THIRD EDITION

INQUIRY in ACTION

Investigating Matter Through Inquiry

A project of the
American Chemical Society Education Division
Office of K–8 Science

American Chemical Society

American Chemical Society

Inquiry in Action—Investigating Matter Through Inquiry
Third Edition

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The activities described in this book are intended for students under the direct supervision of teachers. The American Chemical Society cannot be held responsible for any accidents or injuries that might result from conducting the activities without proper supervision, from not specifically following directions, or from ignoring the cautions contained in the text.

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Introduction

Welcome to *Inquiry in Action—Investigating Matter Through Inquiry*, *Third Edition*. Based on teacher reviews from *Inquiry in Action*, *Second Edition*, the *Third Edition* includes more opportunities for student reading and writing, additional activities, and more extensive teacher background information.

The purpose of *Inquiry in Action* is to give elementary and middle school teachers a set of physical science activities to help teach the major concepts in the study of matter while helping students develop the abilities and understandings of scientific inquiry. The activities were developed to lend themselves to a guided-inquiry approach and to work across the range of Grades 3–8. To be effective over such a wide grade range, the activities are designed to cover basic concepts but have the flexibility to be modified by teachers through varying questioning strategies, the degree of guidance given students, and the vocabulary used. The materials for all activities are very common, safe, and inexpensive and may already be present in an elementary or middle school science classroom or are available at any grocery or hardware store.

To help determine which concepts to include within the topic of matter, we based our decisions on the *National Science Education Content Standards* for *Physical Science* and *Science as Inquiry* and also on the results of teacher surveys asking for the content most often studied within the topic of matter. Based on the *Standards* and teacher input, the physical science topics covered include:

- Scientific questions and their investigation
- Physical properties
- Physical change
- Dissolving solids, liquids, and gases
- Chemical change
- States of matter
- Density

Inquiry in Action uses a guided-inquiry approach. Each investigation begins with an introductory activity or teacher demonstration that serves as motivation for either student or teacher questioning. Together, the teacher and students develop a question to investigate and begin to design an experiment to answer that question. In most investigations, this initial designing and conducting of experiments is done with substantial teacher guidance. This approach allows teachers to model the thinking processes involved in investigating a scientific question and gives students some familiarity with the science concepts and a context for further investigation. As students gain experience, they take on more responsibility in designing experiments later in the investigation to answer related questions.

The activities in *Inquiry in Action* include many suggestions for questioning strategies before, during, and after the activities. Each activity also includes examples of experimental procedures with all the required materials, expected results, and assessment ideas. An activity sheet is included for each activity to help students plan their experiment, record their results, and draw conclusions.

Our hope is that the guided-inquiry approach in *Inquiry in Action* will help teachers think about trying new or traditional activities in a way that will motivate students to explore and achieve the physical science and inquiry goals of today's science standards.

The *National Science Education Standards*

Inquiry

Many science programs place a high priority on students doing hands-on science. But, there are times when students will participate fully in science activities yet have little understanding of the concepts covered or of the scientific processes used. The *National Science Education Standards* (*NSES*), National Research Council, Washington, DC: National Academy Press, 1996, addresses these problems by focusing on the importance of *inquiry.*

In the *Standards,* the term "inquiry" is used in two different ways. It describes what students need to learn and how teachers need to teach. As applied to students, the content standard of "science as inquiry" consists of a set of abilities and understandings that students develop as they contribute their ideas while engaged in the process of scientific investigation. "Science as inquiry," in this sense, deals with student questions, observation, measurement, experimental design, logical reasoning based on evidence, and communicating results.

As applied to teachers, inquiry or inquiry-based teaching refers to the strategies and techniques that teachers use to engage and guide students through scientific investigations. Teachers should involve students as much as possible in the entire process of conducting a scientific investigation. In fact, whenever possible, students' own questions and interests should initiate an investigation. One of the most notable features of inquiry is that teachers help students identify and communicate the thought processes involved in designing and conducting an investigation. Through this experience with inquiry-based teaching and learning, students can acquire both the skills of scientific inquiry and the concepts of the physical science curriculum.

Inquiry can have many variations depending on the needs, experience, and prior knowledge of students; the time and resources available; and the concepts being taught. The five essential features of inquiry on p. 2 and in the chart on p. 3 are adapted from the book *Inquiry and the National Science Education Standards, A Guide for Teaching and Learning*; National Research Council, Washington, DC: National Academy Press, 2000. The five features and the chart show the variety of approaches to teacher and student involvement and input in inquiry-based teaching and learning. More student-centered or "open" inquiry is to the left and more teacher-centered, or "guided" inquiry, is to the right.

Concerning the more open inquiry, *Inquiry and the National Science Education Standards* states,

> *…students rarely have the ability to begin here. They first have to learn to ask and evaluate questions that can be investigated, what the difference is between evidence and opinion, how to develop a defensible explanation, and so on. A more structured type of teaching develops students' abilities to inquire…. Experiences that vary in "openness" are needed to develop inquiry abilities. Students should have opportunities to participate in all types of inquiries in the course of their science learning* (*Inquiry and the NSES*, pp. 29–30).

Inquiry in Action uses a guided-inquiry approach by first presenting a common phenomena that students can experience or observe through an introductory activity or demonstration. Students are then encouraged to help develop an experimental design to investigate the phenomena further. In each activity, students design and conduct experiments, make and record observations, draw logical conclusions, and communicate their results.

The full text of the *National Science Education Standards* and *Inquiry and the National Science Education Standards* can be found at the National Academy Press at www.nap.edu. The following information and charts on pp. 2–8 are adapted from *Inquiry and the National Science Education Standards* and the *National Science Education Standards.*

Essential features of inquiry

Inquiry-based learning has five essential features that apply across all grade levels. Although not all features must be present in each lesson, each feature should be present at some time over the course of a series of lessons.

