarize the key concepts and review the answers to the student handout questions.

- Explain to students that you are going to discuss their 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" boxes on **Handout 2.4.B**.
- Ask for volunteers to share their answers question by question. If you noticed groups that had particularly strong responses or approached the questions in a different way, you may want to call on them to highlight their responses.
- Restate, clarify, or extend the students' responses as needed to ensure that all students hear a complete response.

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. Commercial scuba divers use tanks filled with a mixture of gases known as Trimix on very long, deep dives. Trimix is composed of 70 percent nitrogen, 10 percent oxygen, and 20 percent helium. The total pressure of Trimix inside a certain tank at the beginning of a dive is 118.4 atm.

   (a) What is the partial pressure of oxygen in the tank?

   $P_{O_2} = X_{O_2} \times P_{total}$

   $P_{O_2} = (0.10)(118.4 \text{ atm})$

   $P_{O_2} = 12 \text{ atm}$

   (b) Recall that the total pressure of air at sea level is about 1 atm, and that air is 20.9 percent oxygen. How does the partial pressure of oxygen in the tank compare to the partial pressure of oxygen in air?

   The partial pressure of oxygen is air is

   $P_{O_2} = X_{O_2} \times P_{total}$

   $P_{O_2} = (0.209)(1 \text{ atm})$

   $P_{O_2} = 0.2 \text{ atm}$

   So the partial pressure of the oxygen in the scuba tank is almost 60 times greater.

2. Heliox is a mixture of gases and is used in medicine to help people with breathing problems such as severe asthma. A typical Heliox mixture contains He at a partial pressure of 0.75 atm and O_2 at a partial pressure of 0.35 atm.

   (a) What is the total pressure of the Heliox mixture?

   $P_{total} = P_{He} + P_{O_2}$

   $P_{total} = 0.75 \text{ atm} + 0.35 \text{ atm}$

   $P_{total} = 1.10 \text{ atm}$

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(b) What fraction of the molecules in Heliox are helium?

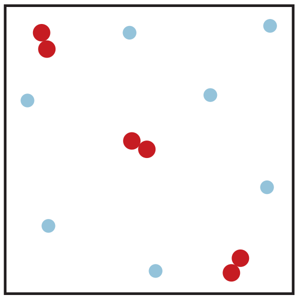
$$P_{He} = X_{He} \times P_{total}$$

$$X_{He} = \frac{P_{He}}{P_{total}}$$

$$X_{He} = \frac{0.75 \text{ atm}}{1.10 \text{ atm}}$$

$$X_{He} = 0.68$$

(c) Draw a particulate representation of Heliox that contains 10 particles.



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 2.4.B: The Chemistry of Running at High Altitude – Check Your Understanding

All answers provided here are the final correct answers after the whole-class discussion.

1. $P_{N_2} = X_{N_2} \times P_{total}$

   $P_{N_2} = (0.781)(0.987 \text{ atm})$

   $P_{N_2} = 0.771 \text{ atm}$

2. The total pressure would increase. As the gas is heated, the average kinetic energy of the particles increases, meaning that they strike the container walls more frequently and with greater force, increasing the pressure.
3. The percentage of oxygen would remain unchanged. Heating does not change the relative amount of gas particles present.
4. As in question 2, the average kinetic energy of the oxygen particles increases, meaning that they strike the container walls more frequently and with greater force, increasing the partial pressure.

5. (a) $P_{total} = P_{CO_2} + P_{Ar}$

$P_{total} = 0.080 \text{ atm} + 0.24 \text{ atm}$

$P_{total} = 0.32 \text{ atm}$

(b) $P_{Ar} = X_{Ar} \times P_{total}$

$X_{Ar} = \frac{P_{Ar}}{P_{total}}$

$X_{Ar} = \frac{0.24 \text{ atm}}{0.32 \text{ atm}}$

$X_{Ar} = 0.75$

6. Pressurize means to increase the partial pressure of oxygen. It is necessary because the atmospheric partial pressure of oxygen decreases with increasing altitude, and 10,000 m is a very high altitude, meaning that the natural partial pressure is very low. If the cabins weren't pressurized, people would have difficulty breathing and experience adverse health effects.

7. 8 nitrogen particles and 2 oxygen particles. Each particle in a representation that contains 10 particles represents 10 percent of the total. Air is about 80 percent nitrogen and about 20 percent oxygen. The other gases present represent far less than 10 percent of the particles in air, so they would not appear in this representation.

UNIT 2

LESSON 2.5

Distillation and Electrolysis Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Identification of Gases
Students are introduced to tests used to identify gases by reading a short text, answering comprehension questions, and observing a demonstration. This information sets students up to identify the gases that are produced later in this lab, during the distillation of soda and electrolysis of water.

Part 2: Distillation of Soda
Students build and use a small-scale distillation apparatus to separate components of colored soda. The purpose is for students to understand that distillation separates water from the other components of a solution only by physical means; it does not change the components. Changes in intermolecular forces are the only changes that occur.

Part 3: Electrolysis of Water
Students build a simple electrolysis apparatus out of household materials and use it to send electricity through water. The purpose is for students to determine that the gases produced when water is electrified are hydrogen and oxygen and to conclude that this change is chemical, meaning that intramolecular forces (or bonds) have been broken and formed.

CONTENT FOCUS

Students conduct two labs—distillation of soda and electrolysis of water—to determine which process overcomes intermolecular forces and which overcomes

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~90 minutes

HANDOUT

- 2.5: Distillation and Electrolysis Lab

MATERIALS

For teacher demonstration:

- copper(II) carbonate
- test tube
- lab burner
- wood splint

For each group:

- large beaker (600 or 800 mL)
- small beaker (50 or 100 mL)
- graduated cylinder
- balance
- large stopper
- colored soda
- aluminum foil
- crushed ice

intramolecular forces. A misconception some students have is that when water boils it produces hydrogen gas and oxygen gas. This misconception is directly addressed by having students determine the identity of the gases produced in both distillation and electrolysis. Students use the evidence they collect to revise their models and explain what happens in each process at the particle level. Students can return to these models as explanations throughout the unit as they explore both intermolecular and intramolecular forces in more detail.

- beaker tongs
- cobalt chloride paper
- hot plate
- clear plastic condiment cup
- plastic spoon or scoop
- two metal thumbtacks
- 9-volt battery
- distilled water
- baking soda
- two plastic pipettes
- tape (optional)
- scissors
- wood splints
- lighter
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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 charged 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.

SETUP AND PREPARATION NOTES

Part 2: Distillation of Soda

- Any colored soda works for this lab. Not all groups have to test the same brand or color of soda. There are more dramatic color changes for sodas that are blue or orange than for caramel colored.
- It is also not necessary to use soda for this lab. For some students, working with soda makes the activity more engaging, but any colored beverage will work.
- Make a sample setup as an example for students. A diagram is included on the student handout. A few things to consider for the setup include:
  - Multiple sizes of beakers can be used in this experiment. It is important to test your exact procedure for the activity in order to ensure student safety and success.
  - The stopper just acts as a base for the small beaker. Place it large side down in the large beaker. Choose a size that allows the small beaker to be stable. A size 11 stopper is a good starting point, depending on the size of your small beaker. If you don't have large stoppers, you can use a few small stoppers instead.
  - The amount of soda used will depend on the size of your large beaker. A good starting point is 50 mL, but you want the soda to be about 1 cm high in the beaker.
  - The aluminum foil should come to a sharp point over the small beaker.
  - The aluminum foil should form a tight seal at the top of the large beaker.
  - Heap the ice into the aluminum foil cone. Crushed ice works best, but you can also use ice cubes.
  - Students may need to scoop out the water as the ice melts so it does not overflow.

Part 3: Electrolysis of Water

- Make a sample setup for the students. A diagram is included on the student handout. There are also several videos on video-sharing sites that show the process.
- To save time, you can place the thumbtacks in the correct position in the condiment cup and reuse the cups.
- Students will need to hold the cup in place over the battery and hold the pipettes in place. They could also use tape to support the apparatus.

SAFETY NOTES

- All general safety guidelines should be followed.
- The entire setup in Part 2 will be warm. Remind students of this, particularly when they are starting the tests for the presence of the gases.
- Students should wear goggles throughout the lab.

PART 1: IDENTIFICATION OF GASES

Students are introduced to tests used to identify gases by reading a short text, answering comprehension questions, and observing a demonstration. This information sets students up to identify the gases that are produced later in this lab, during the distillation of soda and electrolysis of water.

- Ask students to individually read the Introduction and Part 1 on **Handout 2.5: Distillation and Electrolysis Lab**. These handout sections orient students to the goal of this lab and to some tests we can use to identify unknown gases. Students may not know what a wooden splint is, so you may want to show them one and offer a general explanation of how it is used before assigning the reading.
- Next, to help students make sense of what they have read, have them work in pairs to answer the two comprehension questions after the reading. These are shown below, with answers for reference.

Classroom Ideas

You may want to have student pairs record their answers to the comprehension questions on small whiteboards (or large pieces of paper) and then share them with the class. Knowing they will be sharing answers can help students feel more accountable for the information.

1. Which gases can be identified using a burning wood splint? How will you differentiate between the gases?
   Carbon dioxide, water vapor, hydrogen, and oxygen. Carbon dioxide and water vapor extinguish the flame, hydrogen pops, and oxygen reignites the flame.

2. Which gases can be identified using test papers? How will you differentiate between the gases?
   Ammonia, chlorine, and water vapor. Ammonia turns red litmus blue, chlorine turns blue litmus red or starch iodide paper black, and water vapor turns cobalt chloride paper pink.

Handout 2.5

Review the answers together as a class and discuss any incorrect responses. A careful review of the answers is important because students need a clear understanding of the gas tests to succeed in the lab portion of the lesson.

- Since students will likely be unfamiliar with the process of performing tests using burning splints, demonstrate a test for them. A good one to use is the test for carbon dioxide, since this test will not be used in the lab. A possible procedure for this demonstration is as follows:

  1. Heat copper(II) carbonate in a small test tube over a flame.

  2. Once the green compound has turned black and gas has accumulated, place a burning wood splint into the gaseous area.

  3. Allow students to observe that the flame is extinguished.

  4. Have students identify the gas based on the Part 1 reading and the reactant used.

  If copper(II) carbonate is not available, a test can be done by heating calcium carbonate, though no color change will occur. Alternatively, vinegar and baking soda can be reacted to form carbon dioxide for the test.

PART 2: DISTILLATION OF SODA

Students build and use a small-scale distillation apparatus to separate components of colored soda. The purpose is for students to understand that distillation separates water from the other components of a solution only by physical means; it does not change the components. Changes in intermolecular forces are the only changes occur.

- Use the Pre-Lab Questions on Part 2 of the handout to get students thinking about what will happen as soda boils. These questions are shown on the following page for reference. For the first question, you may want to share with students the list of ingredients in the colored soda that will be used in the activity.

Meeting Learners' Needs
If students struggle with question 2, you can rephrase the question as, "If you were the size of an atom, what would you see as the soda is heated over a hot plate?"

1. Is soda a pure substance or a mixture? Provide evidence to support your answer.
   Soda is a mixture because it has water, carbon dioxide, sugar, dyes, flavoring, and other ingredients physically mixed together. Each component retains its identity, even when combined in the soda. At a soda dispenser, the water and the other ingredients (the soda syrup) are mixed right before serving.
2. Read the procedure on the next page. Make a prediction about what will happen as the soda boils in a closed container. Then, in the space below, draw a particle diagram to model your prediction.
   Responses and models will vary. It is okay for the predictions to be incorrect. Many students will think the entire soda will boil and will all turn to gas at the same time. Encourage students to use different colored circles for the different parts in the mixture of soda.

Handout 2.5

Allow students time to answer the questions individually; then have them share their responses with their lab groups. Address any questions that arise as students are discussing in their groups.

Instructional Rationale

Predictions are often overlooked when conducting a lab investigation. You can gain a lot of insight about students' misconceptions from explanations they create or models they draw based on their early thinking. Try to read the predictions as the students are working on the lab to spark questions and insights that will help students better understand the flaws in their predictions and models.

- Show students your example setup for the lab and walk them through the procedure they will perform. Let students know that goggles must be worn at all times. Although only aqueous solutions are being boiled, glass is being heated and liquid can splatter.

Instructional Rationale

Many distillation techniques can be too abstract for students to completely understand. One advantage of the cold-finger technique used here is that is easier for students to determine what happens.

- Allow student groups to carry out the lab and complete all sections of Part 2 of the handout. As you circulate around the room while student are working, offer the following types of support:
  - Check to ensure the aluminum foil is fitted to the beaker so vapor cannot escape. You can also check for holes in the aluminum foil, that the cone comes to a point above the small beaker, and for the water level in the cone as the ice melts.
  - Depending on the soda you choose, there may be a visible color change as the concentration changes. You could ask students to take pictures before and after for comparison.
  - Students may notice that the volume of the solution increases. Ask them to consider where the extra volume came from.
  - During the lab, be mindful not to refer to the vapor as water because students are trying to determine that information. Ask students what they think the vapor is and to provide evidence for their claim.
  - When different groups are ready to do the tests using cobalt chloride paper and the wooden splints, you may want to stay close in case they need help. Remind students that the beakers and aluminum foil will be hot and they should be careful.
  - Density, burning wood splint tests, and cobalt chloride test strips should suffice to determine that the vapor and the liquid inside the small beaker are water.
  - Question 5 asks students to evaluate and revise their earlier prediction and model for the lab. Encourage them to consider which components were separated out of the soda mixture and ended up in the small beaker. Then, support them in thinking about whether the evidence from this lab shows a change in the identity of any of the soda components.

Classroom Ideas

For question 5, you may choose to have each team create a revised model on a whiteboard before drawing it on their handout.
One student can stay at their lab station with the whiteboard to defend their depiction while the others migrate around to other lab stations in order to observe their peers' models. Migrating students can give "warms" and "cools" about each other's models and then return to their team to amend their own whiteboard model before drawing it on their lab activity handout as a final version.

PART 3: ELECTROLYSIS OF WATER

Students create a simple electrolysis apparatus out of household materials and use it to send electricity through water. The purpose is for students to determine that the gases produced when water is electrified are hydrogen and oxygen and to conclude that this change is chemical, meaning that intramolecular forces (or bonds) have been broken and formed.

- Use the Pre-Lab Question in Part 3, shown below, to orient students to the procedure and to elicit a model-based prediction about what will happen as electricity is conducted through water. After students have had time to make their predictions, ask them to share with a partner.

PRE-LAB QUESTION

Read the procedure below. Predict what will happen as electricity is conducted through water. In the space below, draw a model to help explain your prediction.

Responses will vary. Students might predict that the water will evaporate, explode, or separate into components. Students should develop a model that supports their line of thinking.

Handout 2.5

- Show students your example setup for the lab and walk them through the procedure they will perform. One student should hold the cup over the battery, ensuring the terminals on the battery are touching the thumbtacks. A second student should hold the plastic pipettes over the thumbtacks to trap the generated gases. Students can also decide to tape the pipettes in place. A third student should cut the plastic pipette when gas has evolved while another student brings a burning wood splint near the gas. This last step has to be done quickly and efficiently, but also very carefully.

  Now is also a good time to introduce students to the word *electrolysis*, which may be unfamiliar. If possible, help them decode the word instead of just providing a definition. Students might recognize the root word *lysis*, meaning "to break down," from studying lysosomes in biology.

- Have students work in groups of 3 or 4 to conduct the lab and complete the Analysis questions on the handout. As you circulate around the room, take a look at students' predictions and use them to guide your support for each group. As groups get to the part where they test for various gases, you may want to be close by to help them with the process.

- Once students have finished the questions, ask them to work with another group to compare their revised models from question 4 and their explanations for question 5. After each group has had time to share, allow groups time to revise their models and explanations.

Guiding Student Thinking

Students' models may not show that oxygen and hydrogen are diatomic gases, but that is not a problem at this point. As long as their model indicates twice as much hydrogen as oxygen, they have understood the main point of the lab. You can return to these models as students learn about diatomic substances and ask students to revise their model again.

- Once all groups have finished the experiment, lead a whole-class debrief on both parts of the lab. You can use both sets of Analysis questions to guide your discussion. The key points students should leave with are that distillation overcame intermolecular forces in water and separated just the components of a mixture, while electrolysis broke the bonds within a molecule of water, forming new substances.

UNIT 2

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 2.5: Distillation and Electrolysis Lab

Part 1

Answers are provided in the lesson.

Part 2

Pre-Lab Questions

Answers are provided in the lesson.

Observations and Data

Student answers will vary. Sample data are provided below for reference.

General observations	Clear liquid evaporated from the soda and condensed onto the aluminum. That liquid dropped into the smaller beaker. The soda appears to be a darker color as the process continues.
Results of cobalt chloride paper test	The paper turned pink.
Results of burning splint test	The flame was extinguished.

Volume of soda	50.0 mL
Mass of small beaker	50.0 g
Mass of small beaker with liquid	60.0 g
Volume of liquid in small beaker	10.0 mL
Volume of leftover liquid in large beaker	42.0 mL

Analysis

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

1. mass of liquid = 60.0 g − 50.0g = 10.0 g

   $D = \frac{m}{V}$

   $D = \frac{10.0 \text{ g}}{10.0 \text{ mL}}$

   $D = 1.00 \text{ g/mL}$

2. Water vapor. We knew it was either carbon dioxide or water vapor because the splint was extinguished. The cobalt chloride paper turned pink, indicating it was water vapor.
3. I think the liquid in the small beaker is water. I think this because the density of water is 1.00 g/mL, which is what I calculated as the density in question 1.
4. The other parts of the mixture that makes up soda were left in the large beaker. These include the caramel color, flavorings, etc.
5. Students answers will vary, but should reflect the understanding that the soda began to separate into what makes up the mixture as the water boiled and condensed into the small beaker, leaving behind other substances such as sugar and flavoring.
6. No. The data we collected in this lab showed only that boiling separated components of the mixture by causing water to change phase.
7. Boiling breaks intermolecular forces. The water molecules from the soda stayed the same; there were just changes in the distances between the molecules when the water changed phase.
8. Water vapor in the air inside the beaker could also have condensed, increasing the total amount of liquid.

Part 3

Pre-Lab Question

Answers are provided in the lesson.

Observations

Student answers will vary. Sample responses are provided below for reference.

Volume of gas in each pipette	One pipette has twice as much gas as the other.
Results of burning splint test on pipette #1	The burning splint "popped."
Results of burning splint test on pipette #2	The burning splint reignited.

Analysis

1. Hydrogen was in one pipette and oxygen was in the other. One burning wood splint popped, indicating that hydrogen gas was present in one pipette. The other splint reignited, which shows that oxygen gas was present in the other pipette.
2. The pipette with hydrogen contained more gas. Water has two hydrogen atoms for each oxygen atom.
3. Electrolysis is a chemical change because the process changed water into separate substances, hydrogen gas and oxygen gas. The production of a new substance is a chemical change.
4. Students answers will vary but should reflect the understanding that chemical bonds between hydrogen and oxygen atoms in water molecules were broken, and bonds were formed between hydrogen atoms and between oxygen atoms.
5. Distillation overcomes intermolecular forces between the water molecules as the water boils and then forms intermolecular forces between the water molecules as the water condenses. Electrolysis breaks intramolecular bonds between the atoms within each water molecule, forming hydrogen and oxygen separately.