1. Students begin with a question that can be answered in a scientific way.

Questions that can be investigated in an elementary or middle school classroom develop in a variety of ways. Most commonly, teachers provide opportunities that invite student questions by demonstrating a phenomenon or having students engage in an open investigation of objects, substances, or processes. Sometimes, questions will develop from something the students observe and suggest. Other times, the teacher provides the question. Either way, students must be able to investigate the questions in a developmentally appropriate way in an elementary or middle school classroom. Teachers will likely have to modify student questions into ones that can be answered by students with the resources available, while being mindful of the curriculum.

2. Students rely on evidence in attempting to answer the question.

This evidence can come from designing and conducting an investigation; observing a teacher demonstration; collecting specimens; or observing and describing objects, organisms, or events. The evidence can also come from books or electronic media.

3. Students form an explanation to answer the question based on the evidence collected.

Scientific explanations provide causes for effects and establish relationships based on evidence and logical argument. For students, scientific explanations go beyond current knowledge to build new ideas upon their current understanding.

4. Students evaluate their explanation.

Students consider questions such as the following: Can other reasonable explanations be based on the same evidence? Are there any flaws in the reasoning connecting the evidence to the explanation?

5. Students communicate and justify their proposed explanations.

Sharing explanations can help strengthen or bring into question students' procedures as well as their reasoning in connecting the evidence from their experiments to their explanations.

These five features of scientific inquiry do not need to happen in a formal and strict step-by-step sequence. Some features may cycle a few times as students learn about the topic or concept and generate new questions. These elements merely guide the process of doing science and should unfold during the course of an activity or series of activities and discussions. If all of the features are present in an activity, the lesson is considered to be full inquiry. Partial inquiry is acceptable as long as students gain experience with all of the features at some time. The role of the teacher and of the students can shift, as well. At times, the investigation is more student-directed, or open, and at times the teacher takes a more direct role in guiding the lessons. All of these variations are valid inquiry.

Inquiry and its variations

Student role	**Variations**			
Engages in scientifically oriented *questions*	Poses a question	Selects among questions, poses new questions	Sharpens or clarifies question provided by teacher, materials, or other source	Engages in question provided by teacher, materials, or other source
Gives priority to evidence in responding to questions	Determines what constitutes evidence and collects it	Directed to collect certain data	Given data and asked to analyze	Given data and told how to analyze
Formulates explanations from evidence	Formulates explanation after summarizing evidence	Guided in process of formulating explanations from evidence	Given possible ways to use evidence to formulate explanation	Provided with evidence
Connects explanations to scientific knowledge	Independently examines other resources and forms the link to explanations	Directed toward areas and sources of scientific knowledge	Given possible connections	
Communicates and justifies explanations	Forms reasonable and logical argument to communicate explanations	Coached in development of communication	Provided broad guidelines to sharpen communication	Given steps and procedures for communication
	More ◄——— Amount of Learner Self-Direction ———► Less Less ◄——— Amount of Direction from Teacher or Material ———► More			

Selected science teaching standards

Teaching Standard A
Teachers of science plan an inquiry-based science program for their students.

Develop a framework of yearlong and short-term goals for students.

- Teachers adapt school and district program goals, as well as state and national goals, to the experiences and interests of their students individually and as a group.
- A challenge to teachers of science is to balance and integrate immediate needs with the intentions of the yearlong framework of goals.
- The content standards, as well as state, district, and school frameworks, provide guides for teachers as they select specific science topics.
- In planning and choosing curricula, teachers strive to balance breadth of topics with depth of understanding.

Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.

- Whether working with mandated content and activities, selecting from extant activities, or creating original activities, teachers plan to meet the particular interests, knowledge, and skills of their students and build on their questions and ideas.
- Teachers are aware of and understand common naïve concepts in science for given grade levels, as well as the cultural and experiential background of students and the effects these have on learning.

Select teaching and assessment strategies that support the development of student understanding and nurture a community of learners.

- Inquiry into authentic questions generated from student experiences is the central strategy for teaching science.
- Teachers focus inquiry predominantly on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities.

Teaching Standard B
Teachers of science guide and facilitate learning.

Focus and support inquiries while interacting with students.

- Teachers and students collaborate in the pursuit of ideas, and students quite often initiate new activities related to an inquiry.
- Teachers match their actions to the particular needs of students—deciding when and how to guide, when to demand more rigorous grappling by the students, when to provide information, when to provide particular tools, and when to connect students to other sources.
- Teachers continually create opportunities that challenge students and promote inquiry by asking questions.

- Although open exploration is useful for students when they encounter new materials and phenomena, teachers need to intervene to focus and challenge the students, or the exploration might not lead to understanding.
- Teachers must decide when to challenge students to make sense of their experiences and ask students to explain, clarify, and critically examine and assess their work.

Orchestrate discourse among students about scientific ideas.

- Teachers encourage oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the world beyond the classroom.
- Teachers require students to record their work—teaching the necessary skills as appropriate—and promote many different forms of communication (for example, spoken, written, pictorial, graphic, mathematical, and electronic).
- Teachers assist students to work together in small groups and give groups opportunities to present their work to explain, clarify, and justify what they have learned.

Challenge students to accept and share responsibility for their own learning.

- Teachers give individual students active roles in the design and implementation of investigations, in the preparation and presentation of student work to their peers, and in student assessment of their own work.

Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas, and skepticism that characterize science.

- A teacher who engages in inquiry with students models the skills needed for inquiry.
- Teachers who exhibit enthusiasm and interest and who speak to the power and beauty of scientific understanding instill in their students some of those same attitudes toward science.

Teaching Standard C

Teachers of science engage in ongoing assessment of their teaching and of student learning.

Use multiple methods and systematically gather data on student understanding and ability.

- Teachers carefully select and use assessment tasks that are also good learning experiences.
- Teachers observe and listen to students as they work individually and in groups. They interview students and require formal performance tasks, investigative reports, written reports, pictorial work, models, inventions, and other creative expressions of understanding.
- Teachers examine portfolios of student work, as well as more traditional paper-and-pencil tests.

For more information about inquiry-based teaching and learning, see *Frequently Asked Questions About Inquiry*, pp. 463-468.

Inquiry content standards

Science as inquiry: Abilities necessary to do scientific inquiry

The *Standards* describe a set of abilities that enables students to meaningfully participate in the processes of scientific investigation. These abilities of scientific inquiry focus on student questions, observation, measurement, experimental design, logical reasoning based on evidence, and communicating results.

K–4	**5–8**
Ask a question.	Identify questions that can be answered through scientific investigations.
Plan and conduct a simple investigation.	Design and conduct a scientific investigation.
Use simple equipment and tools to gather data and extend the senses.	Use mathematics in all aspects of scientific inquiry. Use appropriate tools and techniques to gather, analyze, and interpret data.
Use data to construct a reasonable explanation.	Develop descriptions, explanations, predictions, and models using evidence.
	Think critically and logically to make the relationships between evidence and explanation.
	Recognize and analyze alternative explanations and predictions.
Communicate investigations and explanations.	Communicate scientific procedures and explanations.

Science as inquiry: Understandings about scientific inquiry

As students become active participants in scientific investigations, they will develop certain ideas about science. They will realize that certain kinds of questions can be answered in a scientific way. They will also come to understand that scientific investigations use a logical approach to answer a question. The cumulative experience of inquiry-based teaching and learning will give students a fuller understanding of the work of scientists.

K–4	**5–8**
Scientific investigations involve asking and answering a question.	Different kinds of questions suggest different kinds of scientific investigations.
Scientists use different kinds of investigations depending on the questions they are trying to answer.	Current scientific knowledge and understanding guide scientific investigations.
Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.	Mathematics is important in all aspects of scientific inquiry.
	Technology used to gather data enhances accuracy.
Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge).	Scientific explanations emphasize evidence and have logically consistent arguments.
	Science advances through legitimate skepticism.
Scientists make the results of their investigations public.	Scientific investigations sometimes result in new ideas and phenomena for study.
Scientists review and ask questions about the results of other scientists' work.	Scientists review and ask questions about the results of other scientists' work.

Physical science content standards

Properties of objects and materials

Properties and changes of properties in matter

The *Standards* place most topics traditionally considered chemistry-related under the physical science content standard of “Properties of objects and materials” for Grades K–4 and “Properties and changes of properties in matter” for Grades 5–8. The topics addressed under these content standards are summarized in the chart below.

K–4 **Properties of objects and materials**	**5–8** **Properties and changes of properties in matter**
Objects have observable properties, including size, weight, and temperature, which can be measured with tools such as rulers, balances, and thermometers.	A substance has characteristic properties such as density, a boiling point, and solubility, which are all independent of the amount of the sample. Substances react chemically in characteristic ways with other substances to form new substances with different characteristic properties.
Objects can be described by the properties of the materials from which they are made and can be separated or sorted according to those properties.	A mixture of substances can often be separated into the original substances by using one or more of the characteristic properties. Substances are often placed in categories or groups if they react in similar ways.
Materials can exist in different states—solid, liquid, and gas—and can be changed from one state to another by heating and cooling.	
	There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving things we encounter.
	In chemical reactions, the total mass is conserved.

The physical science topics in *Inquiry in Action*

Most of the concepts in the chart on the left are addressed under the following topics covered in *Inquiry in Action*: physical properties; physical change; dissolving solids, liquids, and gases; chemical change; states of matter; and density.

To facilitate student understanding of the concepts in the chart, the *Standards* strongly encourage student participation in the design of investigations. As students design and conduct investigations, they will observe and measure various properties and changes of properties in matter. The degree of sophistication with which students can conduct these investigations will depend largely on the grade level of the students and their experiences doing science activities.

Many, if not all, of the properties of objects, materials, and substances listed in the chart can be explained by referring to the atoms and molecules of which they are made. The types of atoms and molecules that make up a substance and the arrangement and strength of the bonds between them determine the different characteristic properties of that substance, including its physical properties and how it undergoes physical and chemical change. But for students at the 3–8 grade level, for whom *Inquiry in Action* is written, it is not necessary to focus primarily on the atomic and molecular explanation of why substances have the properties or undergo change the way they do. Students can learn a great deal about the properties and changes of properties in matter through their own direct macroscopic observations of the different characteristics of substances and processes.

In fact, the *National Science Education Standards* state: *It can be tempting to introduce atoms and molecules or improve students' understanding of them so that particles can be used as an explanation for the properties of elements and compounds. However, use of such terminology is premature for these students and can distract from the understanding that can be gained from focusing on the observation and description of macroscopic features of substances and of physical and chemical reactions* (*NSES, p. 149*).

Although the *Standards* suggest that introducing explanations on the atomic and molecular level is premature for students below 9th grade, many state and district science standards expect students to be introduced to these concepts and to develop a basic understanding of them in earlier grades. For this reason, we have included a short optional reading section for students at the end of each investigation, which explains some of the main observations on the molecular level. We have also included extensive teacher explanations for each activity on the molecular level. These explanations should help teachers better understand the phenomena students will observe, and help them explain it to students on the molecular level to the extent teachers think it is appropriate.

Features of *Inquiry in Action* investigations

Activities

Each investigation consists of a series of activities that build upon one another to fully develop the science concepts. In the beginning of each investigation, students read an introductory story and either do an introductory activity or watch a demonstration related to the story and topic being investigated. This serves as a way for teachers to assess students' prior knowledge and experience with the topic. The introductory activity also gives students a common context in which to ask questions and motivates them to investigate some of these questions in the activities that follow.

The suggested questions for teachers to ask students are an important part of the activities. These questions can be used to engage students in the activity by involving them in the process of identifying and controlling variables, designing experiments, communicating observations, logically connecting evidence to explanations, and evaluating results. The questions are not written as a script but as suggestions for teachers to use as needed, along with other questions that arise naturally during the course of the activity.

Question to investigate

A question at the beginning of each activity serves as a guide for designing and conducting the experiments to answer that question. All the activities within an investigation lead up to or contribute to the overall objective of the investigation.