LESSON 2.6

UNIT 2

Launch Lesson – Comparing Methane and Butane

OVERVIEW

LESSON DESCRIPTION

In this lesson, students observe and compare methane and butane under different conditions. Their observations and explanations lead to a class discussion about the role of intermolecular forces in physical properties.

CONTENT FOCUS

In Unit 1, students learned about the energy involved in phase changes, and earlier in Unit 2, students examined how intermolecular forces change during distillation. Now, in this launch lesson, students use that knowledge and continue to develop an understanding of intermolecular forces by explaining why methane gas and butane gas behave differently when exposed to the same conditions. This lesson is designed to set students up for subsequent lessons about the different types of intermolecular forces and why they have different strengths.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 2.6.A: Comparing Methane and Butane
- 2.6.B: Comparing Methane and Butane – Particle Diagrams

MATERIALS

- two 1-quart plastic freezer bags
- mixing bowl (glass, plastic, or stainless steel) or large beaker for ice bath
- spatula or spoon
- sodium chloride
- ice
- butane spray can
- methane gas
- cryo-gloves or heavy winter gloves
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- You can purchase cans of butane at most home improvement stores. Make sure you purchase one with a spray nozzle, not the type designed to be connected to other equipment.
- Before the demonstration, prepare an ice bath with a 1:3 mass ratio of sodium chloride to ice in a glass, plastic, or stainless steel bowl or a beaker large enough to accommodate a quart-sized freezer bag. For a 1-quart freezer bag, 100 g of sodium

chloride and 300 g of ice works well. Stir the mixture thoroughly. The temperature of the ice bath should be between −10°C and −20°C. Since the boiling point of butane is −1°C, the ice bath will condense the butane quickly.

SAFETY NOTES

- All general safety guidelines should be followed.
- Wear gloves when depressing the nozzle of the butane can: the rapid drop in pressure along with the vaporization of the butane liquid can cause frostbite.
- Both butane and methane are highly flammable. Make sure you are not near a flame or electrical equipment. Release gas into the hood at the end of the demonstration.

LAUNCH LESSON

Students observe demonstrations of phase changes of methane and butane and use their observations to begin to develop their ideas about intermolecular forces.

- To begin the lesson, it may be helpful to show students models of both methane and butane molecules. Students should be familiar with the structure of butane since they used it in an earlier lesson, but methane may be new to them.
- When you are ready to begin the demonstration, put the opening of a freezer bag over the opening of a methane gas valve (such as those on your lab tables, if you have natural gas) and zip it as tightly as possible around the opening. Fill the bag until it is nearly taut. Quickly seal the bag as you remove it from the valve.
- Next, pass the bag around to the students and let them make observations. Ask them to record their observations in the first row of the table at the top of **Handout 2.6.A: Comparing Methane and Butane**, in the Demonstration 1 – Methane and Butane in Freezer Bags section, shown here for reference.

DEMONSTRATION 1 – METHANE AND BUTANE IN FREEZER BAGS

OBSERVATIONS

Your teacher will perform a demonstration using methane and butane. Record your observations in the following table.

Methane Bag	
Butane Bag	

Handout 2.6.A

- Put the opening of a second freezer bag over the butane spray-can nozzle and zip it as tightly as possible around the opening. Press the nozzle for about 5 seconds. The bag should be partially inflated, and several milliliters of liquid butane will be in it. Quickly seal the bag as you are removing it from the nozzle.
- Once the butane bag is sealed, move the liquid around within the bag to aid in the vaporization process. Then pass it around the room to allow students to feel the temperature change of the bag as it inflates. Ask students to record their observations in the second row of the table at the top of the handout.

- Now ask students to individually answer the questions for Demonstration 1 on their handout. After students have had a chance to work individually, have them discuss their responses with a partner and revise their answers as needed.
- Once students have had a chance to revise their answers based on the partner discussion, lead a whole-class discussion about what they observed and how it connects to intermolecular forces, using the questions from the handout as a starting point. The questions are also included here, with model responses for students' final answers provided.

Meeting Learners' Needs
If you think students will need additional support with the questions, consider stopping to discuss each one as a class as students work through them, rather than having students complete them all individually first.

1. At room temperature, water is a liquid, the butane in the can is a liquid that quickly vaporizes when released (because it is a volatile liquid), and methane is a gas. Compare the strength of the intermolecular attractive forces between neighboring molecules for these three substances.

   Water has the strongest attractive forces and methane has the weakest. As the strength of attractive forces increases, fewer molecules can escape to the gas phase and the boiling point increases.

2. Think back to what you learned about gases and phase diagrams in Unit 1. Why was butane a liquid when it first came out of the can?

   When the butane was in the can, it was under high pressure, so it was a liquid. Once it was out of the can, the pressure decreased to atmospheric pressure. As it adjusted to atmospheric pressure and room temperature, the butane became a gas.

3. Why is the butane bag cold but the methane bag is not?

   Energy is required to break the attractive forces between neighboring molecules during vaporization of butane. Vaporization is an endothermic process. The energy is absorbed from the surroundings, resulting in a decrease in temperature. There was no phase change for the methane, therefore no energy was transferred.

4. If water condensed on the exterior surface of the butane bag, what caused this to happen?

   The vaporization of butane involves the absorption of energy from water molecules in the air. This loss of energy by the water molecules causes them to slow down and get close enough to each other to form attractions between neighboring molecules and condense into liquid water.

5. Once the bags are at about the same temperature, which of the gases has the higher average kinetic energy?

   Since temperature is a measure of average kinetic energy, the gases would have the same average kinetic energy.

- After you have discussed the vaporization of butane and the comparison between methane and butane, put the methane bag onto the ice bath. The bag may deflate a bit due to temperature change, but the methane will not condense since it has a boiling point of −162°C. Ask students to record their observations in the first row of the table in the second section of **Handout 2.6.A: Comparing Methane and Butane**, Demonstration 2 – Methane and Butane Bags in an Ice Bath, shown here for reference.

DEMONSTRATION 2 – METHANE AND BUTANE BAGS IN AN ICE BATH

OBSERVATIONS

Your teacher will perform a demonstration using methane and butane. Record your observations in the following table.

Methane Bag	
Butane Bag	

Handout 2.6.A

- Next, put the butane bag onto the ice bath. The bag should begin to deflate, and the gas should condense inside it. Ask students to record their observations in the second row of the table.
- Now ask students to answer the questions about Demonstration 2 on their handout. You can follow the same process you used for the previous set of questions, leading into a whole-class discussion about what students observed and how it connects to intermolecular forces. The questions and sample responses are included on the following page.

1. What happens to the gas molecules in the methane bag as the temperature decreases?

   The gas molecules slow down and move closer together, causing the bag to deflate slightly.

2. What happens to the gas molecules in the butane bag as the temperature decreases?

   The gas molecules slow down. Eventually they move close enough together to form attractions between neighboring molecules and condense to form a liquid.

3. What role does the ice bath play in this process?

   Condensation is an exothermic process; heat is released to the surroundings. The ice bath absorbs this heat to continually shift the process in the direction of condensation.

4. Why doesn't the methane gas condense?

   The gas molecules slow down. Although they are somewhat closer together, the attractions between neighboring molecules are not strong enough for the gas to condense to form a liquid at the temperature of the ice bath. The boiling point of butane is −1°C and that of methane is −162°C.

5. What difference between methane and butane could account for this different behavior?

   Answers will vary. Butane is a larger molecule than methane.

Instructional Rationale

The next lesson introduces students to types of intermolecular forces. The last question above is designed to prime students' thinking about this topic and provide a reference point for later learning.

- Finally, ask students to work with a partner on questions 1 and 2 on **Handout 2.6.B: Comparing Methane and Butane – Particle Diagrams**. These questions ask students to create particle diagrams representing the processes observed in the lesson. Encourage students to find a way to represent changes in kinetic energy and a way to represent intermolecular forces.
- After students have drawn their models, have them complete questions 3 and 4 on the handout, sharing with another group to get feedback. Allow students to revise their models based on the feedback they receive.
- Finally, identify a few models to share with the whole class. If possible, identify models that represent the processes differently.

UNIT 2

ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

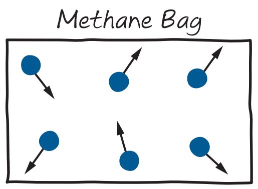
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

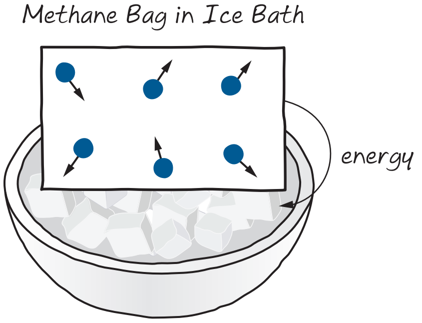
Handout 2.6.A: Comparing Methane and Butane

Answers are provided in the lesson.

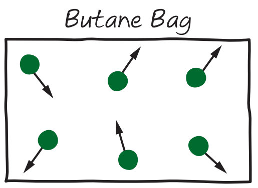
Handout 2.6.B: Comparing Methane and Butane – Particle Diagrams

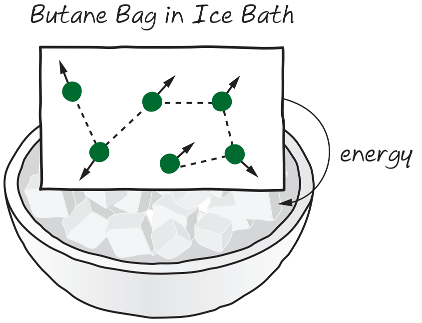
1.





2.





3. Answers will vary.

4. Answers will vary.

LESSON 2.7

Exploring Intermolecular Forces

UNIT 2

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring Boiling Points and Evaporation Rates

Students examine data about boiling points of alkanes and collect data about evaporation rates of alcohols to identify patterns. Students are challenged to determine possible reasons for these patterns, based in part on prior knowledge from the course.

Part 2: Relating Boiling Point Trends to Intermolecular Forces

In this part of the lesson, students are introduced to the different types of intermolecular forces through a video and a graphic organizer. They reevaluate their explanations from Part 1 with this new information about IMF.

Part 3: Comparing Relative Strengths of Intermolecular Forces

In this part of the lesson, students use a simulation to explore the relative strengths of intermolecular forces. In the simulation, the molecules initially represent the liquid state. Students pull the molecules apart to simulate evaporation or boiling and compare the relative ease of separating the pairs of molecules. They relate the strength of the intermolecular forces back to boiling points from the beginning of the lesson.

AREAS OF FOCUS

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

SUGGESTED TIMING

~90 minutes

HANDOUTS

Lesson

- 2.7.A: Exploring Boiling Points and Evaporation Rates
- 2.7.B: Types of Intermolecular Forces
- 2.7.C: Relative Strengths of Intermolecular Forces

MATERIALS

For each group:

- cotton swabs
- *n*-propanol
- *n*-butanol
- ethanol
- stopwatch
- goggles

CONTENT FOCUS

This lesson builds on the introduction to attractive forces from Unit 1 and earlier in Unit 2. Students construct their own knowledge about intermolecular forces by examining data about trends in boiling points of alkanes and exploring evaporation rates of alcohols. In the lesson, students are encouraged to relate patterns in the macroscopic properties of substances to chemistry principles at the molecular or atomic level, and to use their knowledge from Unit 1 on phase changes to inform their explanations. They then relate their understanding of the energetic process of boiling and evaporation to the strength of interactions between the molecules.

This lesson is scaffolded so students first examine groups of molecules that exhibit only dispersion forces before they examine groups of molecules that exhibit dipole–dipole forces or hydrogen bonding. Students will continue to learn about the types of intermolecular forces, and how they influence the properties of matter, throughout the unit and particularly in their study of molecular geometry.

- computers/tablets with internet access to the Comparing Attractive Forces simulation from the Concord Consortium (available at **lab.concord.org/embeddable.html#interactives/interactions/comparing-attractive-forces.json**)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings
▪ 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.

Learning Objectives	Essential Knowledge
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.

SETUP AND PREPARATION NOTES

- Students will need access to the cotton swabs, alcohols, stopwatch, and goggles for question 5 of Handout 2.7.A.

SAFETY NOTES

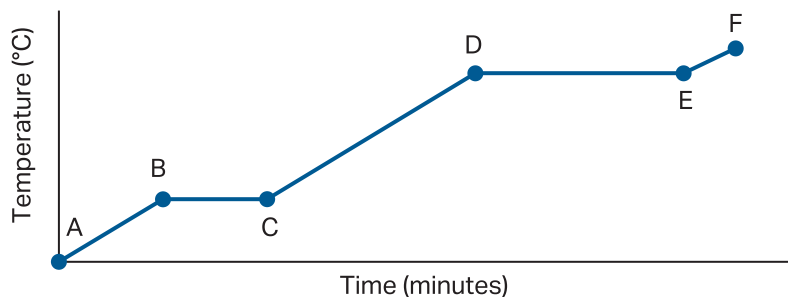
- All general safety guidelines should be followed.

PART 1: EXPLORING BOILING POINTS AND EVAPORATION RATES

In the first part of this lesson, students examine data about boiling points of alkanes and collect data about evaporation rates of alcohols to identify patterns. Students are challenged to determine possible reasons for these patterns, based in part on prior knowledge from the course.

- Lead into the topics of boiling points and evaporation rates by having students revisit the process of identifying boiling and melting points on a heating curve. Call on students to describe what is happening during those phase changes, including any changes that occur at the molecular level. You can show a heating curve like the one below for this brief review.

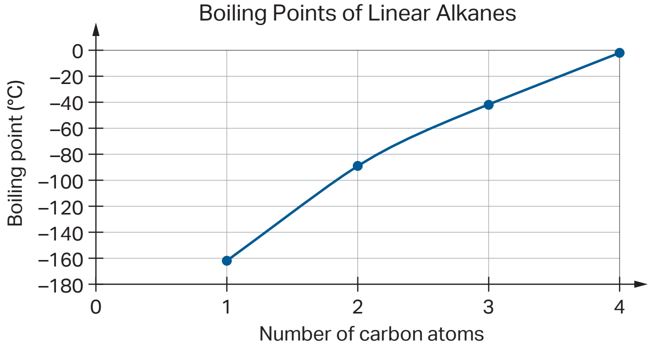
Heating Curve



- Next, ask students to find **Handout 2.7.A: Exploring Boiling Points and Evaporation Rates** and give them time to examine the data table and graph of boiling points, reproduced below and on the following page.

Substance	Boiling Point (°C)
Methane (CH_4)	–162
Ethane (C_2H_6)	–89
Propane (C_3H_8)	–42
Butane (C_4H_{10})	–1

Handout 2.7.A



Handout 2.7.A, continued

- Ask students to work with a partner to respond to questions 1 and 2 on the handout, which guide students to identify and try to explain trends in the data. As you circulate around the room while students are working, you can support students' critical thinking with prompts such as the following:
  - How are the molecules different? How are they the same?

    Sample responses: Numbers of atoms are different; masses are different; all have carbon atoms; all have hydrogen atoms.
  - What must happen in order for a substance to boil?

    The molecules in the liquid must separate completely from one another to exist as a gas.
  - How is temperature related to the movement of the molecules?

    Temperature is directly proportional to the movement of the molecules and the average kinetic energy.
- When students have completed questions 1 and 2, ask a few pairs to share their thoughts about the molecular differences that are responsible for differences in the boiling points. Try to call on students who have different explanations so the class is exposed to a few different working theories.

  Some students will likely identify that the size of the molecule (or mass or surface area) is the main factor that affects boiling point, reasoning that "it takes more energy to get bigger, heavier particles moving." This hypothesis is consistent with the data. Data shared later in the lesson will require them to refine this hypothesis.

To extend their thinking about intermolecular forces, students next collect data about the evaporation rates of some alcohols.

Instructional Rationale

The extension to evaporation is included so students can begin to develop an understanding of the many properties of a substance that are affected by the strength of its intermolecular forces. Also, this step allows students to further explore their initial ideas about what factors influence the boiling point of a substance.

- Let students know that they will conduct a short experiment to determine which of three alcohols evaporates fastest. Explain that the alcohols they will use have a similar structure to the alkanes listed in the table on the handout but are readily available in the liquid state. Then, to activate prior knowledge relevant to this experiment, lead a whole-class discussion about the relationships between boiling and evaporation. Some questions you can ask include:
  - How is evaporation different from boiling?

    Boiling is when the vapor pressure of the substance equals the atmospheric pressure. Evaporation is the ability of surface molecules to escape the liquid state, even if the liquid isn't at the boiling point.
  - How is evaporation similar to boiling?

    Both involve the phase change of liquid to gas.

  At this time, you can also help students synthesize new information about alkanes and alcohols, with prompts such as the following:
  - Why can't we use the alkanes listed in the boiling point data table for the experiment?

    The alkanes listed are all gases at room temperature, and therefore can't be used to determine which evaporates first.
  - Why can we smell the alcohols when the bottles are opened? What is happening at the particle level?

    In the bottles, the particles that have evaporated are trapped above the liquid. When the bottles are opened, the particles are released, diffusing throughout the room.

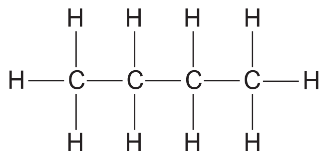
Guiding Student Thinking

When discussing smell, encourage students to refer back to what they learned about diffusion in Unit 1. Elicit from the class the understanding that we smell a substance when particles of it reach our nostrils, just like we taste a substance when particles of it touch our tongue.

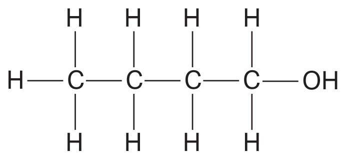
- Why might it make sense to use alcohols to determine the evaporation rate?

  They are structurally similar to the alkanes so they may behave in similar ways, but they are available as liquids that readily evaporate.

- Help students connect the structures of the three alcohols—propanol, butanol, and ethanol—to the structure of the alkanes examined earlier. One approach is to display structural formulas of butane and butanol (shown below) and have students identify the difference. Students will already be somewhat familiar with the structure of butane from Lesson 2.2. You could also give students the formulas of all the alcohols and ask them to match each to its corresponding alkane.



Butane



Butanol

- Ask students to work with their partners to make predictions about and then collect data on how quickly the three alcohols evaporate, as directed in questions 3–7 on the handout. (Students will need access to cotton swabs and the three alcohols for this portion of the lesson.) The following are some ways you can support students as they are working:
  - In questions 3 and 4, students are asked to predict which alcohol will evaporate fastest and to draw a particle diagram representing evaporation. To help students with their predictions, ask them to examine the data about the boiling points of the alkanes again and to think about how evaporation and boiling are similar.
  - For question 5, you may want to have each member of the group collect their own data on evaporation rates and then have them share with their group and record average times. As students work, encourage them to compare their evaporation data to the boiling point data for the alkanes to identify any trends.
- When students have finished, bring the class together for a discussion of question 7, which asks about molecular differences that might be responsible for the differences in the evaporation rates.

  Students should observe that the trends in the evaporation rates seem to match those for boiling points, and they are likely to cite the same factor(s) they cited previously (such as size or mass) as the reason for the differences.

Instructional Rationale

At this point, having observed two sets of data, students might start feeling like they have the relationship between molecular structure and boiling point/evaporation rate figured out. The data table below will help students see that they don't necessarily have the full picture and motivates the transition into Part 2.