Procedure

Procedures are examples or models of ways to design and conduct an experiment to answer the question to investigate. Because student input in the experimental design is encouraged, the procedure may be modified or completely changed. The procedure is offered as a guide to show one way an activity can be conducted.

Expected results

The expected results describe what would happen if the activities were conducted exactly as written. These should be used as a guide, as the procedures students develop may vary.

Activity sheets

Each activity has a corresponding activity sheet, which guides students as they conduct the activity. The activity sheets help students plan their experiments, record their observations, draw conclusions based on observations, offer explanations, and apply their learning. When needed, the activity sheets also contain science content.

Assessment

One scoring rubric is included with each investigation. This can be used as a formative assessment of the students' work on the activity sheets and their performance doing the hands-on activities that were a part of the investigation. A separate summative assessment for the investigation, called *Review and apply*, is included at the end of each investigation.

Safety

All activities in *Inquiry in Action* have been reviewed for safety. Although only household substances and equipment are used, participants should wear safety goggles when doing all of the activities. The American Chemical Society publishes safety books for teachers that are available free online. *Safety in the Elementary Science Classroom*, for grades K–6, and *Chemical Safety for Teachers and Their Supervisors,* for grades 7–12, are available at **www.acs.org/education**.

Materials chart

The materials for each activity in an investigation are listed in one chart at the beginning of the investigation. The materials included in this chart are needed if the suggested procedures written for each activity are conducted exactly as written. The materials charts are intended to give teachers a good idea of the materials they will need for one group to conduct each activity within the investigation. When gathering the materials for each activity, multiply the amounts listed by the number of student groups working in the class.

Teacher preparation

A number of activities require advanced preparation, such as labeling cups, making solutions, or preparing source cups of substances for each group. These instructions are included on the colored introductory page for each activity.

Science background information for teachers

Each investigation includes science background information about the topic being investigated. Explanations on the molecular level are also included for each activity so that teachers will have a reference for better understanding the phenomena observed in the activities.

Online supplement

This online resource, specifically designed for elementary and middle school teachers, includes videos of selected activities, molecular animations, and additional information. The resource is organized around each investigation so that the content relates to the activities students will do. View this resource at **www.inquiryinaction.org**.

Review and apply

At the end of each investigation, students can demonstrate their understanding of the physical science and inquiry content by completing the *Review and apply* worksheets. These include a review of the investigation, a hands-on activity, and a short reading. An additional optional reading for students called *What's going on here?* explains observations on the molecular level. These explanations are not appropriate for elementary students; however, they may support state or district standards, particularly at the middle school level.

Investigation 1

Scientific questions and their investigation

What happens when the colored coating of an M&M gets wet?

Summary

Students will experience all five elements of inquiry as they ask questions about M&M's in water, design and conduct experiments to answer these questions, and develop explanations based on their observations. Once students observe what happens when an M&M is placed in a plate of room-temperature water, they will have enough background to consider variables that affect dissolving such as the color of the M&M's, the number of M&M's, the temperature of the water, and the concentration of the solution in which the M&M's are placed. Students will then formulate questions and design experiments to investigate the effect of these variables on the way M&M's dissolve in water.

Investigation 1: Scientific questions and their investigation

Key concepts for students

- In a scientific experiment, a "variable" is something that can affect the outcome of the experiment.
- When designing a scientific experiment, it is necessary to identify and control variables.
- In an experiment to find out if a certain variable affects the outcome, only that variable should be allowed to vary and all other variables should be kept the same.
- The temperature of a solvent affects the speed of dissolving.

Learning objectives

Students will be able to:

- Ask scientific questions that they can investigate.
- Identify and control variables as they design an experiment to answer the questions.
- Be able to make predictions, design and conduct tests, record their observations, and draw logical conclusions.
- Understand the meaning of the "characteristic properties" of an object or substance.
- Identify variables that affect dissolving.

Investigation questions

What happens when the colored coating of an M&M gets wet?

- What happens when one M&M is placed in water?
- Do some M&M colors dissolve in water faster than others?
- What would the colors look like if we place two or more M&M's in a plate of water?
- Is the "line" that forms when two colors meet a special property of M&M's?
- Does the temperature of the water affect how fast the colored coating dissolves from an M&M?
- Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves?

Assessment

The assessment rubric *Scientific questions and their investigation*, pp. 52–53, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section, pp. 54–65.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Types of investigations include describing objects…and doing a fair test.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties including density…and solubility.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

1.1 Mysterious M&M's
1.2 Racing M&M colors
1.3 Colors collide or combine?
1.4 Investigating the line
1.5 M&M's in different temperatures
1.6 M&M's in sugar solutions

Each group will need

	Activities					
	1.1	1.2	1.3	1.4	1.5	1.6
M&M's	●	●	●	●	●	●
White plastic or foam dessert plates	1	6	1		3	3
Room-temperature water	●	●	●	●	●	●
Clear plastic container				●		
Hot tap water					●	
Cold water					●	
Round film canister lid or a quarter		●			●	●
Plastic cups, 3½ ounce		1			1	3
Plastic cups, 9 or 10 ounce						2
Crayons or colored pencils	●	●	●	●	●	●
Permanent marker		●			●	●
Sugar						●
Teaspoon						●
Bucket or large bowl	●	●	●	●	●	●
Paper towels	●	●	●	●	●	●
Dropper with red corn syrup				●		
Dropper with blue corn syrup				●		

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.
- **Students should use care when handling hot tap water**.
- Students will use the bucket or bowl to empty the liquid from the plates after each activity. They will then dry the plates with paper towels so that the plates can be used again. The crayons and colored pencils will be used as students record their results on the activity sheets.
- Students should use white plastic or foam plates for this investigation. For best results, students will need plates with the flattest bottoms possible. Some types of plastic and foam plates have slightly convex bottoms, which affect the results. Any size plate will be fine. However, smaller places are more manageable because less water is required.
- The materials required for the *Review and apply: Science in action!* activity, pp. 57–58 will vary widely depending on how students choose to conduct the activity. Students will need different types of candies with colored coatings.

Science background information for teachers

The following explanations are intended to give teachers a better understanding, on the molecular level, of observations students will make during the activities. Although elementary and middle school students can gain a fundamental understanding of basic chemistry concepts through macroscopic observations, it may be helpful for teachers to have a deeper understanding of these concepts on the molecular level. If teachers think that molecular explanations are developmentally appropriate for their students, an optional reading for students called *What's going on here?* is provided on pp. 63–65.

In *Investigation 1*, students will observe the colored coating from an M&M dissolving in water. Most of their observations will focus on the coating dissolving and the color moving through water. It is important to note that the coating is made of sugar and color, which both dissolve and move through water. The following explanation is about why sugar dissolves in water and applies to all of the activities in *Investigation 1.*

For videos, animations, and other information related to this investigation, go to **www.inquiryinaction.org**.

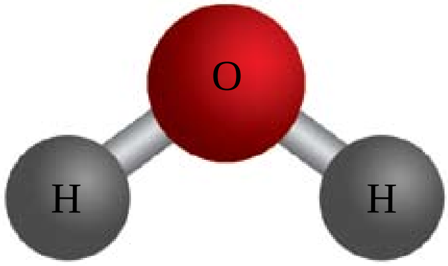
Chemistry concepts

- A water molecule has an area of positive charge and an area of negative charge.
- Dissolving the M&M coating depends on the interaction between water molecules and the molecules of sugar in the coating.
- If the attraction between water molecules and the sugar molecules overcomes the attractions the sugar molecules have for each other, dissolving can take place.

The molecular structure of water molecules

Atoms have a certain number of protons in their nucleus and the same number of electrons around the nucleus. Protons have a positive charge and electrons have a negative charge. The nucleus of all atoms, except hydrogen, also contains neutrons, which have no charge. Because the nucleus contains protons, it has an attraction for electrons. Since an atom has the same number of positively charged protons as negatively charged electrons, an atom has no overall or net charge. It is neutral.

A water molecule, or H_2O, is made up of two hydrogen atoms bonded to one oxygen atom. It is the special character of this oxygen–hydrogen bond that makes water such a good dissolver.



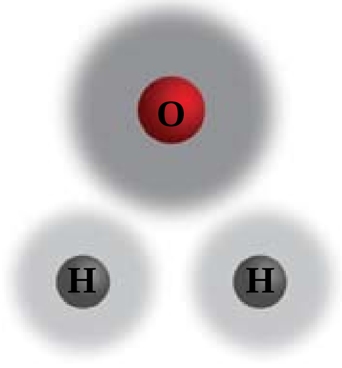
Atoms can form a covalent bond

When two atoms get near each other, the protons in the nucleus of each atom have a certain amount of attraction for the electrons of the other atom. If the attractions are just right, one or more electrons from each atom can end up moving around the nuclei of both atoms. This sharing of electrons is called a *covalent* bond.

Even though the atoms in the water molecule share electrons, the total number of electrons in the molecule is still equal to the total number of protons. Therefore, the water molecule has no overall or net charge. It is neutral.

The special characteristic of the oxygen–hydrogen bond

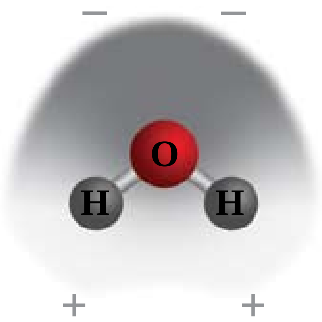
Here's what makes water so special. Because the oxygen has a greater attraction for electrons than the hydrogens have, the electrons shared between the oxygen and hydrogen atoms spend more time around the oxygen than they do around the hydrogens. Because electrons have a negative charge, this makes the area around the oxygen atom slightly negatively charged. It also leaves the area around the hydrogen atoms slightly positively charged.



Before

This illustration shows a model of an oxygen atom and two hydrogen atoms before they covalently bond to form a water molecule. The gray "cloud" surrounding the atoms represents the area around the atom where electrons are likely to be found. The cloud around the oxygen is a little larger and a little darker than the clouds around the hydrogen atoms. This indicates that oxygen has more electrons going around it than hydrogen does.

This illustration shows a model of the oxygen and hydrogen atoms covalently bonded in a water molecule. Notice that the cloud around the oxygen is now darker than in the "before" picture. Also, the cloud around the hydrogen atoms is lighter. This indicates that in a water molecule, electrons spend more time near the oxygen than the hydrogen. This makes the area near the oxygen slightly negative and the area near the hydrogens slightly positive. This is also shown by the "–" and "+" signs at opposite ends of the water molecule.



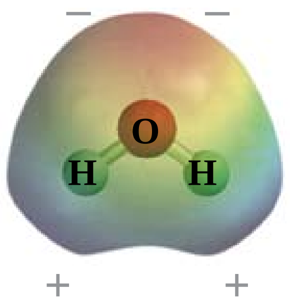
After

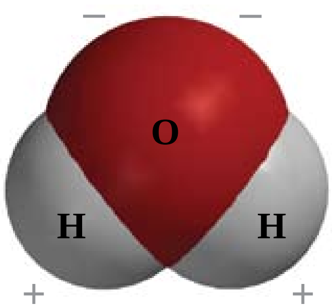
A water molecule has an area of positive charge separated from an area of negative charge, yet has no overall charge. Although it is a neutral molecule, the areas of opposite charge make water a *polar* molecule. Polar molecules are neutral but have areas that are slightly negative and areas that are slightly positive due to the uneven sharing of electrons within the molecule. The light gray "-" and "+" signs indicate the negative and positive areas in a neutrally charged polar molecule.

A picture of water

No one has actually seen a water molecule, but scientists have developed models based on how water molecules behave. No model is perfect, but each has its advantages. The *ball-and-stick* model of a water molecule shows the number and type of atoms in the molecule, which atoms are bonded to each other, and the overall structure or geometry of the molecule. The colored *charge density* model and the gray *cloud* model above use balls to represent the nucleus of the atoms. In reality, the nucleus would be much smaller in relation to the electron cloud around it.