- Now show or display a third data table, provided below.

Substance	Boiling Point (°C)
Methane (CH_4)	–162
Nitrogen monoxide (NO)	–152
Ammonia (NH_3)	–33

Invite students to spend a few moments studying the table. Then ask:

- What do you notice about the molecules in this data table, compared to those in the data sets we looked at earlier?

  Students should note that the molecules in this data set vary more from one another in terms of molecular structure than those in previous data sets. The molecules listed in this data table are subject to different types of intermolecular forces, although students will be unaware of this.

- Are these data consistent with your previous explanations about the boiling point and evaporation rate of a substance?

  Students will likely find that their previous explanation is not sufficient in this case. In the new data set, molecules with similar mass (CH_4 and NH_3) have very different boiling points. Similarly, the number of carbon atoms isn't relevant, since not all molecules have carbon atoms. The number of atoms in total also doesn't appear to be a factor in determining boiling point.

PART 2: RELATING BOILING POINT TRENDS TO INTERMOLECULAR FORCES

In this part of the lesson, students are introduced to the different types of intermolecular forces through a video, a reading passage, and a graphic organizer. They reevaluate their explanations from Part 1 with this new information about IMF.

- To begin, show students a video of a gecko climbing a wall. You can find many options on video sharing sites such as YouTube.
- Ask students to discuss with a partner how they think geckos are able to climb walls. Ask for a few volunteers to share their thoughts. Then have students read the passage on **Handout 2.7.B: Types of Intermolecular Forces** from *ChemMatters* about how intermolecular forces and the structure of a gecko's feet are the key. You might want to have student volunteers read the passage aloud and stop after each paragraph to discuss as a class.
- When students have finished reading the passage, prompt them to make connections between the intermolecular forces described in the passage and the boiling point and evaporation data. The following prompts might be helpful:
  - What are the forces that allow geckos to stick to walls?

    The intermolecular forces between the molecules of the feet of the gecko and the wall, specifically London dispersion forces, allow the feet to stick to the wall.
  - Why do London dispersion forces occur?

    The motion of electrons causes temporary, uneven distribution of electrons in molecules. This uneven distribution causes regions of partial positive and negative charges. These partial charges induce dipoles on neighboring molecules.
  - Do you think there could be a substance that geckos cannot stick to?

    Answers will vary. An accurate response is that, yes, in some substances, the distribution of charge is too small for there to be an electrostatic interaction with the feet of the gecko—for example, with Teflon, or something coated with oil.

Meeting Learners' Needs

If students struggle with unfamiliar vocabulary in the reading, ask them to circle or highlight those words and then attempt to define them based on how they are used. Allow students time to compare their definitions with a partner.

Students might need support to understand that the term *van der Waals forces*, which is used in the passage, is an umbrella term for types of intermolecular forces.

- How is the phenomenon of a gecko's feet sticking to a wall similar to the behavior of molecules in a liquid state?

  The intermolecular forces between molecules in a liquid cause them to stick together and stay liquid.

- Now is an appropriate time to give students more details about the different types of intermolecular forces. Handout 2.7.B has a graphic organizer on which students should record important information about each type. You might consider giving a brief lecture and having students use their graphic organizer as a tool for note-taking. Alternatively, students could read an additional passage, watch a video, or conduct their own research to learn more about the three types of IMF.
- Next, have each student work with a partner to answer the Check Your Understanding questions that follow the graphic organizer. These questions require close observation and analysis of the information in the passage, the completed graphic organizer, and the data from earlier in the lesson. Circulate around the room, examine student work, and promote critical thinking by asking questions based on their responses.

Guided Student Thinking

For the graph before Check Your Understanding questions 4–6, students may need help understanding that the group number in the key tells them the group of the element that is bonded to hydrogen in each compound.

Come together for a whole-class discussion about the differences between the types of intermolecular forces and their effects on properties of substances. In addition to the questions on the handout, some guiding prompts for the class discussion could include:

- What are the two main factors that determine the boiling point of a substance?

  The two main factors are the size of the molecule and the types of intermolecular forces between molecules.

- What is the relationship between size of molecule and boiling point?

  For molecules with only London dispersion forces, as size increases, the boiling point of the molecule increases as well.

- Why is hydrogen bonding the strongest type of intermolecular force?

  The large electronegativity difference between hydrogen and nitrogen, oxygen, or fluorine creates a more unequal sharing of electrons, which creates stronger dipoles.

- Explain how boiling point relates to the strength of intermolecular forces in a liquid.

  The boiling point of a substance describes the energy that must be added in order for the molecules of that substance to break apart from their neighbors and exist freely as a gas. The higher the temperature necessary to boil the substance, the stronger the IMF of the molecules in its liquid state. So, lower boiling points indicate weak forces that are easily broken with little energy, while high boiling points indicate strong forces that require significant energy to break.

PART 3: COMPARING RELATIVE STRENGTHS OF INTERMOLECULAR FORCES

In this part of the lesson, students use a simulation to explore the relative strengths of intermolecular forces. In the simulation, the molecules initially represent the liquid state. Students pull the molecules apart to simulate evaporation or boiling and compare the relative ease of separating the pairs of molecules. They relate the strengths of the intermolecular forces back to the boiling points from the beginning of the lesson.

- Have each student work with a partner through the guided steps of the simulation on **Handout 2.7.C: Relative Strengths of Intermolecular Forces**. The steps and table for responses are shown below and on the following page for your reference. (Note that the handout directs students to try only the first three of the four sets of molecules available in the simulation. The fourth set involves dipole-induced dipole forces and therefore is beyond the scope of the course.)

SIMULATION AND RECORDING DATA

1. Open the Comparing Attractive Forces simulation from the Concord Consortium (**lab.concord.org/embeddable.html#interactives/interactions/comparing-attractive-forces.json**).

2. Predict how difficult it will be (easy, medium, or hard) to pull apart each of the different combinations of molecules listed in the table below. Record your predictions in the second column of the table.

Handout 2.7.C

3. From the menu in the simulation, select each pair of molecules to separate and use the green star to move one molecule away from the other. Describe the difficulty of separating the molecules—easy, medium, or hard—in the third column of the data table. Repeat for the other two combinations of molecules listed in the table.

4. In the last column, identify the type of intermolecular forces the molecules exhibit.

Molecules	Prediction	Actual	Type of IMF
H_2 and H_2	Answers will vary.	easy	LDF
Br_2 and Br_2	Answers will vary.	medium	LDF
HBr and HBr	Answers will vary.	hard	dipole–dipole

Handout 2.7.C, continued

When students have completed the simulation, have them move on to the Analysis questions. As you circulate while students work, support them in answering the questions. The questions and sample responses are shown below and on the following page.

ANALYSIS

1. Explain why you classified the intermolecular forces the way you did for each pair of molecules, taking into account how hard they were to separate.

   It took a medium amount of force to separate Br_2 and Br_2. It took little force to separate H_2 and H_2, indicating weaker IMF. It took a significant amount of force to separate HBr and HBr, indicating stronger IMF.

2. Explain how the strength of intermolecular forces is related to the boiling point of a substance.

   The stronger the intermolecular force, the more energy is required for the molecules in the liquid state to break free from their neighbors and become a gas, meaning substances with stronger IMF have higher boiling points.

Handout 2.7.C

3. How does the boiling point temperature relate to the ease of separating the molecules in the simulation?

   A lower boiling point corresponds to easier separation of molecules. A higher boiling point corresponds to harder separation of molecules.

4. Predict the boiling points of HBr, H_2, and Br_2. Research the actual boiling points of HBr(*aq*), H_2, and Br_2. How close were you to the accepted values?

   Predictions and answers will vary. Accepted values: HBr(*aq*) = 122°C, H_2 = −253°C, Br_2 = 59°C.

Handout 2.7.C, continued

- Come together for a whole-class discussion to help students connect the representations in the simulation to what they have learned about intermolecular forces. Some guiding prompts for the discussion could be:
  - What does the difficulty of separating the molecules represent in the simulation?

    The pull represents the amount of energy needed to separate the molecules and allow them to exist as a gas.
  - What is different about the orientation of the HBr molecules when compared to the H_2 and Br_2 molecules?

    HBr has a permanent dipole, where Br is the negative end and H is the positive end. One molecule of HBr is oriented upside down, and the other is right side up. In H_2 and Br_2 there are only temporary dipoles, so the molecules connect in any orientation. The simulation doesn't show the temporary positive and negative regions of each molecule.
  - What are some of the limitations of the simulation that you investigated?

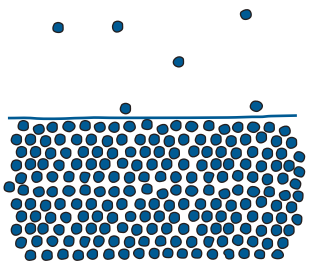
    Sample responses: The simulation shows only two molecules at a time.
    The relative strengths of the intermolecular forces are difficult to compare.
    The temporary dipoles are not represented for H_2 and Br_2.

ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

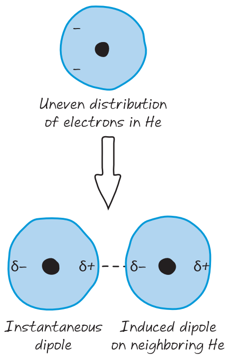
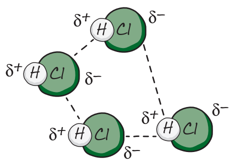
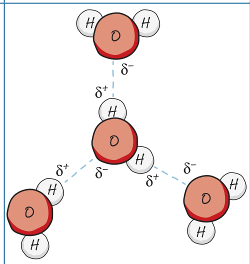
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 2.7.A: Exploring Boiling Points and Evaporation Rates

1. Answers will vary but may include:
    - The number of carbon atoms increases.
    - The number of hydrogen atoms increases.
    - The boiling point increases with these changes.
2. Answers will vary but may include the sizes of the molecules or the additional atoms.
3. Answers will vary. Ethanol should evaporate fastest, if the pattern for evaporation is the same as the pattern for boiling point, since it is the one with the fewest carbons.
4. 
5. Times will vary based on conditions in the room, but ethanol should evaporate the fastest and butanol the slowest.
6. Answers will vary.
7. Answers will vary but, as in question 2, may include the sizes of the molecules or the additional atoms.

Handout 2.7.B: Types of Intermolecular Forces

Types of Intermolecular Forces Graphic Organizer

	London Dispersion Forces	Dipole–Dipole Forces	Hydrogen Bonding
Where does this IMF occur?	Between all molecules	Between polar molecules	Between molecules that have H bonded to N, O, or F
What causes the IMF?	Random movement of electrons that creates temporary dipoles; more electrons mean stronger LDF.	Permanent dipoles	Permanent dipoles
Relative strength compared to other forces	Generally the weakest, but can be strong in large molecules	Generally in the middle	Generally the strongest
Does the presence of this IMF indicate that a substance will have relatively high melting and boiling points?	No	Somewhat	Yes
Does the presence of this IMF indicate that a substance will likely be soluble in water?	Generally, no	Generally, yes	Generally, yes
Example of a substance in which this kind of IMF occurs	a sample of helium gas	HCl	H_2O
Diagram			

Handout 2.7.B

Check Your Understanding of Intermolecular Forces

1. *Temporary dipole* refers to the uneven distribution of charge resulting in a positive region and a negative region of space around the molecule. This is not permanent since the electrons can reposition and become evenly distributed.
2. Of these substances, the molecules with the largest surface area or the most atoms would have the strongest London dispersion forces. So, the total strength of London dispersion forces must be contributing to the trend in boiling points.

3. The polar molecules have stronger intermolecular forces than the nonpolar molecule. For the two polar molecules, there must be a difference in the strength of the polarity of each of the molecules. Since the boiling point of NO_2 is higher, it must have a stronger polarity.
4. SiH_4 has the stronger intermolecular force since it boils at a higher temperature. The higher boiling point indicates a stronger attractive force between molecules.
5. Group 14 contains no atoms that are capable of forming hydrogen bonds. Therefore, the molecules all only have London dispersion forces.
6. London dispersion forces are the weakest forces, as seen in Group 14, where that is the only force for those molecules. The strongest force is hydrogen bonding, as indicated on the graph; those molecules have significantly higher boiling points than their counterparts in the other groups.

Handout 2.7.C: Relative Strength of Intermolecular Forces

Answers are provided in the lesson.

LESSON 2.8

Evaporation and Intermolecular Forces Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Pre-Lab

In this portion of the lesson, students are introduced to information about the relationships between the observed temperature change during evaporation, the evaporation rate, and the strength of intermolecular forces (IMF). They identify types of IMF in substances they will use in the upcoming lab and make predictions about the relative evaporation rates of these substances. Finally, students watch a demonstration of the procedure they will use in the data collection portion of the lesson.

Part 2: Data Collection and Analysis

In the second part of the lesson, student groups work in the laboratory to collect data on the temperature change during evaporation of two liquids, either isopropanol and acetone or methanol and pentanol. They report their temperature change data to the class. Groups then use this class data to draw conclusions about the effects of molecule size and hydrogen bonding on IMF strength.

Part 3: Ethanol Prediction and Testing

Students predict the temperature change for ethanol and justify their predictions based on earlier results and their understanding of IMF. They then test their predictions.

AREAS OF FOCUS

- Strategic Use of Mathematics
- Attention to Modeling

SUGGESTED TIMING

~60 minutes

HANDOUT

- 2.8: Evaporation and Intermolecular Forces Lab

MATERIALS

For each group:

- 2 digital thermometers or temperature probes
- filter paper
- clear tape
- stopwatches
- two small plastic cups (each covered with plastic wrap and a rubber band), with 20mL of isopropanol in one cup and 20 mL of acetone in the other, or with 20 mL of methanol in one cup and 20 mL of pentanol in the other

UNIT 2

CONTENT FOCUS

In this lab, students build on prior lessons about the types of intermolecular forces and learn more about how the structures of molecules determine the types of IMF present. By examining molecular structures and analyzing data involving temperature change and evaporation rates, students draw conclusions about the relative strengths of different types of IMF. Students use their conclusions about the relationships between molecular structure and IMF to make a prediction about the evaporation of ethanol, which they then have the opportunity to test.

- small plastic cup (covered with plastic wrap and a rubber band) containing 20 mL of ethanol
- goggles

By empowering students to use critical thinking skills to make and evaluate an important claim about intermolecular forces, this lesson is designed not only to promote deeper understanding of the attractions between molecules, but also to build students' confidence in their abilities to construct authentic scientific knowledge.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

Before the lab, prepare for each student group two small plastic cups, each containing about 20 mL of one of the two liquids the students at that station will analyze. Cover the cups with plastic wrap secured by a rubber band. Also prepare plastic cups of about 20 mL ethanol (one per group), covered in the same way, and set them aside until you get to Part 3.

For Part 2, students will need a way to share their data with the rest of the class. You can have them write on the board or a set up a shared document for them use.

SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear chemical splash goggles.
- All liquids used in this experiment are flammable. Avoid heat sources.

UNIT 2

PART 1: PRE-LAB

In this portion of the lesson, students are introduced to information about the relationships between observed temperature change during evaporation, evaporation rate, and IMF strength. They identify types of IMF in substances they will use in the upcoming lab and make predictions about the relative evaporation rates of these substances. Finally, students watch a demonstration of the procedure they will use in the data collection portion of the lesson.

Meeting Learners' Needs
If students are struggling to understand why evaporation causes cooling, you may want to show a short, engaging video on the topic, such as "LeBron Asks: Why Does Sweating Cool You Down?" from Khan Academy (**https://www.khanacademy.org/science/biology/water-acids-and-bases/water-as-a-solid-liquid-and-gas/v/lebron-asks-why-does-sweating-cool-you-down**).

- Direct students' attention to Part 1 of **Handout 2.8: Evaporation and Intermolecular Forces Lab**. This part of the handout provides introductory information about the process of evaporation, evaporation rate, and IMF strength. It then asks students to apply this information to analyzing the molecular structures of four substances. Have students work in small groups to complete this section.
- As you circulate among the small groups while they are working, it may help to ask the following questions to guide students' thinking:
  - What determines if a substance's molecules experience dispersion forces? What about dipole–dipole forces? Hydrogen bonding?

    All molecules experience dispersion forces, polar molecules also experience dipole forces, and molecules with O-H, N-H, or F-H bonds also experience hydrogen bonding.
  - Are C-H bonds polar? C-O bonds? O-H bonds?

    No; yes; yes.
  - What factors do you think affect the overall strength of IMF in a substance?

    Answers will vary but should include polarity or IMF type(s) and molecule size.

Classroom Ideas
You may want to have each small group record on the board their hypothesis for question 3, about the relative rates of evaporation of the substances. This strategy of making their thinking public can help motivate students to take hypothesis formulation seriously.

While you are supporting students, you can also assign each group the two liquids they will test in Part 2: either isopropanol and acetone, or methanol and pentanol. You should have an approximately equal number of groups working with each pair of substances.

- Once students complete the pre-lab, demonstrate the lab procedure for the class. Aspects of the procedure that you may want to highlight include the following:
  - Show them how to secure a piece of filter paper over the tip of the thermometer with a small rubber band and tape the thermometer down so that it extends over the edge of the bench.
  - Remind them that during the evaporation time, the thermometer should not be moved, and they should avoid walking by it or doing anything to disturb the air around it.
  - Be sure students are aware of appropriate safety procedures.

PART 2: DATA COLLECTION AND ANALYSIS

In the second part of the experiment, student groups work in the laboratory to collect data on the temperature change during evaporation of two liquids, either isopropanol and acetone or methanol and pentanol. They report their temperature change data to the class. Groups then use this class data to draw conclusions about the effects of molecule size and hydrogen bonding on IMF strength.

Instructional Rationale

This split structure for data collection, in which each group works with only two of the four substances being investigated, has the advantage of emphasizing the appropriate pairs of molecules to compare in order to separate out the effect of different types of IMF (acetone and isopropanol) versus different molecule sizes (methanol and pentanol). Also, the split structure is efficient in terms of time spent collecting data. Pooling class data for evaporation temperature changes and averaging them ensures that the effect of outlier data is minimized and that all students complete the analysis with a more reliable set of numbers.

- Direct students to put on their safety goggles and work in their groups to follow the procedure on their handout. Once students have completed two trials for each of their two liquids, they should report their data to the class by writing on the board or using a shared document.
- Support groups in working through the Calculations and Analysis section of the handout. These questions involve analyzing the class data to draw conclusions about the factors that influence overall IMF strength in a substance. For question 1, remind students to average all groups' data for each liquid and use those averages for their analysis. The questions and sample responses for questions 2 through 6 are provided below for reference.

2. Rank the substances from strongest IMF to weakest. Provide evidence and reasoning to support your ranking.

   Pentanol > isopropanol > methanol > acetone
   The molecule with the smallest temperature change is evaporating the slowest, indicating that it has the strongest IMF. Thus, the molecules are ranked from smallest temperature change to largest.

3. Which two substances should be compared to examine the effect of molecular size on relative IMF strength? Explain your choice.

   Any two of the three alcohols can be selected here. The alcohols can be compared to examine the effect of molecular size because they all have similar structures and thus the same types of IMF, but they vary in size. Because size is the major difference between them, the observed difference in evaporation rate can be attributed to the size difference.