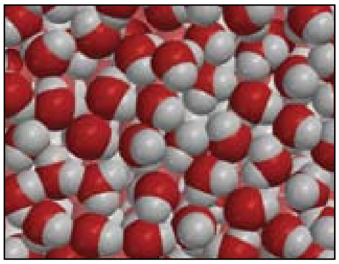
The charge density model shown at the right uses color to indicate where electrons are most likely to be found. The red region near the oxygen indicates an area of negative charge, while the blue region near the hydrogen atoms indicates a more positive area. This model is very similar to the gray model shown above but uses the colors of the spectrum to indicate where electrons are most likely to be found.

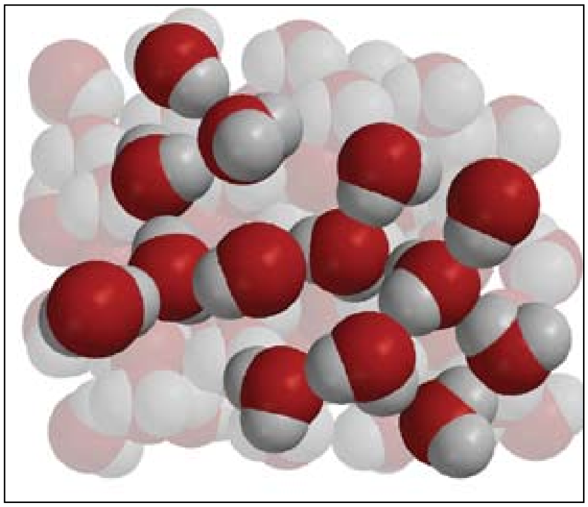




The model using red and white balls is called a *space-filling* model. The smooth hard shell-like surface gives a sense of the three-dimensional space occupied by the electrons in the water molecule.

The power of polarity



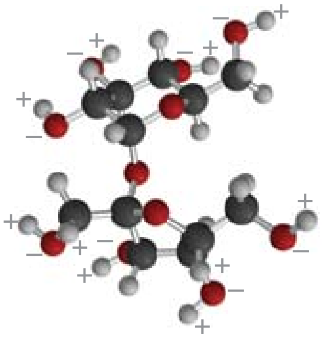


The smaller illustration to the right shows that the molecules in liquid water associate very closely with one another. The larger illustration shows how the water molecules tend to orient themselves according to their polarity. Notice how the positive area of one water molecule is attracted to the negative area of another. Remember that this is only a model or a two-dimensional shapshot. In reality the molecules would be moving in three dimensions, sliding past and bumping into each other. Attractions between water molecules would be constantly breaking and forming with other water molecules.

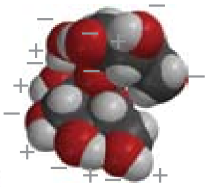
Because of their positive and negative regions, water molecules are attracted to each other and to other particles with positive or negative charges and to particles that have polar areas. The attraction water molecules have for other polar or charged particles is what makes water so effective at dissolving many substances.

The molecular structure of sucrose molecules

Sugar dissolves in water because of the special structure of the water molecule, but also because of the structure of the molecules that make up sugar (sucrose). The sucrose molecule is made up of carbon, hydrogen, and oxygen atoms. Compared to a water molecule, sucrose is pretty big. Its chemical formula is $C_{12}H_{22}O_{11}$. Like with the ball-and-stick and space-filling model of water, the red balls indicate oxygen and the light gray balls indicate hydrogen.

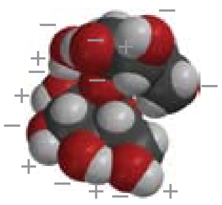


Sucrose ball-and-stick model



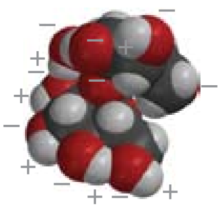
Sucrose space-filling model

A sucrose molecule has many areas where hydrogen and oxygen atoms are bonded together. Like water molecules, the area near the oxygen atoms has a slight negative charge and the area near the hydrogen atoms has a slight positive charge. These polar areas on the sucrose molecule are attracted to oppositely charged polar areas on other sucrose molecules. This is what holds sucrose molecules together within a grain of sugar. An actual sugar crystal is made up of an enormous number of sucrose molecules. Only two are shown here and on the following page to help make the process of dissolving sugar easier to illustrate.