4. What is the relationship between molecular size and IMF? Provide evidence and reasoning to support your claim.

   The larger the molecule, the greater the IMF (for molecules with similar structures). Pentanol, the largest of the alcohols used, has the smallest temperature change, which indicates stronger IMF. Methanol, the smallest of the alcohols used, has the largest temperature change, which indicates weaker IMF.

5. Which two substances should be compared to examine the effect of hydrogen bonding on relative IMF strength? Explain your choice.

   Acetone and isopropanol are similar sizes but have different structures and thus different IMF. Because the presence (or absence) of hydrogen bonding is the major difference between the two, the observed difference in evaporation rate can be attributed to the presence or absence of hydrogen bonding.

6. What is the relationship between the presence of hydrogen bonding and IMF? Provide evidence and reasoning to support your claim.

   Molecules that form hydrogen bonds have stronger IMF than similarly sized molecules that do not form hydrogen bonds. Isopropanol, which can form hydrogen bonds, had a temperature change of 11°C, while acetone, which cannot form hydrogen bonds, had a temperature change of 18°C. The larger temperature change of acetone indicates weaker IMF.

Handout 2.8

Guiding Student Thinking

If students have trouble identifying which two molecules to choose to analyze the effect of molecular size, encourage them to think about experimental design and the need to have a single independent variable for a comparison to be a valid test. If they are still stuck, remind them that they want to choose two molecules that differ only in size and not in types of IMF to ensure that differences observed are due only to differences in size.

Likewise, if students have trouble identifying which two molecules to choose to analyze the effect of IMF type, remind them that they want to choose two molecules that differ only in IMF and not in size to ensure that differences observed are due only to differences in IMF type (i.e., the presence or lack of intermolecular hydrogen bonds).

PART 3: ETHANOL PREDICTION AND TESTING

In the final part of the lesson, students predict the temperature change for the evaporation of ethanol and explain their rationale before moving to the laboratory and testing their prediction.

- Ask students to make a prediction about the temperature change they will observe for ethanol. If students are struggling with how to go about making a prediction, suggest that they compare the structure of ethanol (which is shown in Part 3 of the handout) to the structures of the substances from Part 1.

Guiding Student Thinking

Ideally students will notice that ethanol is similar to the other alcohols in structure and thus experiences the same types of IMF. They should also notice that ethanol is between isopropanol and methanol in size, so they should predict a temperature change for ethanol in between those observed for isopropanol and methanol.

- Once students have made a prediction about the temperature change of ethanol, record their hypotheses on the board. Lead a brief discussion in which a few groups share their rationales.
- Instruct students to test their predictions by following the same lab procedure that they used with their previous substances. Record all the student data for temperature change and have students find an average. The average temperature change observed for ethanol should fall between those observed for methanol and isopropanol (about 13–15°C, depending on conditions in the classroom).

- Next, give students a few moments to answer the Conclusion questions on the handout. When students are done, hold an informal class debate about the response to question 2: Which factor—molecular size or presence of hydrogen bonding—is more important to consider when ranking these substances in terms of relative strength of IMF?

  To hold the debate, you might ask for two student volunteers who answered the question differently to come to the front of the room. Each student can give a statement in support of which "side" they are on and why. Then allow each student volunteer to ask the other student some follow-up or challenge questions. Volunteers could elicit suggestions for questions from their classmates if they wish.

  Continue the debate until it becomes clear, at least to most students, why hydrogen bonding is more important in determining the relative strength of IMF in the substances examined. After the lesson, follow up with individuals who may still be struggling with the concept.

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 2.8: Evaporation and Intermolecular Forces Lab

Part 1: Pre-Lab

1.

Name	Formula	London Dispersion Forces? (yes or no)	Dipole–Dipole Forces? (yes or no)	Hydrogen Bonds? (yes or no)
Pentanol	$C_5H_{11}OH$	Yes	Yes	Yes
Methanol	CH_3OH	Yes	Yes	Yes
Acetone	CH_3COCH_3	Yes	Yes	No
Isopropanol	C_3H_7OH	Yes	Yes	Yes

2. Answers will vary. Students may rank acetone as the weakest, because it lacks hydrogen bonding. They may rank methanol as weaker than isopropanol, which is weaker than pentanol, due to size.
3. Answers will vary. Ranking should correspond to ranking from question 2, with the molecule identified as having the weakest IMF evaporating the fastest.

Part 2: Data Collection and Analysis

1. Note that the values measured in your classroom may vary significantly from those shown here depending on the temperature and other conditions in your room. However, the ranking of smallest to largest temperature change should be consistent with this data.

Substance	Average Temperature Change (°C)
Methanol	16
Isopropanol	11
Acetone	18
Pentanol	6

2–6. Answers provided in the lesson.

Part 3: Ethanol Prediction and Testing

Making and Testing a Prediction

1. Answers will vary; ideally, the predicted temperature change will be between the average temperature changes of methanol and isopropanol.
2. Answers will vary.
3. Answers will vary.

Conclusion

1. The strengths of intermolecular forces in substances can be compared by measuring the temperature change at the surface of the liquids for a set time. A larger temperature change means faster evaporation, which indicates weaker IMF. Students could also reference determining melting and boiling points of substances.
2. Hydrogen bonding is more important. Acetone, a substance whose molecules do not hydrogen bond, evaporated more quickly than methanol, a substance whose molecules do hydrogen bond, even though acetone is larger. Thus, hydrogen bonding is a more important factor than size for the substances used in this lab.

LESSON 2.9

Molecular Geometry

OVERVIEW

LESSON DESCRIPTION

Part 1: Shapes of Molecules

Students build models of molecules to explore the three-dimensional space that peripheral atoms occupy around a central atom due to electron–electron repulsion. Students estimate the angles formed in their structures and describe the shapes that result. This part of the lesson provides the backdrop for an exploration of valence shell electron pair repulsion (VSEPR) theory using a PhET simulation.

Part 2: Detecting Explosives Using Molecular Geometry

Students investigate how scientists can use bond angles in the detection of explosives by viewing a video from MIT and discussing a series of related questions. This part of the lesson serves to connect the study of bond angles to a real-world context.

Part 3: Search for Stability

Students engage in a guided inquiry activity using an interactive computer simulation to explore the underlying principles of VSEPR theory. This allows them to observe changes in bond angles and molecular shapes as the number of bonding pairs and lone pairs changes.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~60 minutes

HANDOUT

- 2.9: Molecular Geometry

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing an online video and displaying a computer simulation
- internet access to the video “Detecting Explosives to Save Lives in War Zone” (3:33) from MIT Open Learning, available at **https://techtv.mit.edu/collections/chemvideos/videos/24166**
- internet access to the “Molecule Shapes” simulation from PhET, available at **https://phet.colorado.edu/en/simulation/molecule-shapes**

CONTENT FOCUS

This lesson builds on students' knowledge of Lewis diagrams and is designed to introduce them to the valence shell electron pair repulsion (VSEPR) model and molecular geometry. Rather than memorizing tables of molecular geometries, students discover this information by considering the factors that determine molecular geometry and then creating and examining 3-D models that minimize repulsion. Students then learn about one real-world application of molecular geometry—the detection of explosives. The final piece of the lesson has students use a simulation to explore how bonding versus nonbonding electrons affect molecular geometry.

For each group:

- modeling clay
- toothpicks
- protractor (optional)
- molecular model kits
- device for students to access the "Molecule Shapes" simulation

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of their constituent atoms.	
Learning Objectives	**Essential Knowledge**
2.2.D.1 Create and/or evaluate Lewis diagrams for molecular compounds and/or polyatomic ions.	**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.
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.

SETUP AND PREPARATION NOTES

- Gumdrops or other soft, round objects can be used in place of modeling clay spheres.

SAFETY NOTES

- All general safety guidelines should be followed.

PART 1: SHAPES OF MOLECULES

Students build models of molecules to explore the three-dimensional space that peripheral atoms occupy around a central atom due to electron–electron repulsion. Students estimate the angles formed in their structures and describe the shapes that result. This part of the lesson provides the backdrop for an exploration of valence shell electron pair repulsion (VSEPR) theory using a PhET simulation.

Instructional Rationale

Students often perceive concepts of molecular geometry as abstract and therefore difficult to internalize. Introducing this topic through three-dimensional modeling is a useful way to show students that they can apply concrete spatial reasoning skills to an understanding of molecular geometry.

- Set students up to work in small groups with a supply of modeling clay and toothpicks. Also provide a protractor if you want them to measure rather than estimate angles. Then present them with the following task:

> Make a structure that connects three spheres together with toothpicks. Place one sphere in the center of the structure. Place the other two spheres as far apart from one another as possible.
>
> What is the angle between the toothpicks? What is the shape of the structure?

Guiding Student Thinking

The sphere in the middle represents the central atom in a molecule, and the spheres on the end represent peripheral atoms, but don't tell students this yet. They will draw conclusions about what the structure represents later on in the lesson.

- When groups have finished, invite them to share their responses.

  The structure is a straight line; the angle between the toothpicks is 180 degrees.

- Have groups repeat the task again, using four and then five spheres. Each time one sphere should be central in the structure, and the remaining spheres should be as far apart as possible. Students should keep all their models assembled for comparison. Again, have students share responses with the class.

  The structure with four spheres is shaped like a triangle with one sphere at the center of the triangle. The angle between the toothpicks is 120 degrees. The structure with five spheres is shaped like a triangular pyramid, or tetrahedron, with one sphere at the center of the structure. The angle between the toothpicks is 109.5 degrees.

Guiding Student Thinking

Encourage students to think three-dimensionally when they are constructing their tetrahedral model since they may initially make a flat "cross" shape. A contest to see if anyone can get a bigger angle may encourage groups to continue seeking options for the arrangement. If students struggle for more than a few minutes to get a tetrahedral arrangement, suggest that not all arrangements are flat.

- Have students work with their group to write a statement that relates the number of spheres to the angle between the toothpicks. Ask a few groups to share their statements. Students should come to the conclusion that as the number of objects around the middle increases, the angle between the objects decreases.
- Now present students with the following set of questions:
  - These models represent molecules. Which parts represent atoms? Which parts represent bonding electrons?
  - What are some things you might conclude about the structure of molecules based on these models?

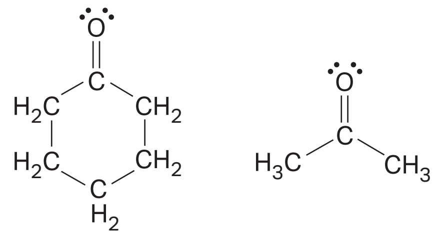
  Allow discussion of these questions to lead into the observation that, in a molecule, bonding electrons are positioned as far apart from each other as possible. As a result, there are a few predictable shapes that simple molecules take.
- To conclude this portion of the lesson, provide a brief verbal introduction to VSEPR theory and let students know that their models demonstrate this theory.

PART 2: DETECTING EXPLOSIVES USING MOLECULAR GEOMETRY

Students investigate how scientists can use bond angles in the detection of explosives by viewing a short video (3:33) from MIT Open Learning and discussing key questions about it. This part of the lesson serves to connect the study of bond angles to an important real-world context.

- Before showing the video, post the following questions to guide students' note-taking as they watch the video.
  - Why is it harder to detect the newer explosives?
  - What role does hydrogen bonding play in detecting explosives?

  You might also want to preview with students the structures of cyclohexanone and acetone, specifically pointing out the carbonyl group (C═O) that both structures have in common. These will be mentioned in the video at 0:48.



Cyclohexanone Acetone

- Start playing the video, and then pause it at 1:21 to discuss how the acetone molecules are lined up with the explosive molecule. You could reference a biological example like enzymes and how they "line up" with the substrate. Ask the students if the shape or arrangement of the molecules will impact how they interact.
- Pause again at 1:29. Review the differences between bonding and nonbonding pairs. Have students predict what might happen to angles between atoms when the nitrogen-hydrogen bond becomes "more lone-pair-like." Show the rest of the video.
- After the video, lead a whole-class debrief on the questions posed before they watched the video. Sample responses are provided below.
  - Why is it harder to detect the newer explosives?

    They don't vaporize as easily as traditional explosives, so there is a smaller amount of them in the air, making them harder to detect.

  - What role does hydrogen bonding play in detecting explosives?

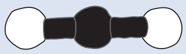
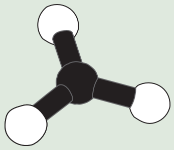
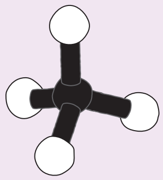
    The hydrogen bonds between molecules change the bond angles in the explosive. This change in bond angles causes other changes that are detectable using scientific equipment. These changes are used to alert people that explosives may be in the area.

PART 3: SEARCH FOR STABILITY

Now that students have explored bond angles using macroscopic materials and seen one example of a real-world use, they examine molecular geometry using a computer simulation. Students engage in a guided inquiry activity using the simulation to explore the underlying principles of VSEPR theory. With this simulation, students can observe changes in bond angles and molecular shapes as the number of bonding pairs and lone pairs changes.

- You will guide students through the simulation as a class while the students build physical models with a small group. Students can complete the first table on **Handout 2.9: Molecular Geometry** as you lead them through the simulation and modeling activities.
- Assign students to small groups and distribute molecular modeling kits to each group. Ask students to construct a model of a molecule with two bonding pairs of electrons. The central atom should be chosen so that the 180° bond angle can be achieved.
- When students have built their models, display the PhET simulation at **https://phet.colorado.edu/en/simulation/molecule-shapes** for the class and click on "Model." The structure will match the one that students have just built. Click and drag the molecule to show students the rotation.
- Then, ask students the following questions about the molecular structure and use the simulation to reveal the answers:
  - What angle exists between the bonds?
    180°. (To reveal the answer in the simulation, click "Show Bond Angles" in the Options box.)
  - What would happen if we replaced one of the bonds with a double or triple bond?
    The shape of the molecule and the angles within it do not change as a result of this substitution. (To show the answer, click on different bonds in the Bonding box in the upper right of the simulation.)

  Students can use this information to fill in the first row of the table on the handout and identify the shape as linear. Have the students draw a representation of the model in such a way that they will remember its shape.
- Continue guiding students through the main molecular shapes *without any lone pairs of electrons* on the central atom. This includes trigonal planar with three bonding pairs, in the second row of the table, and tetrahedral with four bonding pairs, in the fourth row of the table. (For now, skip the rows with nonbonding pairs—the third, fifth, and sixth rows. We will work on those in the next step of the lesson.) Have students build the molecule using the model kit first and then add the bonds on the simulation to display the angle. You can show trigonal bipyramidal and octahedral shapes if you wish, but shapes requiring an expanded octet are beyond the scope of this course. A sample of the completed rows for these shapes is shown on the next page for reference. The table is color-coded based on the number of electron domains on the central atom. Students may find the color-coding useful to help them identify patterns.

Number of Bonding Pairs	Number of Nonbonding Pairs	Drawing	Molecular Geometry	Bond Angle
2	0		linear	180°
3	0		trigonal planar	120°
4	0		tetrahedral	109.5°

Handout 2.9

- Once shapes with only bonding pairs of electrons have been modeled and students have completed the corresponding rows on their table, have them look again at their tetrahedral model and display it on screen. Ask students to consider the following question:
  - What will happen to the shape of the molecule if one of the bonded atoms is replaced with a nonbonding pair of electrons?

  Allow students enough time to formulate a response and encourage them to consider what was described in the video before they respond. Take a few responses from students and then show the result on the simulation. Discuss what you observe as a class.

  The simulation shows that the structure changes from a tetrahedral shape to a trigonal pyramidal shape. (It will not show the slight difference in bond angle but you can discuss this change with the students if you wish. It will suffice to say that the bond angle decreases slightly with the one lone pair rather than having students know the exact angle that results.)

- Continue through the rest of the table, using the simulation and models, until students have complete information for the following shapes: linear, trigonal planar, tetrahedral, bent, and trigonal pyramidal.

- Support students in drawing conclusions about VSEPR based on what they observed in the simulation. Ask questions such as:
  - Why do the bonds appear to "bend" before bouncing back into place when we click on the structure?

    The molecules are returning to where electrons are as far away from one another as possible.
  - What is causing the shapes to form the way they do?

    It is caused by electron–electron repulsion, which leads to electron domains being as far apart from one another as possible.
  - Predicting the shape of molecules can be done using VSEPR theory. This stands for *valence shell electron pair repulsion theory*. What is this theory about, in your own words? Take a few minutes to write down your answer before sharing with a partner or the class.

    Electrons on the outer shell pair up and repel each other, resulting in predictable geometric shapes.
- The second table on the handout identifies some specific molecules and provides space for students to draw Lewis diagrams of each one. Allow a few minutes for students to draw structures for each molecule. They should then build each molecule with their model kits, matching the structure with the correct shape and angles using information from the first table.
- When students are finished building their structures, show them how to use the first table they created to determine the shape and angles of the molecule from the Lewis diagram. Complete the first row of the table, for H_2O, together as a class, and then use the PhET simulation to show students a water molecule. (To do this, click "Real Molecules" at the bottom of the screen. Choose the molecule from the drop-down menu in the upper right.) This will allow students to continue to visualize the placement of the lone pairs and how they change the shape and angle. There are options to show the bond angle and molecular geometry if you wish to display them.
- Do a few more examples as a class, and then allow students to finish the rest of the table in small groups, using the PhET simulation on a device assigned to each group.

- To close the lesson, ask each student to do a quickwrite to respond to these prompts:
    - Why do molecules take the shapes they do?
    - How do you determine the geometry of a molecule?
- Once students have had time to respond individually, ask them to discuss their responses with a partner and revise them as necessary.

Instructional Rationale

A quickwrite is simply a short, written response to an open-ended prompt. It allows students to reflect and can be used to informally assess their thinking. Having students write a quick response before discussing with a partner gives them time to formalize their thoughts. The discussion after writing allows students to hear another perspective and revise their thinking.

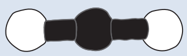
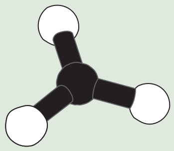
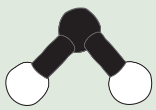
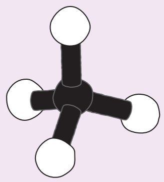
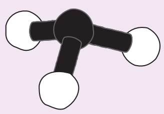
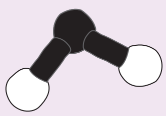
UNIT 2

ASSESS AND REFLECT ON THE LESSON

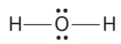
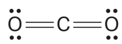
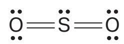
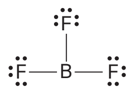
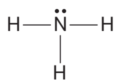
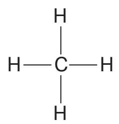
HANDOUT ANSWERS AND GUIDANCE

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

Handout 2.9: Molecular Geometry

Number of Bonding Pairs	Number of Nonbonding Pairs	Drawing	Molecular Geometry	Bond Angle
2	0		linear	180°
3	0		trigonal planar	120°
2	1		bent	less than 120°
4	0		tetrahedral	109.5°
3	1		trigonal pyramidal	less than 109.5°
2	2		bent	less than 109.5°

Handout 2.9

Molecule	Lewis Diagram	Molecular Geometry	Bond Angle
H_2O		bent	less than 109.5°
CO_2		linear	180°
SO_2		bent	less than 120°
BF_3		trigonal planar	120°
NH_3		trigonal pyramidal	less than 109.5°
CH_4		tetrahedral	109.5°

Handout 2.9

UNIT 2

LESSON 2.10

Spicy Chemistry – The Flavors of Isomers

OVERVIEW

LESSON DESCRIPTION

Part 1: Analytical Reading
Students read a text about two structural isomers that give two common spices their distinct flavors and aromas.