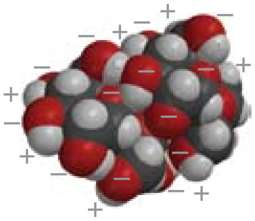
Sucrose molecule

+



Sucrose molecule

=

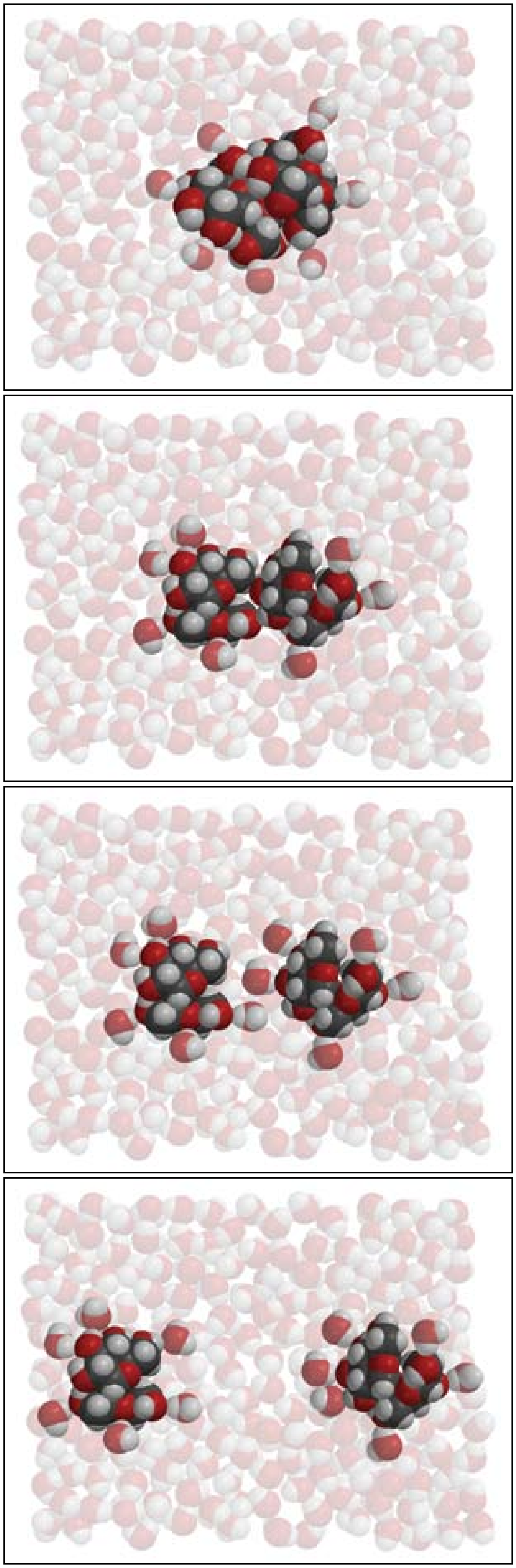


Two sucrose molecules closely associated due to oppositely charged polar areas

The dissolving duo

This graphic shows two sucrose molecules dissolving in water. Notice how the positive areas of the water molecules (near the hydrogen atoms) are attracted to the negative area near the oxygen atoms on the sucrose. And the negatively charged areas of the water molecules (near the oxygen atoms) are attracted to the positive area near the hydrogen atoms on the sucrose. The mutual attraction between the water and the sucrose molecules overcomes the attraction the sucrose molecules have for each other and they separate and dissolve. They become completely surrounded by water molecules, and move throughout the water.

It is both the polar nature of water and the polar nature of sucrose that explain why sugar dissolves in water.



Activity 1.1—Mysterious M&M's

When an M&M is placed in water, the colored sugar coating dissolves into the water in a relatively circular pattern around the M&M. The water molecules have an attraction for the molecules that make up the sugar and the coloring and in effect pull them from the surface of the M&M, which results in dissolving. The color dissolves in a uniform way around the entire M&M because the M&M is exposed to about the same amount of water all around its surface. Students will notice that the chocolate part of the M&M does not seem to dissolve. This is because chocolate contains a relatively large amount of fat. Substances like oils, fats, and wax are not nearly as polar as sugar and do not dissolve well in water.

Activity 1.2—Racing M&M colors

Students will probably notice very little difference, if any, in how fast different colored M&M coatings dissolve and move through water. This is because most of the candy coating is made up of sugar and each colored coating most likely has a similar amount of sugar. The molecules of pigment get caught up in the bulk flow of the sugar dissolving from the M&M, which keeps the movement of color fairly uniform. However, if students do notice some difference, this could have something do with the solubility of different pigments. It is possible that some colors of M&M's are more soluble in water than others. The molecular structures of different food-grade pigments show differences in molecular weight and polarity. Pigment molecules with lower molecular weights or with more polar areas should dissolve and move through water more quickly than others.

Activity 1.3—Colors collide or combine?

When the colors from two or more M&M's come together, the colors seem to form a kind of line or barrier and the colors do not readily mix. This occurs regardless of the number or arrangement of the M&M's in the plate. The question of whether placing two or more M&M's in the water affects the movement of the color can be answered "yes" based on this experiment. The question of what might cause this barrier and non-mixing is explored in *Activity 1.4.*

Activity 1.4—Investigating the line

Clear plastic containers are used so that students can better observe the position and movement of the dissolved sugar and color. Whether using M&M's or the colored sugar solutions, students will see that the color stays on the very bottom of the container with the two areas of color touching but not seeming to mix.

The sugar and color sink to the bottom because sugar, which makes up most of the coating, is more dense than water. This makes a sugar solution more dense than pure water. As the colored sugar solution spreads, it pushes less-dense water aside. When the spreading colored sugar solutions come in contact with each other, neither can easily push the other aside. So they build up next to each other and create what appears to be a line between them. Another reason for this apparent non-mixing is that molecular motion in water at room temperature is relatively slow.

Usually, to get similar substances to mix, you need to physically stir or agitate them, heat them, or do something to encourage mixing. Allowing them to touch usually will not cause much mixing in the short term. Normal molecular motion will eventually cause mixing, but it will take a long time—probably at least a day.

Activity 1.5—M&M's in different temperatures

When the mutual attraction between water molecules and a sucrose molecule overcomes the attraction the sucrose molecule has for the other sucrose molecules around it, it will be pulled away into solution, or dissolved (p. 20). The reason why sugar dissolves at a faster rate in hot water has to do with increased molecular motion. The added energy in the hot water causes water molecules to move faster and sucrose molecules to vibrate faster. This added movement tends to make the associations between sucrose molecules easier to overcome. When water molecules associate with sucrose molecules, a higher proportion of these sucrose–water associations have enough energy to pull sucrose molecules away from other sucrose molecules, so the rate of dissolving increases.

Activity 1.6—M&M's in different sugar solutions

The M&M coating seems to dissolve and spread the most in water with no sugar and dissolve and spread the least in water with the highest concentration of sugar. In the water with the intermediate concentration of sugar, the amount of dissolving and spreading is between the other two. One possible reason for these differences is that the most concentrated sugar solution is also the most dense. Because it is more dense, it is more difficult for the dissolved sugar and color from the M&M to push the dense sugar solution in the plate out of the way, making it more difficult to spread. Also, much of the water near the M&M is already associated with sugar and is less available to dissolve more sugar and color from the M&M.

Activity 1.1
Mysterious M&M's

What happens when one M&M is placed in water?