Part 2: Individual and Partner Questions
Students answer questions about the reading on their own first, then discuss their answers with a partner and revise.

Part 3: Whole-Class Discussion
Students participate in a whole-class discussion of the reading and questions.

CONTENT FOCUS

This lesson introduces students to the concept of structural isomerism. It also details a vivid example of the relationship between chemical structure and macroscopic properties using eugenol and isoeugenol, two isomers that are the fragrant components of the common spices nutmeg and cloves, respectively. The lesson situates the content in a historical and everyday context to engage students and help them connect chemical ideas to their own lives and experiences. It is structured as a reading and writing task in order to expand students' abilities to decode, understand, summarize, and analyze an informational text about chemical concepts and models. Additionally, the lesson develops written and oral argumentation skills, including appropriate selection of relevant evidence and use of reasoning to link evidence and claims logically.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 2.10.A: The Flavors of Isomers
- 2.10.B: The Flavors of Isomers – Check Your Understanding

MATERIALS

- samples of nutmeg and cloves (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

If possible, provide samples of cloves and nutmeg to pass around to students prior to the reading in Part 1.

PART 1: ANALYTICAL READING

To spark student engagement in thinking about isomers, this lesson focuses on students' everyday experiences with their sense of smell. In the first part of the lesson, students use their analytical reading skills to explore structural isomerism with two common spices, nutmeg and cloves.

- To begin, ask students if they know what cloves and nutmeg are and how they are used. Encourage a brief discussion around this topic; students might mention some favorite foods that use these spices. If possible, pass around samples of cloves and nutmeg for students to see and smell.
- To transition to the reading, ask students to consider whether spices have much importance in our lives: Do they play any role in history? Can we learn anything from them about chemistry? Allow a variety of responses, and then direct students to read the passage on **Handout 2.10.A: The Flavors of Isomers**. Encourage students to take notes and annotate the text in order to identify key ideas as well as questions they have or confusion that arises.
- Before students answer the text-dependent questions in the next part of the lesson, it can be helpful to check their understanding of the text. 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 are isomers?

> **Meeting Learners' Needs**
> If your students have difficulty with the reading, you can have them read the text aloud in pairs, alternating paragraphs in reader and summarizer roles. After each paragraph is read by the reader, the other student summarizes the content aloud.

PART 2: INDIVIDUAL AND PARTNER QUESTIONS

In this part of the lesson, students first individually answer a series of text-dependent questions and then discuss and revise their answers with a partner. The question types include reading comprehension, argumentation, and application of chemistry content (VSEPR and Lewis diagrams).

- Have students find **Handout 2.10.B: The Flavors of Isomers – Check Your Understanding** and instruct them to answer each question on their own in the "My first answer, thinking on my own" box.

As students answer the questions, have them look back at **Handout 2.10.A** and highlight text that is relevant to each question and number their selection 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 attempt to come to a consensus. Each student should then record their new answer to each question in the "My revised answer after discussing it with my partner" box.
- Some specific strategies you can use to support students while they are working are:
  - Questions 1–4: Some students find the distinction between structure and properties confusing and may have trouble distinguishing differences or similarities in structure from differences or similarities in properties. Remind students that structure describes the physical arrangement of the components of the substance and is represented by the model on their paper, and properties describe the wide array of nonstructural qualities a substance possesses, such as polarity or melting point, that can be observed empirically or experimentally. Consider using simpler structures as examples, such as sugar, salt, and water.
  - Question 5: Some students may find it challenging to determine the geometry of specific atoms in a larger structure. Consider having three-dimensional models of both eugenol and isoeugenol available, or even having students build their own models.
- As you circulate during the pair discussion and revision time, make note of which pairs have strong responses to each question so that you can call on them during the whole-class discussion, if needed. You can also look for pairs who used different evidence in their response to each question so the class can see that there may be multiple correct approaches.

Meeting Learners' Needs

If you have students who work at very different paces, you may want to assign each pair to start the discussion and revision process on a different question—so some pairs will start at question 1, others with question 2, and so on. This strategy ensures that at least some pairs will have answered each question before the whole-class discussion, even if everyone isn't able to get to all the questions.

PART 3: WHOLE-CLASS DISCUSSION

This final part of the lesson involves a whole-class discussion to summarize the key concepts and review the answers to the student handout questions.

- Ask for volunteers to share their answers, question by question. If you noticed pairs that had particularly strong responses or approached the questions in a different way, you may want to call on them to highlight their responses.
- Restate, clarify, or extend students' responses as needed during the discussion to ensure that all students hear a complete response.
- For each question, allow students time to record a final answer, based on any changes in their thinking that arise from the group discussion.

Classroom Ideas

The book *Napoleon's Buttons* by Penny Le Couteur and Jay Burreson has chapters about peppers, nutmeg, and cloves with more detailed examples of the relationship between structure and properties of these spices. To extend the lesson, you could have students read the relevant chapters to learn more about the properties of isomers.

ASSESS AND REFLECT ON THE LESSON

HANDOUT ANSWERS AND GUIDANCE

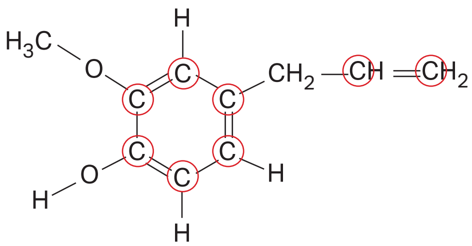
To supplement the information within the body of the lesson, additional answers and guidance on the handouts are provided below.

Handout 2.10.B: The Flavors of Isomers – Check Your Understanding

Sample responses for students' final answers are provided below.

1. The structures of eugenol and isoeugenol both contain 10 carbon, 12 hydrogen, and 2 oxygen atoms, and they have similar shapes, each with a ring attached to a chain, an -OCH_3 group, and an -OH group.
2. The position of a double bond in the chain portion of the molecule is different.
3. Both molecules have a distinct aroma and taste and are safe to consume.
4. The flavor and taste of each type of molecule is different.
5. (a) This model shows each carbon atom as a C and shows each hydrogen atom as an H.

   (b)



   (c) Trigonal planar geometry results from having three bonding domains. Each of the circled carbon atoms has one double bond and two single bonds, and thus has three bonding domains total.

   (d) Tetrahedral
6. The molecule in the center is most likely a spice. The center molecule has a structure that is most similar to that of eugenol and isoeugenol. Since molecules with similar structures often have similar properties, it makes sense that the properties of being fragrant, pleasant-tasting, and safe to consume would be common to eugenol, isoeugenol, and the center molecule shown here. (Note: this molecule is zingerone, which is found in ginger.)

UNIT 2

LESSON 2.11

Solubility and Laundry Detergents Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Reading About Laundry Detergents
Students read a *ChemMatters* article about laundry detergents and surfactants in order to gain an understanding of how molecular structure influences particle interactions and solubility.

Part 2: Solubility Lab – Pre-Lab, Procedure, and Observations
Students engage in several simple laboratory procedures in which they investigate interactions among oil, water, food dye, detergent, and antacids.

Part 3: Solubility Lab – Analysis
Supported by post-lab questions and a class discussion, students use observations from the lab to develop the understanding that substances with similar types of intermolecular forces are soluble in one another.

CONTENT FOCUS

This lesson is designed so that students first explore the idea of "like dissolves like" in a familiar, everyday context: doing laundry. Students then examine the idea further as they perform a series of lab investigations. With guidance, they analyze their own observations from the labs to come to the conclusion that substances with similar intermolecular forces tend to be soluble in one another.

This lesson builds on what students have previously learned about Lewis diagrams, molecular geometry,

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 2.11.A: Solubility and Molecular Structure – Laundry Detergents
- 2.11.B: Solubility Lab – Pre-Lab, Procedure, and Observations
- 2.11.C: Solubility Lab – Analysis

MATERIALS

For each group:

- two 400 mL beakers
- food coloring, such as FD&C Blue 1
- dish soap
- antacid tablets (such as Alka-Seltzer)
- olive oil
- vegetable oil
- tap water
- goggles

and molecular polarity. Before starting this lesson, students should have had opportunities to determine the molecular polarity and the types of intermolecular forces present in molecules based on Lewis diagrams.

Of course, solubility is complex and the phrase "like dissolves like" has exceptions and complications. These complexities will be explored in AP Chemistry, and there are several places in this lesson where students could extend their thinking, if appropriate. However, the intent of this Pre-AP lesson is to help students build a basic chemistry concept.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.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.

SAFETY NOTE

All general safety guidelines should be followed.

FORMATIVE ASSESSMENT GOAL

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

1. A student adds hexane (C_6H_{14}) and water (H_2O) to two beakers. They observe two distinct layers of liquid in each beaker.
   (a) Make a list of all intermolecular forces present in pure hexane.
   (b) Make a list of all intermolecular forces present in pure water.
   (c) Explain, in terms of intermolecular forces, why the student sees two distinct layers of liquid in the beaker.
2. At room temperature, iodine (I_2) is a purple solid. The student adds several crystals of solid iodine to the first beaker containing water and hexane. They stir the contents with a stirring rod. The top layer becomes purple, and the bottom layer stays colorless.

   Is the top layer of liquid composed of hexane or water? Justify your selection in terms of intermolecular forces.

PART 1: READING ABOUT LAUNDRY DETERGENTS

Students read a *ChemMatters* article about laundry detergents and surfactants in order to gain an understanding of how molecular structure influences particle interactions and solubility.

- To activate students' prior knowledge, ask them why we use soap or detergent when doing laundry, instead of just washing clothes with water. Allow students to share their reasoning and comment on each other's responses; at this point, refrain from confirming any of the responses as valid.

  As students are sharing their responses, weave into the conversation the following two ideas:

  - The idea of water as a universal solvent: If water is a universal solvent, why do we need soap too?
  - The idea of two people being "like oil and water": Ask a student volunteer to interpret the statement. If students are unfamiliar with the phrase, tell them they will learn what it means by the end of the lesson.
- Next, ask students to complete the pre-reading questions on **Handout 2.11.A: Solubility and Molecular Structure – Laundry Detergents** in pairs. When students are finished, have several of the pairs share their responses to build a complete explanation for question 1(b) and a complete list for 1(c), since many pairs will likely have only partial answers. Then allow students to move forward with reading the article.
- Once students finish reading the article, have them answer the Check Your Understanding questions with a partner.
- Next, lead a class discussion about the reading using the Check Your Understanding questions as a guide. Choose which questions to focus on based on your observations of students' understanding. Points you may want to discuss include:
  - Students may be familiar with the words *hydrophobic* and *hydrophilic* from biology classes, so focus on connecting those vocabulary words to the concept of polar and nonpolar regions of surfactant molecules, as this language will be more prevalent in chemistry-specific contexts.
  - Question 6 asks students to think about how molecular structure affects solubility. You can build on the discussion of this question to transition into the lab in Part 2.

PART 2: SOLUBILITY LAB – PRE-LAB, PROCEDURE, AND OBSERVATIONS

Students engage in several simple laboratory procedures in which they investigate interactions among oil, water, food dye, detergent, and antacids.

- Have students work in groups to answer the pre-lab questions and carry out the procedure described on **Handout 2.11.B: Solubility Lab – Pre-Lab, Procedure, and Observations**. As students are working, circulate through the room and probe their thinking to ensure they are connecting their knowledge of molecular structure to their observations.

  Some examples of questions you may want to ask include:

  - What is surprising to you about what you are observing?
  - Do you see how the water and oil do mix a little bit where they meet? Why do you think this is?
  - Do you think olive oil has intermolecular forces that are more similar to those in vegetable oil or water?
  - Why do you think the food coloring mixed with the water but not with the oil?
  - Do you think all types of food coloring would behave the same way?
  - Why do you think the dish detergent allowed the layers to mix? What did you learn about detergents in the reading that supports your thinking?
  - What do you think is actually moving in the lava lamp? Why do you think this?

Guiding Student Thinking

Some questions provided here review students' conceptual understanding of molecular geometry and intermolecular forces, and some ask students to make predictions. If you find that many groups are not able to answer the questions, you may want to find a moment for a whole-class discussion before moving on.

PART 3: SOLUBILITY LAB – ANALYSIS

Supported by post-lab questions and a class discussion, students use observations from the lab to develop the understanding that substances with similar types of intermolecular forces are soluble in one another.

- Students may work on the analysis questions from **Handout 2.11.C: Solubility Lab – Analysis** individually, in pairs, or in small groups. Once students have finished, review the questions in a whole-class discussion. Ensure that students connect their understanding of solubility to intermolecular forces.

- As you support students while they are working, or during the class discussion, consider the following:
  - Questions 1 through 3 (fatty acids): You may need to remind students that the C-H bond is essentially nonpolar despite being different atoms. If students are struggling, ask students if the hydrocarbon section of the lauric acid molecule is symmetrical or not.
  - Questions 4 and 5 (FD&C Blue 1): To avoid having students feel overwhelmed by the large molecule of FD&C Blue 1, focus on the fact that there are regions of strong charge on the molecule (indicated by + and – signs). If the FD&C Blue 1 molecule proves too much for your students, simplify the example by considering sodium chloride (NaCl). Tell students that Cl^- is a negative ion analogous to the large ion with multiple negative sites present in FD&C Blue 1.

Meeting Learners' Needs

The carboxyl group on the lauric acid molecule provides an opportunity to extend the discussion. Lauric acid has a partially polar group on one end of the molecule but is largely nonpolar—this can explain why some of the oil molecules mix with the water at the water-oil interface but most do not. If your students are not ready for that extension, focus their attention on the carbon-hydrogen section of the molecule.

- When concluding the lesson, write the takeaway sentences (from question 11) on the board as students share their answers to highlight the importance of the information learned. These are shown below for reference.

DRAWING CONCLUSIONS

11. Fill in the blanks below using the following words: *polar*, *nonpolar*, *ionic*.

    We can derive two general takeaways from our observations:

    - Polar solvents are able to dissolve ___polar___ and ___ionic___ solutes.
    - Nonpolar solvents are able to dissolve ___nonpolar___ solutes.

Handout 2.11.C

Guiding Student Thinking

If your students struggled with the statement at the beginning of the lesson that some people are "like oil and water," ask them what they think it means now that they have completed the lesson.

UNIT 2

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 adds hexane (C_6H_{14}) and water (H_2O) to two beakers. They observe two distinct layers of liquid in each beaker.
   (a) Make a list of all intermolecular forces present in pure hexane.

   London dispersion forces

   (b) Make a list of all intermolecular forces present in pure water.

   Hydrogen bonding forces

   Dipole–dipole forces

   London dispersion forces

   (c) Explain, in terms of intermolecular forces, why the student sees two distinct layers of liquid in the beaker.

   Hexane is nonpolar and does not have similar intermolecular forces to water. Therefore, hexane has a very low solubility in water.

Guiding Student Thinking

Drawing Lewis diagrams for the structures may help students determine the types of intermolecular forces present in the samples.

2. At room temperature, iodine (I_2) is a purple solid. The student adds several crystals of solid iodine to the first beaker containing water and hexane. They stir the contents with a stirring rod. The top layer becomes purple, and the bottom layer stays colorless.

   Is the top layer of liquid composed of hexane or water? Justify your selection in terms of intermolecular forces.

   The top layer is hexane. The iodine, which is nonpolar and therefore has London dispersion forces between molecules, dissolved in the top layer. Since substances with similar intermolecular forces are soluble in one another, the top layer must be hexane.

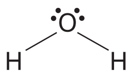
UNIT 2

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 2.11.A: Solubility and Molecular Structure – Laundry Detergents

Pre-Reading Questions

1. (a) 

   (b) Polar. Water has an asymmetrical geometry (bent) and therefore has an asymmetrical distribution of charge. The oxygen side of water is partially negative and the hydrogen side of water is partially positive because oxygen is more electronegative than hydrogen.

   (c) Hydrogen bonding forces, London dispersion forces

2. Answers will vary.

Check Your Understanding

1. Since water is polar and many stains are oil or grease, which are nonpolar, water does not attract the molecules that make up most stains.
2. Surfactants reduce the surface tension of water by interrupting the intermolecular hydrogen bonding forces. This allows the water molecules to spread apart more and be absorbed by fabrics quicker. Surfactant molecules have both polar and nonpolar regions. The polar part is attracted to water and the nonpolar part is attracted to grease and oil, which allows them to lift stains from clothes and allows the water to wash away the stains.
3. *Hydrophilic* means something is attracted to water, and *hydrophobic* means something is not attracted to water. The polar part of a surfactant molecule is considered hydrophilic because it is polar and can dissolve in water, which is also polar.
4. Micelles are groups of surfactant molecules surrounding nonpolar oil or grease molecules. The nonpolar ends of the surfactant molecules are attracted to the grease and the polar ends of the surfactant molecules are attracted to the water.
5. Answers will vary.
6. Answers will vary.

Handout 2.11.B: Solubility Lab – Pre-Lab, Procedure, and Observations

Pre-Lab Questions

1. Answers will vary.
2. Answers will vary but will probably be along the theme of "oil and water do not mix," which is the prior knowledge we are seeking to activate.
3. Answers will vary. A possible explanation would be as follows:

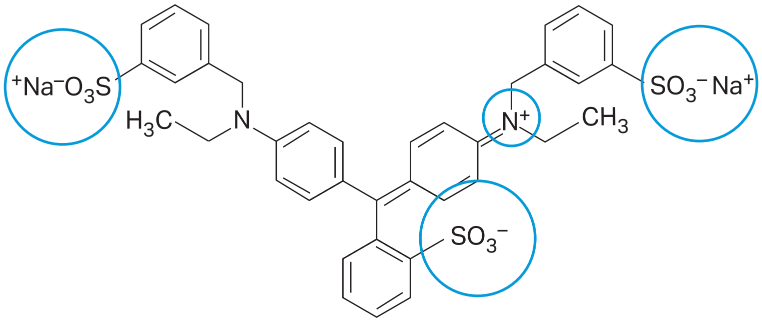
   Nonpolar. I know from prior experience that oil and water do not mix and the reading suggested that nonpolar substances do not dissolve in water (i.e., nonpolar substances are hydrophobic).

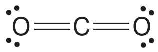
Procedure and Observations

3. (a) Students should comment on the fact that the oil and water form separate layers, but that there appears to be some mixing at the interface.
   (b) There appears to be an area where the oil and water mix a little. The line between them is not "perfect."
   (c) Water. Since it is the bottom layer we can conclude that water is more dense than oil.
4. (a) Two.
   (b) No. It may be nonpolar.
   (c) Yes. It is nonpolar.
5. (a) No. It may be polar.
   (b) Yes. It is polar.
6. (a) The layers mix. Everything now seems to be similar in color to the dish detergent.
   (b) Answers will vary.
7. Answers will vary.
8. Answers will vary.
9. Answers will vary.

Handout 2.11.C: Solubility Lab – Analysis

1. Nonpolar.
2. Hydrophobic. Most of the molecule is nonpolar and the article suggested that polar molecules are hydrophilic.
3. (a) Hydrogen bonding forces, dipole–dipole forces, London dispersion forces
   (b) London dispersion forces
   (c) London dispersion forces

4. 

5. The charged ions will be attracted to the polar water molecules and therefore be able to mix with them.
6. 

7. Nonpolar. The molecule is symmetrical so it will have an even charge distribution.
8. London dispersion forces
9. Since carbon dioxide exhibits only London dispersion forces, it is not able to interact strongly with polar water molecules that exhibit hydrogen bonding forces. Carbon dioxide is a gas at room temperature, so it is less dense than either the water or the oil and therefore rises to the top of the solution.
10. The small pieces reacted faster because more of the tablet was exposed to the water and able to react with it.
11. Polar, ionic, nonpolar.

UNIT 2

PRACTICE PERFORMANCE TASK

Properties of Limonene

OVERVIEW

DESCRIPTION

In this practice performance task, students reason about intermolecular forces from data and a video demonstration and predict relative strengths of London dispersion forces based on molecular structure. They then read about the extraction of limonene and calculate yield. Finally, students construct particulate models to model solutions and mixtures and reason about partial pressure.

CONTENT FOCUS

This task is designed to assess students' understanding of molecules, solutions, and mixtures and to allow them to practice their reasoning about intermolecular forces and partial pressure from data. This task is intended to be used after students have completed their study of Key Concept 2.2: Molecular Structure and Properties.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 2 Practice Performance Task: Properties of Limonene

MATERIALS

- calculator
- equation sheet
- periodic table

For Part 1, question 2:

- LCD projector, electronic whiteboard, or other technology for showing an online video
- internet access to the video demonstration "Pop a Balloon with an Orange Peel!" (0:29) from the Chemical Education Xchange at **https://www.chemedx.org/blog/how-does-orange-peel-pop-balloon-chemistry-course** (first video on the page)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The macroscopic physical properties of materials can be explained by the intermolecular forces among particles.	
Learning Objectives	**Essential Knowledge**
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.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.

2.2.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.D.1 Create and/or evaluate Lewis diagrams for molecular compounds and/or polyatomic ions.	**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.
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.

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:

- If students need a refresher on calculations required for proportional reasoning, you could give them some sample problems to work on with a partner.
- If they need additional support identifying and utilizing data from analytical readings, consider giving them problems with extraneous data embedded in the text to help them isolate and decode relevant information.
- You could have students practice drawing particulate representations of mixtures and solutions for all states of matter.

DURING THE TASK

For question 2, show students the video demonstration "Pop a Balloon with an Orange Peel!" (0:30), available from the Chemical Education Xchange at **https://www.chemedx.org/blog/how-does-orange-peel-pop-balloon-chemistry-course** (first video on the page) or from YouTube at **https://youtu.be/M3K6aESmgxg**. (Alternatively, you could perform the demonstration in class if you prefer.)

Because this is a practice performance task, you could have students engage in the task differently from how they might engage with a conventional assessment. You may want to use an implementation strategy such as the following:

- 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 meaningfully engage in the task.
- You could chunk the task into parts and have students complete one part at a time. The reading segment after the video is a natural break point at which to divide this task. 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 what changes, if any, they could make to their responses to craft a more complete response.
- Have students complete the task individually. Then distribute the scoring guide to students and have them score either their own tasks or the response of a classmate. Finally, have students reflect on their work and make recommendations to themselves about how they could improve their performance next time.

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. Students should understand that converting their score into a percentage does not provide a good measure of how they performed on the task.

SCORING GUIDELINES

There are 25 possible points for this performance task.

Question 1

Sample Solutions	Points Possible
The words *compound* and *molecule* should be circled. Compounds are formed when two or more different elements are bonded together. Since limonene is a covalent compound, the fundamental unit is the molecule.	**3 points maximum** 1 point for circling *compound* 1 point for circling *molecule* 1 point for correct justification
Targeted Feedback for Student Responses	
Refer students back to the card sort activity in which particles were classified at various levels.	

TEACHER NOTES AND REFLECTIONS

Question 2, part (a)

Sample Solutions	Points Possible
I agree with Jacob. Disrupting the intermolecular forces between particles of isoprene in the balloon causes a tiny hole to form that allows the gases inside to escape. Angel is incorrect because the structures of limonene and isoprene are similar in terms of the type of bonds (only C and H) that both have. Therefore, one can't be polar and the other nonpolar. Kayla's explanation does not make sense, as balloons are often struck by a variety of particles in motion, including gas particles, without popping. Even raindrops and grains of sand can hit a balloon without popping it. So it's not clear why the limonene particles would apply a stronger force than any of these other things that are of a similar or larger size.	**4 points maximum** 1 point for agreeing with Jacob 1 point for explaining why Jacob's rationale is the most logical in terms of intermolecular forces 1 point for explaining why Angel's rationale is incorrect 1 point for explaining why Kayla's rationale is incorrect
Targeted Feedback for Student Responses	
Remind students to think about what holds solid substances such as rubber together on a molecular level.	

TEACHER NOTES AND REFLECTIONS

Question 2, part (b)

Sample Solutions	Points Possible
The forces between isoprene molecules are London dispersion forces. Since isoprene is nonpolar, it only experiences London dispersion forces.	**2 points maximum** 1 point for identification of London dispersion forces 1 point for correct justification
Targeted Feedback for Student Responses	
Ask students to refer back to the lessons on intermolecular forces and ask them to identify the type of intermolecular forces present in isoprene based on its structure.	

TEACHER NOTES AND REFLECTIONS

Question 2, part (c)

Sample Solutions	Points Possible
I would predict that limonene has a higher boiling point than isoprene. Since both limonene and isoprene are nonpolar, they both only have London dispersion forces. The strength of London dispersion forces depends on the number of electrons. Limonene has significantly more carbon and hydrogen atoms than isoprene and, consequently, has many more electrons that are involved in London dispersion forces. Thus, the intermolecular forces between limonene molecules are greater, and the energy needed to separate one limonene molecule from another, as measured by boiling point, would be greater.	**3 points maximum** 1 point for selection of limonene 1 point for explaining that stronger London dispersion forces in limonene are due to a greater number of electrons 1 point for discussing the relationship of boiling point to the strength of intermolecular forces
Targeted Feedback for Student Responses	
Remind students to consider the factors that would increase the strength of intermolecular forces for various types of molecules. They can refer back to the evaporation lab and examine the trends they saw there.	

TEACHER NOTES AND REFLECTIONS

Question 3, part (a)

Sample Solutions	Points Possible
The increase in temperature would cause the molecules to move around more, overcoming intermolecular forces between limonene and other substances in the peel.	**1 point maximum** 1 point for a discussion of the agitation of the molecules disrupting the intermolecular forces between limonene and other substances in the peel
Targeted Feedback for Student Responses	
Ask students to recall what temperature actually measures and to consider where the added energy goes when heating a substance.	

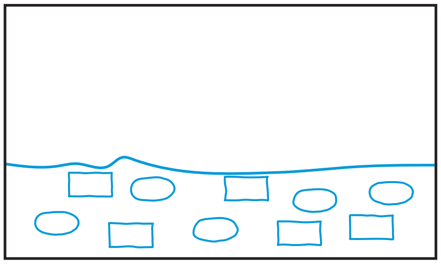
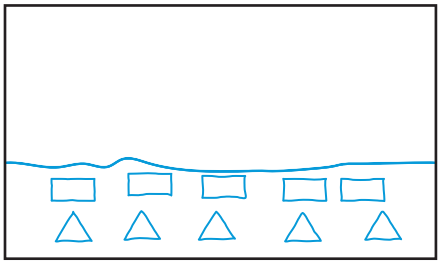
TEACHER NOTES AND REFLECTIONS

Question 3, part (b)

Sample Solutions	Points Possible
$2.0 \text{ g limonene} \times \dfrac{1{,}000 \text{ mg limonene}}{1 \text{ g limonene}} \times \dfrac{15 \text{ g peel}}{150 \text{ mg limonene}} \times \dfrac{1 \text{ orange}}{85 \text{ g peel}} = 2.4 \text{ oranges}$ The recipe requires about 2.4 (or 3) oranges.	**3 points maximum** 1 point for identifying the ratio of the mass of peel to the mass of limonene from the text 1 point for calculating the mass of orange peel needed to extract 2.0 g of limonene (could be implicit in the calculation) 1 point for calculating the number of oranges this would require *Scoring note*: Students may give the number of oranges as an integer, but doing so is not required for credit.
Targeted Feedback for Student Responses	
Students do not need to set up a dimensional analysis calculation, but they should use proportional reasoning to arrive at a solution.	

TEACHER NOTES AND REFLECTIONS

Question 3, part (c)

Sample Solutions	Points Possible
 	**5 points maximum** *Mixture of ethanol and limonene* 1 point for showing a particulate representation of at least 5 ethanol and 5 limonene molecules in a liquid state 1 point for a particulate-level representation of the substances completely dissolved in one another (no layering of individual molecules) *Mixture of water and limonene* 1 point for showing a particulate representation of at least 5 water molecules and 5 limonene molecules in a liquid state 1 point for showing a particulate representation of the lack of mixing of the two different types of molecules 1 point for representing the water molecules as the bottom layer and limonene molecules as the top layer *Scoring note*: Students do not need to draw the liquid line.

Targeted Feedback for Student Responses
Help students think about how the density of the pure substances would manifest in a mixture.

TEACHER NOTES AND REFLECTIONS

UNIT 2

Question 3, part (d)

Sample Solutions	Points Possible
(i) There are a total of 15 gas particles in the sample, 7 of which are nitrogen. Therefore, $\frac{7}{15}$ of the total pressure of the sample is due to the partial pressure of nitrogen. $P_{N_2} = X_{N_2} \times P_{total}$ $P_{total} = \frac{P_{N_2}}{X_{N_2}}$ $P_{total} = \frac{0.70 \text{ atm}}{\left(\frac{7}{15}\right)}$ $P_{total} = 1.5 \text{ atm}$ (ii) Since ethanol particles make up $\frac{4}{15}$ of the total number of gas particles in the sample, they make up $\frac{4}{15}$ of the total pressure. $P_{ethanol} = X_{ethanol} \times P_{total}$ $P_{ethanol} = \left(\frac{4}{15}\right) \times 1.5 \text{ atm}$ $P_{ethanol} = 0.4 \text{ atm}$	**4 points maximum** *(i)* 1 point for the relationship of the number of nitrogen molecules to the total number of molecules in the sample 1 point for correctly setting up and solving the proportion for finding the total pressure (students do not have to explicitly use Dalton's law) *(ii)* 1 point for the relationship of ethanol molecules to nitrogen molecules or ethanol molecules to total number of molecules in the sample 1 point for correctly setting up and solving the proportion for finding the pressure of ethanol (students do not have to explicitly use Dalton's law) *Scoring note*: If a student calculates the total pressure incorrectly in part (i) but uses that pressure correctly in part (ii), they can earn full credit for part (ii).

Targeted Feedback for Student Responses
Encourage students to show all their work and double-check that their answer makes sense. If their answer doesn't make sense, they could have made an algebra mistake.

TEACHER NOTES AND REFLECTIONS

LESSON 2.12

Classifying Solids Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Data Collection
Students rotate through stations, collecting data and making observations about several white solids.

Part 2: Analysis
Students group solids based on common properties they observed. Students identify the groups of solids as ionic or covalent and, using the data they collected, determine the properties of each class of compounds.

CONTENT FOCUS

This lesson introduces covalent and ionic compounds. Students discover properties of different solids that have similar appearances. They observe melting point, conductivity, and solubility, and ultimately group the solids into categories based on common properties. Students then generate a list of properties of ionic and covalent compounds. Throughout the rest of the unit, students build on their observations from this lab to further develop their understanding of covalent and ionic compounds.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 2.12.A: Classifying Solids – Lab Procedure
- 2.12.B: Classifying Solids – Analysis

MATERIALS

- samples of white solids: NaCl, $CaCl_2$, sugar, paraffin wax
- metal can lids or foil boats
- hot plates
- conductivity tester
- test tubes
- deionized water
- computers/tablets for Stations 4 and 5 with access to the simulation available at **https://phet.colorado.edu/en/simulation/sugar-and-salt-solutions**
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.	
Learning Objectives	**Essential Knowledge**
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 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.

SETUP AND PREPARATION NOTES

- Prepare samples for each lab station. To accommodate larger classes, you can set up multiples of each station. The key for the solids is:

  A: sodium chloride

  B: calcium chloride

  C: sugar

  D: paraffin wax

- Directions for each station are included in **Handout 2.12.A: Classifying Solids – Lab Procedure**.
- Students can rotate through the stations in any order.
- Students will need the following solids at each station:

  Station 1: sodium chloride, calcium chloride, sugar, paraffin

  Station 2: sodium chloride, sugar, paraffin

  Station 3: sodium chloride, calcium chloride, sugar

- For Station 3, students need to use deionized water. It is not uncommon for some water samples to be slightly conductive, which can lead to incorrect conclusions and confusion among students. As an extension to the lesson, you can consider testing, or having the students test, the conductivity of tap water and deionized water so students can see the difference. You can use a line of questioning to help students realize that the water itself does not conduct electricity, but that things dissolved in the water may.
- Stations 4 and 5 require students to use a PhET simulation. This simulation uses Java, not HTML5, so the file needs to be downloaded and opened on a device at each station before the lesson. For help with running the simulation, see **https://phet.colorado.edu/en/help-center/running-sims**.

SAFETY NOTES

- Students should wear chemical splash goggles.
- Use caution with ceramic hot plates, as they can crack when exposed to high temperatures.
- If you use can lids, warn students to be careful of sharp edges.
- Follow all general safety guidelines.

PART 1: DATA COLLECTION

Students rotate through five stations, collecting data on various properties of solids.

Instructional Rationale

The goal of this approach as an introduction to ionic and covalent compounds is for students to make observations that they can refer back to as they learn more details about these compounds. Most of the stations focus on macroscopic observations, but Station 5 allows students to connect these observations to atomic-level representations.

- To begin, let students know that they will rotate through several stations to collect data about solids that will eventually let them organize the solids based on their properties.
- Explain to students what the stations are, where they are located in the room, how they should rotate through them, and give cleanup and disposal instructions for each station.
  - Station 1 has students observe the melting temperatures of paraffin, sugar, NaCl, and $CaCl_2$ using a hot plate. Students will observe that the paraffin and sugar melt and NaCl and $CaCl_2$ do not melt, even after an extended time. Students will not record melting temperatures, but rather the order in which the solids melt.
  - At Station 2, students observe NaCl and sugar dissolve in water while paraffin does not.
  - At Station 3, students observe that NaCl and $CaCl_2$ conduct electricity when dissolved in deionized water but sugar does not. The measured conductivity is not as important as whether the solution does or does not conduct.
  - For Stations 4 and 5, PhET simulations are used to allow students to visualize on a molecular level why salt solutions conduct electricity but sugar solutions do not.

Guiding Student Thinking

The microscopic views are introduced here so students have a visual representation as they learn more about covalent and ionic compounds throughout the rest of the unit. Students can return to these simulations or their observations, particularly when they begin to learn about the crystal structure of ionic compounds.

- Have students work in small groups to rotate through the stations. The directions and data table for each station are on **Handout 2.12.A: Classifying Solids – Lab Procedure**.

- As students work, circulate around the room and ensure that they are labeling their samples so they can identify them later. You may want to let students know that they will eventually categorize the solids based on their observations to encourage them to be as detailed as possible. You could ask groups to make preliminary categorizations based on their observations at each station, which they will revise as they collect more data.

PART 2: ANALYSIS

Students use the data collected in Part 1 to group the solids according to their properties. Students also use their data from Part 1 to generate a list of the properties of both covalent and ionic compounds.

- Have students work with their group on questions 1 and 2 on **Handout 2.12.B: Classifying Solids – Analysis**.

Instructional Rationale

The solids used in this lesson were chosen specifically so that the properties did not align perfectly (e.g., sugar and paraffin have different solubility but similar melting points based on data collected here). Since there is no clear way to categorize the solids, students can have robust discussions in which they must justify their thinking to their classmates.

- Question 2 asks students to group the solids based on their observed properties. Since they may disagree about the groupings, now is a good time for them to debate and discuss their groupings. You can facilitate this by pairing up student groups and having them share their answers and reasoning, or you could have each group write their answers and reasoning on a piece of chart paper or a large whiteboard and then do a gallery walk. However you choose to have students share, the focus should be on the reasoning behind their choices.
- Once students have decided on their groupings, introduce the terms *ionic* and *covalent*, and explain to students that compounds can have different types of bonding, which determine the properties they observed.

Guiding Student Thinking

If you have students who recognize that they may have three different groups of solids instead of two, you could introduce *polar* and *nonpolar* as types of covalent bonding that produce molecular solids with different solubility.

- Next, ask students to work with their groups to complete the table in question 3. This question identifies the compounds, labels two of them as either ionic or covalent, and asks students to determine whether the others are ionic or covalent. Encourage students to return to their data and observations and earlier groupings to help with their justifications.
- As a follow-up to question 3, you can ask students to draw particle diagrams of calcium chloride in water and paraffin in water. Students should base their diagrams on their classification from question 3, their observations of paraffin in water at Station 2, and their observations of the simulation at Stations 4 and 5.
- Question 4 asks students to generate a list of properties of covalent and ionic substances, based on their observations. After groups have had time to answer the question, ask them to share their lists with another group. These larger groups should discuss similarities and differences and then come to a consensus about the properties of ionic and covalent compounds.

Meeting Learners' Needs

If students struggle to generate properties, you could give them sentence stems or sentence frames and ask students to complete them for each type of bonding. For example: ____________ compounds have ____________ melting points.

Instructional Rationale

Having students generate their own list based on observations requires that they closely analyze their data and identify patterns. This critical thinking promotes more durable conceptual understanding than just giving students a list of the properties of ionic and covalent compounds.

- Close the lesson by having a whole-class discussion about the properties of ionic and covalent compounds, and ensure that students finish the lesson with an accurate table for question 4. As part of your discussion, you may want to include symbolic representations of the dissolving process, such as $NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$ and $C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11}(aq)$. These representations can lay a foundation for net ionic equations, which are introduced in Unit 4.

Instructional Rationale

So far in the lesson, students have used macroscopic and particle representations. Adding the equation allows them to also use symbolic representations.

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 2.12.A: Classifying Solids – Lab Procedure

Station 1

	Solid A	Solid B	Solid C	Solid D
Observations	does not melt	does not melt	melts 2nd	melts 1st

Station 2

	Solid A	Solid C	Solid D
Observations	dissolves	dissolves	does not dissolve

Station 3

	Solid A	Solid B	Solid C
Observations	conducts	conducts	does not conduct

Station 4

Substance	Solubility in Water (yes or no)	Electrical Conductivity (yes or no)
Pure water (H_2O)	N/A	no
Salt ($NaCl$)	yes	yes
Sugar ($C_{12}H_{22}O_{11}$)	yes	no

Station 5

Substance	Solubility in Water (yes or no)	Dissociation in Water (yes or no)
Salt ($NaCl$)	yes	yes
Sugar ($C_{12}H_{22}O_{11}$)	yes	no

Handout 2.12.B: Classifying Solids – Analysis

1.

Solid	Melts on a Hot Plate	Dissolves in Water	Conducts Electricity in Water	Dissociates in Water
A		x	x	x
B		?	x	?
C	x	x		
D	x			

2. Sample response: I would group these solids into 3 groups. I think solids A and B are similar because neither melted and both conduct electricity when dissolved in water. I'm not sure about solids C and D. I think they are similar because they both melted under 150°C, but C dissolved and D didn't. I would put C and D in groups by themselves.

3.

Solid	Substances	Ionic or Covalent?	Justification
A	Salt	ionic	
B	Calcium chloride	ionic	similar properties to solid A
C	Sugar	covalent	
D	Paraffin wax	covalent	similar properties to solid C

4.

Properties of Covalent Compounds	Properties of Ionic Compounds
lower melting points some dissolve in water don't conduct electricity	high melting points dissolve in water conduct electricity when dissolved in water repeating crystal structure

UNIT 2

LESSON 2.13

The Structure of Ionic Compounds

OVERVIEW

LESSON DESCRIPTION

Part 1: The Migration of Ions
Students watch a video demonstration in which an ionic compound is placed in an electrical field generated by a battery. They then use evidence from the demonstration to determine which of two particulate representations could explain their observations.

Part 2: Examining Molten NaCl
Students observe the differences in electrical conductivity of both solid and liquid sodium chloride and then create a particulate representation of NaCl(*l*) that supports their observations.

Part 3: Properties of Solid Ionic Compounds
Students examine four different particulate representations of solid ionic compounds, deciding which is best based on the formula of the compound and the understanding gained in Parts 1 and 2 of the lesson. Students then model the cleavage of mica and halite using scissors and the particulate representation they have chosen to best represent a solid salt.

Part 4: Phase Changes and Ionic Forces
Combining the knowledge gained in this lesson with concepts of periodicity, students construct representations of three different ionic solids, then tie these representations to melting point data on the solids using Coulomb's law.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 2.13.A: The Migration of Ions
- 2.13.B: Examining Molten NaCl
- 2.13.C: The Properties of Solid Ionic Compounds
- 2.13.D: Phase Changes and Ionic Forces

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing online videos to students

CONTENT FOCUS

This lesson gives students a detailed introduction to the particulate structure of ionic compounds. Many students retain misconceptions from physical science classes that ionic compounds are "molecular" in nature, not understanding that although such compounds are represented as formula units like NaCl, the particulate structure is that of a lattice of ions. Therefore, we cannot use Lewis diagrams to represent such compounds.

The goal of this lesson is for students to observe the behavior of ionic substances in a variety of scenarios and to use their observations to build an understanding of the structure of ionic compounds. They accomplish this by building on their knowledge and skills from Unit 1 and earlier lessons in Unit 2 about the particle nature of matter and particle interactions.

In order to be successful with this lesson, students need to know how to name ionic compounds and write formulas for binary ionic compounds. They should also know periodic trends for atomic radii.

- internet access to show the following video demonstrations: "Ions in electric field" (0:46) posted by ChemToddler (**https://youtu.be/lJ-tTN3PlAY**), "Molten salt (NaCl) conducts electricity" (1:19) by BerkeleyChemDemos (**https://youtu.be/NfNIn4R8tg4**), "Demonstration of mineral cleavage using a muscovite mica crystal" (0:20) by James W. Fatherree (**https://youtu.be/cxtIvxUd4DY**), and "How to observe the mineral halite crystalline form and cleavage" (2:17) by Scott Brande (**https://www.youtube.com/watch?v=OwTWijeDbSo**)
- scissors
- tape or glue
- periodic table (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

This lesson is written using video demonstrations available on the video-sharing site YouTube. If you have trouble accessing these videos or would like to use a different approach, you can find similar videos elsewhere online or conduct your own versions of these demonstrations. Helpful search terms for finding similar videos and procedures are below.

- For Part 1, you can search for procedures or alternative videos using the phrase “fast ionic migration of copper chromate.” See also the article “Fast ionic migration of copper chromate” from the *Journal of Chemical Education*, available at **https://doi.org/10.1021/ed078p207**.
- For Part 2, you can search for procedures or alternative videos using the phrase “molten salt conducting electricity.”
- For Part 3, you can search for procedures or alternative videos using the phrase “mica mineral cleavage.”
- For Part 4, you can search for procedures or alternative videos using the phrase “halite crystal cleavage.”

PART 1: THE MIGRATION OF IONS

In the first part of this lesson, students watch a video demonstration in which an ionic compound is placed in an electrical field generated by a battery. They then use evidence from the video to determine which of two particulate representations could explain their observations. This part of the lesson is designed to have students begin to think about the structure of ionic compounds as a crystal lattice rather than as distinct molecules.

- Begin with a quick review of writing formulas for ionic compounds. Give students several metals and nonmetals from the periodic table and ask them to determine the formulas for the ionic compounds made from these elements. Although you can pick almost any elements, a review of compounds from the alkali metals and the halogens would help prepare students for the rest of the lesson. Specifically, you could ask:
  - What would be the formula for the ionic compound made from:
    - Sodium and bromine? $NaBr$
    - Magnesium and oxygen? MgO
    - Barium and fluorine? BaF_2
    - Potassium and sulfur? K_2S
- Next, introduce the formula $CuCrO_4$ and the name, copper(II) chromate. Ask students to give the identity and charge of the cation and the anion in $CuCrO_4$.

  The copper(II) ion is positive with a charge of +2, while the CrO_4 ion is negative with a charge of −2.

Meeting Learners' Needs

The beginning of this lesson is a good time for a quick formative assessment on formula writing. If students have difficulty with the first step, you might review how to determine the charges of ions from the periodic table, as students must know how to do that. They must also understand that the formulas of ionic compounds are neutral.

Meeting Learners' Needs

The use of the Stock system (Roman numerals) and unfamiliar polyatomic ions may cause confusion for students. It can be helpful to ask them what the charge must be in the compounds JCl_3 and BaQ_2, where J and Q are unknown metals and nonmetals. Seeing the neutrality of the formula coupled with being able to determine the charge of Cl or Ba from the periodic table should help students get comfortable with determining the charges of unknown elements or polyatomic ions, as J must have a charge of +3 and Q must be −1 to satisfy these criteria.

UNIT 2

- Although students can write the formulas for ionic compounds, they may not have a good picture of what the compounds look like on a particle level. The goal of this first demonstration is to create that picture. To lead into the demonstration, ask students the following sequence of questions:
  - If something has a positive charge, what will it do when placed near:
    - Another positive charge? It will be repelled.
    - A negative charge? It will be attracted.
    - Something neutral? Nothing should happen.
    - Why do these things happen? Like charges repel and unlike charges attract. If something is neutral, nothing should happen because there is not an excess of one charge or the other.
  - Based on the formula for copper(II) chromate, what do you expect to happen when it is placed near a positive or negative charge?

    Student answers will vary since they have not been exposed to this content yet but will be later in this lesson. Possible responses might include:
    - It won't be attracted because it's a neutral compound.
    - The chromate ion will be attracted to the positive charge.
- After students answer the questions, tell them that they are going to watch a video demonstration of the scenario described in the last question. Explain to students that copper ions are blue and chromate ions are yellow.

Guiding Student Thinking

Some students may note that the formula used for the copper ion in the video demonstration is not simply Cu^{2+}, but $[Cu(NH_3)_4]^{2+}$. If students notice this, you can tell them that the copper ion was surrounded by two different solvents (in this case water and ammonia) to make it more visible. These are called *complex ions*, and although they are beyond the scope of this course, they are very important for inorganic chemistry.

- Explain the setup to students before showing the video: a small sample of copper(II) chromate was placed on conductive paper and the paper was attached to a battery that is not shown. Point out that the positive and negative terminals of the battery are connected to the edges of the dishes in the video.
- Show the video "Ions in electric field" (**https://youtu.be/lJ-tTN3PlAY?t=14**), starting 14 seconds in.

- After students have watched the video, ask them to work in pairs to answer question 1 on **Handout 2.13.A: The Migration of Ions**. Then have pairs of students form groups of four to share their answers and justifications. The groups should come to a consensus about the correct representation and work together to strengthen their justifications.
- Once groups have reached a consensus on the correct representation, follow the same process and have students work only with their original partner to answer question 2 on the handout. After each pair of students has had time to draw their model, ask them to again partner with another group and review their models. As you monitor the class, look for student discussions on these ideas:
  - Copper(II) is positively charged and therefore attracted to the negative terminal.
  - Chromate is negatively charged and therefore attracted to the positive terminal.
- After groups have had time to discuss and revise their models, lead a whole-class discussion about which representation they chose, their justifications, and their models for question 2.

PART 2: EXAMINING MOLTEN NaCl

In this part of the lesson, students examine experimental consequences of the representation created in Part 1, this time by viewing a video of molten sodium chloride conducting electricity. This also allows students to revisit particle diagrams of the different states of matter that were key components of Unit 1.

- Begin by asking students to consider the statement at the top of **Handout 2.13.B: Examining Molten NaCl**:

Electric current is the consequence of the movement of charged particles.

Handout 2.13.B

- Since students may have different understandings about current, use questions such as the following to elicit their background knowledge:
  - What is meant by the term *current*?

    Current means something is moving. For example, a river current describes the flow of water in a river.
  - With this definition of current and with information from previous classes, what do you think is happening in a wire when it is conducting electricity?

    Students should be guided to the answer that something must be flowing. The statement from the handout clarifies this by stating that an electric current occurs because charged particles move. Some students may say that electrons are flowing in the wire. This is on track, but follow up by asking them: If the statement says "charged particles" must flow, could you create electric current without electrons flowing?

- Next, show the video demonstration "Molten salt (NaCl) conducts electricity" (**https://youtu.be/NfNIn4R8tg4**). Pause at the 15-second mark, which follows a demonstration of the light bulb conducting electricity and introduces the solid sodium chloride. Ask students to individually answer question 1 on the handout. Then ask them to discuss with a partner and revise their prediction and justification based on that discussion.
- Circulate around the room to support any students who are having trouble with a justification. Having students focus specifically on the state of matter should help them in their reasoning. Bring the class back together and ask several students to share their predictions and justifications.
- Now show the remainder of the video. Ask students to record their observations on the handout about both the light bulb and the NaCl during the heating and cooling process. It will likely be necessary to show the video at least twice for students to focus on each element.
- Once students have recorded their observations, ask questions such as the following to ensure students focused on the correct objects and events shown in the video. If they are unable to answer the questions, show the video again.
    - Was something moving in the solution while the bulb was on?

      Charges must be flowing based on the statement at the top of the handout.
    - What state of matter did the NaCl become while the bulb was on?

      Liquid
    - What happened when the NaCl cooled?

      The bulb turned off.
- Finally, allow students time to draw a particle diagram of NaCl during heating that could be used to explain their observations. You could have students do this individually or with a partner. In either case, give students the opportunity to view and discuss their model with other students.

Classroom Ideas

You could have groups draw their models on whiteboards to share with the class.

- After students have had time to revise their models, lead a whole-class discussion about how their models either support or do not support their observations.

PART 3: PROPERTIES OF SOLID IONIC COMPOUNDS

In this part of the lesson, students examine four different particulate representations of solid ionic compounds, deciding which is best based on the formula of the compound and the understanding gained in Parts 1 and 2 of the lesson. Students then model the cleavage of mica and halite using scissors and the particulate representation they have chosen to best represent a solid salt.

- Before beginning this part of the lesson, students might need a refresher on Coulomb's law. You can ask questions such as the following to gauge student understanding:
  - What types of charges are attracted to each other? What types of charges are repelled by each other?

    Objects with like charge repel and objects with unlike charge attract.
  - What role does the amount of charge play in the amount of attraction or repulsion?

    The greater the amount of charge each object has, the greater the attraction or repulsion.
  - What role does the distance between the charges play in the amount of attraction or repulsion?

    The closer the charged objects are relative to one another, the greater the attraction or repulsion.

Guiding Student Thinking

Students may be unfamiliar with the term *Coulomb's law*. Explain that this is the formal name for the phenomenon that like charges repel and unlike charges attract, with the strength of the attraction or repulsion depending inversely on the square of the distance between them. Quantitative applications of the law are beyond the scope of this course, but this is a good time to have students associate the name with what they are exploring in the lab. If students go on to take physics or AP Chemistry, they will learn about Coulomb's law in more detail.

- Have students work with a partner on question 1 from **Handout 2.13.C: The Properties of Solid Ionic Compounds**. This question asks them to identify the correct particulate model of an ionic solid and explain why it is correct and the others are incorrect. Circulate around the room to help guide student thinking as they consider each of the representations.

Guiding Student Thinking

Students may be confused that they don't have the formula of the ionic compound represented by the pictures and think that they can't answer the question. If they have trouble generalizing, ask them what families of elements on the periodic table the ions might come from based on the charges in the diagram. Therefore, what is the likely formula of the compound?

- After students have had time to identify and justify the representations, ask them to share their responses with another pair. Allow time for them to revise their responses after discussion.
- Poll the class about which representation each group believes correctly depicts an ionic compound. After a consensus has been reached, have different groups share why the other representations will not work in terms of Coulomb's law and stability.
- Show the video "Demonstration of mineral cleavage using a muscovite mica crystal" (**https://youtu.be/cxtIvxUd4DY**). You may want to play it several times.
- After students view the video, have them simulate what is happening on a particle level by using scissors to cut the representations on their handout (question 2). Students could do this in pairs or in small groups. Circulate around the room and ask each group why cutting their representation that way would result in two stable samples. Students should tape or glue their representation in the space indicated on their handout.

Instructional Rationale

If your students have taken an Earth science class, ask them what they know about rock and mineral identification. They likely learned that *cleavage*, which describes how readily a mineral separates along a plane, is one property that can be used to identify minerals.

Guiding Student Thinking

Different groups may cut their samples with different thicknesses, e.g., two layers of ions as opposed to one. Technically any number of layers is acceptable as long as students can explain that such a cut will result in the nearest neighbor ions being close to ions of opposite charge. In addition, watch out for students cutting through the middle of an ion. The key here is that students can use Coulomb's law to support the stability of their cut and that the shape they have made resembles what is shown on screen.

- Now show the video demonstration "How to observe the mineral halite crystalline form and cleavage" (**https://www.youtube.com/watch?v=OwTWijeDbSo**). You may want to show it several times.
- After students have viewed the video, have them simulate what is happening on a particle level by cutting the representation on the handout with scissors. Circulate around the room and ask each group why cutting their representation that way would result in two stable samples.

Classroom Ideas

You might want to ask students to examine crystals of sodium chloride, either with the naked eye or with a magnifying glass. Does the structure of these crystals support what they saw?

- Finally, have students complete question 3 on the handout to explain why they cut each model the way they did. Consider having students share their representations, either with a small group or with the whole class.

PART 4: PHASE CHANGES AND IONIC FORCES

The last part of this lesson asks students to relate the structure of ionic compounds to Coulomb's law and to explain trends in melting points.

- Have students find **Handout 2.13.D: Phase Changes and Ionic Forces**. Explain that we would like to tie the melting points of the compounds listed to their structures. Some guiding questions to consider asking before students complete the handout include:
  - What does melting point measure?

    The melting point is the temperature at which a solid transforms into a liquid.
  - What is the relationship between the melting point and intermolecular forces?

    The higher the melting point, the stronger the intermolecular forces between different particles in the compound.

- Highlight that a particulate representation of NaCl is shown on the handout and that they are being asked to draw the representations for three other ionic compounds. Ask students to consider both the charges of the cation and anion in NaCl and the relative position of the elements on the periodic table as they then draw particulate representations of the other ionic compounds.
- Have students work with a partner to answer question 1 on the handout. Circulate around the room checking for both compound neutrality and the relative sizes of ions. If you see that student pairs have different answers, form small groups with these student pairs to share responses and allow them time to make revisions based on their discussions.

Meeting Learners' Needs
Some students may need support in recognizing that different ions may have different sizes. Giving each group a small periodic table they can write on can aid them in remembering both the trends in ion size and the charges each ion takes in the given compounds.

- Bring the groups back together for a whole-class discussion about the various representations drawn. Make sure to come to a consensus about the structures of the various representations.
- Ask students to individually respond to question 2 on the handout by writing a coherent, evidence-based paragraph. Remind students that the paragraph should include a claim, evidence, and reasoning to justify their answers for each compound.

Classroom Ideas
You could assign one structure to each group and have them redraw it on a whiteboard for the other groups to see during the discussion.

- After students have had time to write individually, let them work with a partner or small group to discuss and revise their explanations. They can use the following questions to evaluate the strength of their own and their peers' responses:
  - Does the explanation clearly address each substance?
  - Does the explanation clearly connect Coulomb's law to the particulate structure of each substance?
  - Does the explanation clearly connect the melting point of the substance to the strength of interactions as described by Coulomb's law?
- Have each group create a revised explanation (if needed). Then allow time to have a class discussion of the groups' explanations.

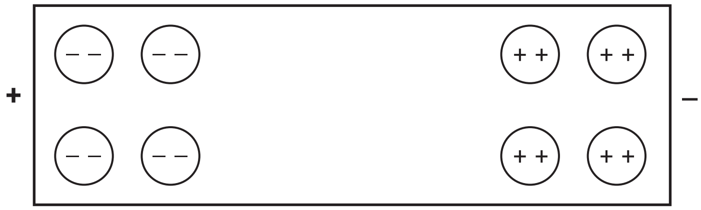
Meeting Learners' Needs
If students need support drafting their paragraphs, consider using sentence starters to guide them to use claims and evidence concisely. For example, "NaCl has a higher boiling point than NaBr because …" or "Although I^- is larger than Cl^- …"

ASSESS AND REFLECT ON THE LESSON

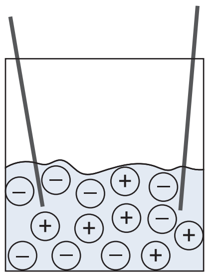
HANDOUT ANSWERS AND GUIDANCE

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

Handout 2.13.A: The Migration of Ions

1. Representation 2. Since two distinct bands are formed, two different sets of particles must be separating from one another. If $CuCrO_4$ consisted of molecules like representation 1, the bands could not expand, as the molecule would eventually "break." Only individual ions, as shown by representation 2, could create the bands shown.
2. 

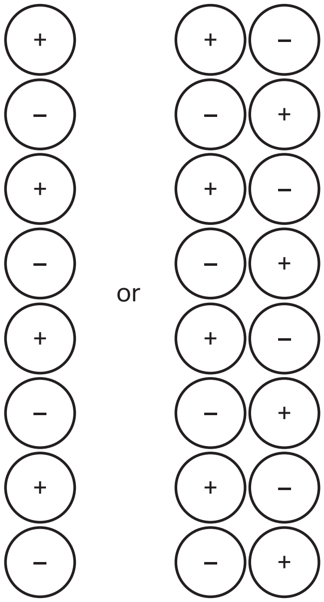
Handout 2.13.B: Examining Molten NaCl

1. Answers will vary. Since ions cannot move in the solid state, there will be no ion conduction and electricity cannot flow.
2. The NaCl becomes liquid and the bulb lights up.
3. 

Handout 2.13.C: The Properties of Solid Ionic Compounds

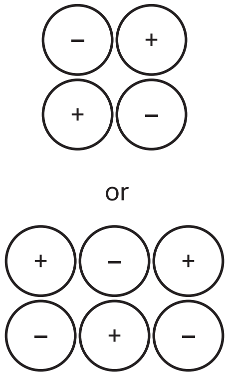
1. A: Incorrect. Having ions with the same charge next to each other would cause extra repulsion and be unstable. B: Incorrect. Having ions with the same charge next to each other would cause extra repulsion and be unstable. C: Incorrect. NaCl only consists of ions with charges of +1 and −1 OR the total charge in this representation is unbalanced. D: Correct. The alternating arrangement of ions with opposite charges of the same strength will result in the greatest overall attraction in and therefore stability of the solid.

2. Potential Mica Answers



Students should show neutral layers one to two particles thick.

Potential Halite Answers

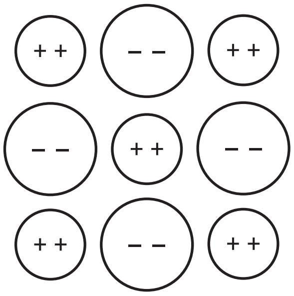


Students should show cubic or rectangular subshape after cleavage. Structure should be neutral with no particles cut down the middle.

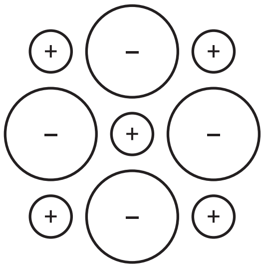
3. Answers will vary. Students should cite evidence observed in the videos for the shapes of their split compounds.

Handout 2.13.D: Phase Changes and Ionic Forces

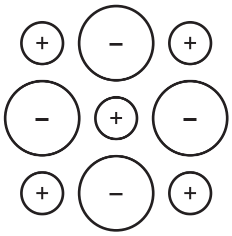
1. MgO



NaI



NaBr



2. The melting point is the temperature at which the forces between ions are completely overcome, allowing particles to separate and become a liquid. According to Coulomb's law, the force between charged particles depends directly on the charge of each particle and inversely on the square of the distance between the particles. MgO has particles with the greatest charge (+2 and –2) and the smallest distance between them. Therefore the force between the particles is the greatest and the energy required to pull them apart is the greatest. This means that the melting point of MgO is the highest.

   All of the other compounds (NaI, NaCl, and NaI) have ions with charges of +1 and –1. However, because the particles get larger as you move down a column on the periodic table, NaI has the greatest distance between particles while NaCl has the smallest. Consequently, the force of attraction between Na^+ and I^- is the smallest of the three while the force between Na^+ and Cl^- is the largest (with NaBr in the middle). Therefore, NaCl has the second highest melting point, NaBr the third highest, and NaI the smallest.

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Unit 2

Performance Task

PERFORMANCE TASK

UNIT 2

Ionic and Covalent Compounds

OVERVIEW

DESCRIPTION

Part 1: The first part of the performance assessment is a pencil-and-paper task, with two options to choose from. Option A is an argumentation task focused on isomerism. Option B involves analyzing melting point data and drawing Lewis diagrams for two covalent compounds.

You will choose to administer either option A or B for Part 1 based on which content and skills you wish to focus on for this assessment.

Part 2: The second part of this performance assessment is a lab-based task that requires students to collect data and analyze it in order to determine the bond type. Students also create particulate representations of ionic and molecular compounds in water.

All students will complete Part 2.

CONTENT FOCUS

Students use their knowledge of ionic and covalent compounds to evaluate claims, draw particulate models, draw Lewis diagrams and determine molecular geometry, and use experimental evidence they collect to determine if compounds are ionic or covalent.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 2 Performance Task: Ionic and Covalent Compounds

MATERIALS

- equation sheet
- periodic table
- calculator
- potassium chloride solid
- glucose solid
- paraffin wax
- water
- conductivity testers
- hot plates
- stirring rods
- small cups or beakers
- deionized or distilled water
- small foil pans for melting
- tongs or hot mitts
- goggles

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The structure and properties of compounds arise from the periodic properties and bonding patterns of the constituent atoms.	
Learning Objectives	**Essential Knowledge**
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.
2.3.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.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.

SETUP AND PREPARATION NOTES

Because this performance task includes both a paper-and-pencil section and a lab section, you will want to plan out how to structure students' time and organize the classroom during this assessment. See Supporting Students: During the Task below for more information.

For Part 2:

- Prior to administering the task, prepare the unknown substances in cups labeled A (KCl), B ($C_{20}H_{42}$), and C ($C_6H_{12}O_6$). Each student will need a set of unknowns, and each cup should contain about one gram of the unknown substance.
- Set up lab stations for students to complete part (c) of this task.

SAFETY NOTES

- All general safety guidelines should be followed.
- Students should wear goggles during Part 2.

SUPPORTING STUDENTS

DURING THE TASK

- You may want to have half the students start on Part 1 (the paper task) and half start on Part 2 (the lab), and then switch places. If you use this structure, let students know which part they should be working on first and when it is time to switch.
- You could present students with both options for Part 1 and allow each student to decide which one they will complete.
- Students could work in pairs to complete Part 2. It is not recommended for students to work in small groups. There is ample work and enough potential discussion areas for two students, but in a group of more than two there may not be quite enough for everyone to meaningfully engage in the task. You may want to approve student procedures before allowing them to proceed.

UNIT 2

Scoring Guidelines

There are 17 possible points for this performance task (6 points for either option A or option B for Part 1, and 11 points for Part 2).

Part 1: Option A

Sample Solutions	Points Possible
Claim 1 (a) I agree with this claim. (b) Both structures show two carbon atoms, four hydrogen atoms, and two oxygen atoms, meaning they have identical chemical formulas, $C_2H_4O_2$. However, the atoms are connected in a different sequence in the two structures. In Molecule 1, one end of the molecule has atoms arranged as COCOH, while in Molecule 2 the sequence is CCOOH. (c) As the definition of *isomers* is molecules that have identical formulas but different arrangements of atoms, this is a valid claim.	**2 points maximum** 1 point for stating that both molecules have the same chemical formula 1 point for stating that the atoms are connected in a different order, which makes them isomers *Scoring note:* No points are assigned for agreeing or disagreeing with the claim.
Claim 2 (a) I disagree with this claim. (b) The two molecules are isomers. (c) Isomers are expected to have different properties that allow them to be distinguished from each other, as is the case with eugenol and isoeugenol. Those two isomers have different odors and flavors, which are chemical properties.	**2 points maximum** 1 point for stating that the molecules would have different properties because they are isomers (or different substances) 1 point for providing reasoning to support the claim. Students do not have to reference eugenol and isoeugenol. *Scoring note:* No points are assigned for agreeing or disagreeing with the claim.

Claim 3 (a) I disagree with this claim. (b) In Molecule 1, the carbon on the left has three electron domains: one double bond to oxygen, one single bond to oxygen, and one single bond to hydrogen, which means it has trigonal planar geometry. (c) An atom with three electron domains has a trigonal planar geometry, not a tetrahedral geometry.	**2 points maximum** 1 point for stating that for a molecule to have tetrahedral geometry it must have four electron domains 1 point for providing evidence for stating that the left carbon has three electron domains *Scoring notes:* ▪ No points are assigned for agreeing or disagreeing with the claim. ▪ Students do not need to identify that the carbon is trigonal planar, only that it is not tetrahedral.
Targeted Feedback for Student Responses	
Give students ample opportunities to craft claims using evidence and support those claims with reasoning.	

TEACHER NOTES AND REFLECTIONS

UNIT 2

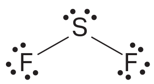
Part 1: Option B

Question 1

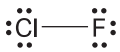
Sample Solutions	Points Possible
Both compounds are covalent. Both compounds have a low melting point. OR Both compounds are covalent. Both compounds are composed entirely of nonmetal elements.	**1 point maximum** 1 point for a correct choice and for providing one of the two justifications
Targeted Feedback for Student Responses	
Remind students that ionic substances generally consist of a metal and a nonmetal, while covalent compounds are generally composed of only nonmetals. Covalent compounds also generally have lower melting points than ionic compounds, and the melting points given are relatively low.	

TEACHER NOTES AND REFLECTIONS

Question 2, part (a)

Sample Solutions	Points Possible
 SF_2 is bent.	**2 points maximum** 1 point for a correct structure for SF_2 1 point for a correct geometry for SF_2 *Scoring notes:* The geometry must be consistent with the Lewis diagram. If the Lewis diagram was incorrect but the geometry is correct based on the Lewis diagram drawn, the second point should be awarded.
Targeted Feedback for Student Responses	
Encourage students to add up the number of valence electrons and ensure that each atom obeys the octet rule. VSEPR is based on electron repulsion. Ask students to recall the activity they did with gumdrops or modeling clay to minimize repulsion and what those shapes were.	

Question 2, part (b)

Sample Solutions	Points Possible
 ClF is linear.	**2 points maximum** 1 point for a correct structure for ClF 1 point for a correct geometry for ClF *Scoring note:* The geometry must be consistent with the Lewis diagram. If the Lewis diagram was incorrect but the geometry is correct based on the Lewis diagram drawn, the second point should be awarded.

Targeted Feedback for Student Responses
Encourage students to add up the number of valence electrons and ensure that each atom obeys the octet rule. VSEPR is based on electron repulsion. Ask students to recall the activity they did with gumdrops or modeling clay to minimize repulsion and what those shapes were.

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
C is the best representation. ClF molecules are formed by polar covalent bonds, so each molecule has a positive end and a negative end as shown in C.	**1 point maximum** 1 point for a correct choice and explanation
Targeted Feedback for Student Responses	
Ask students to consider why some bonds are polar, what it means for a bond to be polar, and how those bonds are different from ionic bonds.	

TEACHER NOTES AND REFLECTIONS

Part 2

Question 1

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

Solid	Observations During Heating	Solubility in Water	Conductivity When Dissolved in Water
A	Does not melt	Dissolves	Yes
B	Melts after 30 seconds	Does not dissolve	Not applicable
C	Melts after 3 minutes	Dissolves	No

</td><td>

3 points maximum

3 points if there are no errors in the data table

2 points if there are 1 or 2 errors in the data table

1 point if there are 3 or 4 errors in the data table

0 points if there are more than 4 errors in the data table

</td></tr>
<tr><th colspan="2">Targeted Feedback for Student Responses</th></tr>
<tr><td colspan="2">Remind students about the importance of being systematic in the lab and making close observations.</td></tr>
</table>

TEACHER NOTES AND REFLECTIONS

UNIT 2

Question 2, part (a)

Sample Solutions	Points Possible
A: ionic B: nonpolar covalent C: polar covalent	**1 point maximum** 1 point for matching all three unknown substances to their correct bond types

Targeted Feedback for Student Responses
Ionic bonds are the strongest intramolecular force, and nonpolar covalent are the weakest, with polar covalent in between. The stronger the attraction, the higher the melting point of a substance.

Question 2, part (b)

Sample Solutions	Points Possible
A: KCl B: $C_{20}H_{42}$ C: $C_6H_{12}O_6$	**1 point maximum** 1 point for matching all three unknown substances to their correct formulas

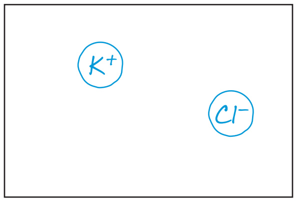
Targeted Feedback for Student Responses
Ionic substances generally consist of metals and nonmetals, while covalent compounds are generally all nonmetals.

TEACHER NOTES AND REFLECTIONS

Question 3, part (a)

Sample Solutions	Points Possible
The particles shown are atoms, not ions, since no charges are indicated.	**1 point maximum** 1 point for a correct response
Targeted Feedback for Student Responses	
Ionic bonds are actually just electrostatic attractions between positive and negative ions, so ionic substances consist of ions, not atoms.	

Question 3, part (b)

Sample Solutions	Points Possible
	**1 point maximum** 1 point for a drawing with one potassium ion and one chloride ion, with the correct charge on each ion
Targeted Feedback for Student Responses	
As ionic substances dissolve in water, they dissociate into positive and negative ions.	

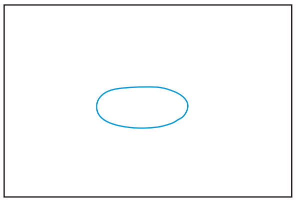
TEACHER NOTES AND REFLECTIONS

UNIT 2

Question 4, part (a)

Sample Solutions	Points Possible
The molecule is shown as individual atoms. The $C_6H_{12}O_6$ molecule does dissociate in water.	**1 point maximum** 1 point for a correct response
Targeted Feedback for Student Responses	
Covalent substances do not dissociate as they dissolve. Many students think *dissociate* and *dissolve* mean the same thing.	

Question 4, part (b)

Sample Solutions	Points Possible
	**1 point maximum** 1 point for a drawing with one molecule of $C_6H_{12}O_6$
Targeted Feedback for Student Responses	
Molecular compounds are made up of discrete molecules that remain intact when they dissolve in water.	

TEACHER NOTES AND REFLECTIONS

Question 5

Sample Solutions	Points Possible
A is the best representation. KCl exists as a lattice of alternating positive and negative ions as shown in A.	**1 point maximum** 1 point for a correct choice and explanation

Targeted Feedback for Student Responses
Ask students to think about why some substances conduct electricity and others do not. Since a glucose solution does not conduct electricity, that means there cannot be charged particles present.

TEACHER NOTES AND REFLECTIONS

UNIT 2

Question 6

Sample Solutions	Points Possible
potassium chloride	**1 point maximum** 1 point for a correct answer

Targeted Feedback for Student Responses
For binary ionic compounds, the metal is named first, followed by the nonmetal. The end of the nonmetal's name is changed to "-ide."

TEACHER NOTES AND REFLECTIONS

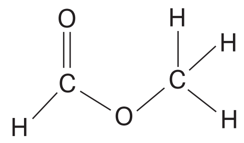
Ionic and Covalent Compounds

PERFORMANCE TASK

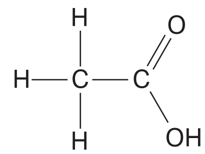
PART 1: OPTION A

Structural formulas for two molecules are shown. Three claims about these molecules are given below. Evaluate each claim by responding to the prompts below it.

Molecule 1



Molecule 2



Claim 1: "These two molecules are isomers."

(a) Agree/Disagree: Do you agree or disagree with the claim?

(b) Evidence: Give evidence to support your choice to agree or disagree.

(c) Reasoning: Explain how your evidence supports your choice.

Claim 2: "These two substances most likely have identical properties."

(a) Agree/Disagree: Do you agree or disagree with the claim?

(b) Evidence: Give evidence to support your choice to agree or disagree.

(c) Reasoning: Explain how your evidence supports your choice.

PERFORMANCE TASK

Claim 3: “Both of the carbons atoms in Molecule 1 have tetrahedral geometry.”

(a) Agree/Disagree: Do you agree or disagree with the claim?

(b) Evidence: Give evidence to support your choice to agree or disagree.

(c) Reasoning: Explain how your evidence supports your choice.

PART 1: OPTION B

PERFORMANCE TASK

Consider the compounds SF_2 and ClF. SF_2 has a melting point of –62°C and ClF has a melting point of –156°C.

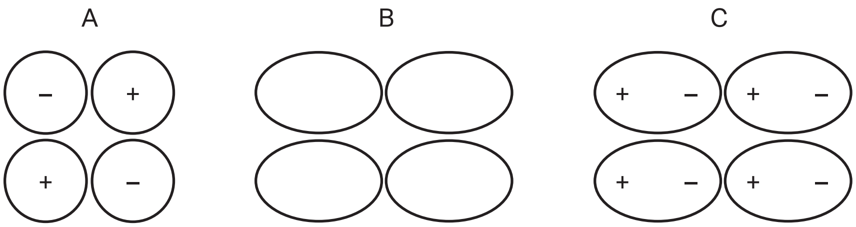
1. Is SF_2 ionic or covalent? Is ClF ionic or covalent? Justify your answers.

2. (a) Draw the Lewis diagram of SF_2. Then, based on the diagram, determine the molecular geometry of the compound.

(b) Draw the Lewis diagram of ClF. Then, based on the diagram, determine the molecular geometry of the compound.

PERFORMANCE TASK

3. Three particle diagrams are shown below.



Which diagram best represents solid ClF? Explain the reasoning for your choice.

PERFORMANCE TASK

PART 2

Part 2 involves a hands-on laboratory task. Do not begin Part 2 until your teacher instructs you to do so.

Safety Note
Follow all safety guidelines provided by your teacher.

1. You will receive samples of three solids: A, B, and C. Complete the data table below by performing tests on each solid. You can use the following items to conduct your tests:

- hot plate
- foil pans
- water
- small cups or beakers
- stirring rods
- conductivity tester
- goggles
- tongs or hot mitts

Solid	Observations During Heating	Solubility in Water	Conductivity When Dissolved in Water
A			
B			
C			

2. Use the data above to answer the following questions about samples A, B, and C.

   (a) What type of bond is found in each of the unknown substances?

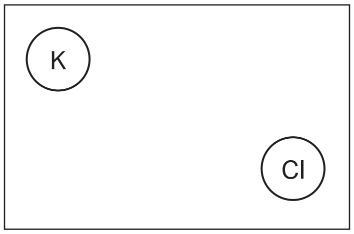
   A: ________________ B: ________________ C: ________________

   (b) The three solids have the chemical formulas KCl, $C_6H_{12}O_6$, and $C_{20}H_{42}$. Match the correct formula with the letter of the unknown substance.

   A: ________________ B: ________________ C: ________________

PERFORMANCE TASK

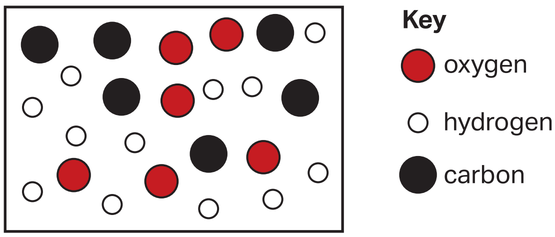
3. A representation of one unit of KCl in water is shown below. (The water molecules are intentionally not shown.)



(a) What is wrong with this representation?

(b) Draw a more accurate representation of one unit of KCl dissolved in water.

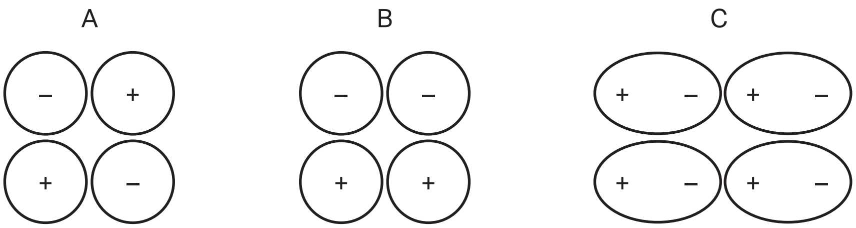
4. A representation of one unit of $C_6H_{12}O_6$ in water is shown below. (The water molecules are intentionally not shown.)



(a) What is wrong with this representation?

(b) Draw a more accurate representation of one unit of $C_6H_{12}O_6$ dissolved in water.

5. Three particle diagrams are shown below.



Which diagram best represents solid KCl? Explain the reasoning for your choice.

6. What is the name of KCl?

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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)

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

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-}

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

Constants	
Constant	**Value**
Avogadro's number	6.02×10^{23} particles per mole
Gas constant, *R*	$0.0821 \dfrac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}$
Specific heat capacity of $H_2O(l)$	$4.18 \dfrac{\text{J}}{\text{g} \cdot \text{K}}$
Standard temperature and pressure	273 K and 1 atm

Solubility Guidelines
All sodium, potassium, ammonium, and nitrate salts are soluble in water.

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	$\text{pH} = -\log[H_3O^+]$	

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