In this introductory activity, students will see that when an M&M is placed in water, the sugar and color coating dissolves and spreads out in a circular pattern around the M&M. When students compare their results, they will discover that every color of M&M dissolves in a similar way. The way the sugar and color dissolve in water is a *property* of M&M's. This introductory activity provides a basis for students to ask questions and to learn more about dissolving, identifying and controlling variables, and designing a fair test.

Materials needed for each group

1 M&M

1 White plastic or foam dessert plate

Room-temperature water

Crayons or colored pencils

Bucket or large bowl

Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.

Activity sheet

Copy *Activity sheet 1.1—Mysterious M&M's*, pp. 26–28, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 1.1
Mysterious M&M's

Question to investigate

What happens when one M&M is placed in water?

Take a closer look

1. Have students read the introductory story on *Activity sheet 1.1* and describe the properties of an M&M.

Distribute an M&M to each student or group of students along with *Activity sheet 1.1.* As students begin to explore the characteristics of an M&M, listen to the conversations that student groups are having. Students should identify properties such as the following:

- Size, shape, color, and texture
- Different colored layers on the inside

Explain to students that their descriptions of M&M's are all *properties* of M&M's. In the story on *Activity sheet 1.1*, the student noticed that the color came off of an M&M when it fell in the water. Ask students if they ever had their M&M's get wet and start to lose their color. Tell students that in the *Try this* activity, they will see what happens to the sugar and color coating of an M&M when it is placed in a plate of water.

Try this!

2. Have students place an M&M in a dish of water and observe.

Giving students an opportunity to observe an M&M in water will give them the context and motivation to want to find out more about how M&M colors look when they dissolve in water. From this experience, you can get them to ask questions that they can investigate. Students will conduct the following procedure and record their observations.

Procedure

1. Pour enough room-temperature water into a white plastic or foam plate so that the water is deep enough to completely cover an M&M.

2. Once the water has settled, place 1 M&M in the center of the plate. Be careful to keep the water and M&M as still as possible. Observe for about 1 minute.

3. Have students compare their results.

Ask students what they notice about the movement of the color from their M&M.

Expected results: **Each colored coating of M&M will dissolve in a circular pattern around the M&M. Students may also mention the white streaks in the water from the sugar coating. If anyone notices differences such as "the color moved over to one side more than the other," check to see that the plate is level.**

Point out to students that because the water makes the colored coating come off the M&M and mix into the water, the water is *dissolving* the sugar and color. Because the colored coating on M&M's dissolves in a similar pattern each time one is placed in water, this is a characteristic *property* of the M&M coating.

Empty the plate of water and M&M into a bucket, bowl, or sink. Dry the plate with a paper towel.

4. Have students write questions they could investigate for each of the variables listed on *Activity sheet 1.1*.

Remind students that they have tested *one* M&M of a certain *color* in a plate of *water* that is at *room-temperature*. The number of M&M's, the color, the type of liquid the M&M's are placed in, and the temperature of the water are variables that can be changed to do new experiments. Tell students that they should write at least one question to investigate for each variable. Encourage students to think of other variables and questions they might want to investigate.

What's next?

5. Compile the questions students write for each variable on chart paper.

Point out particularly well-written questions and identify some of the ones that can be investigated using the materials in your classroom. You may want to select one question for each variable that the entire class can investigate together. Tell students that they will have a chance to investigate some of these questions.

Sample procedures for the following questions are included in this investigation.

- Do some M&M colors dissolve in water faster than others? (*Activity 1.2*, pp. 30–31)
- What would the colors look like if we placed two or more M&M's in a plate of water? (*Activity 1.3*, pp. 34–35)
- Is the "line" that forms when two colors meet a special property of M&M's? (*Activity 1.4*, pp. 38–39)
- Does the temperature of the water affect how fast the colored coating dissolves from an M&M? (*Activity 1.5*, pp. 44–45)
- Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves? (*Activity 1.6*, pp. 48–49)

Student activity sheet Name: ______________________________

Activity 1.1

Mysterious M&M's

Sometimes you can learn a lot about something by looking at it very closely or in ways you haven't looked at it before. You may even discover things kind of by accident. This is what happened to me the other day when I was eating some M&M's and drinking a cup of water.

I was almost done when one of my M&M's fell into the water that was left in my cup. I didn't care too much because I could eat that one even though it was wet. I decided to eat it but when I began to reach into the cup to take it out, I was kind of surprised by what I saw. There was an area of color in the water around the M&M, which I guess had dissolved into the water. As I watched it, the color slowly spread in the water, making the area of color bigger.

This was pretty interesting and something I had never seen before. I thought I could see it better in something wider, so I got a little plate, put some water in it and put a different color M&M in to see what would happen. It was very similar to the first one I saw. I was starting to run out of M&M's but had some other ideas I wanted to try when I got some more.

Take a closer look

What are some things you observe about M&M's?

1. Each person in your group should take one M&M and look at it closely.

Talk to your partners and discuss some of the things you observe about the M&M. Record your observations here.

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2. Break open the M&M and look inside. Describe what you observe in words and make a drawing to show what the inside of the M&M looks like.

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Student activity sheet
Activity 1.1

Mysterious M&M's (*continued*)

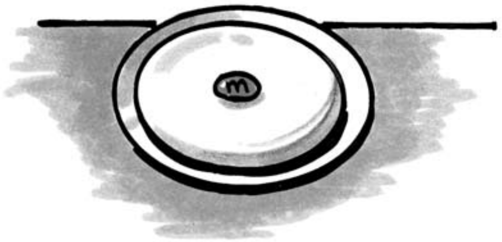
Name: ______________________________

Try this!

Try placing an M&M in water to get a better idea of what the student in the reading saw.

What happens when one M&M is placed in water?

Procedure



1. Pour room-temperature water into a white plastic or foam plate so that it covers the bottom of the entire plate.
2. Once the water has settled, place 1 M&M in the center of the plate. Be careful to keep the water and M&M as still as possible. Observe for about 1 minute.
3. Record your observations with words and an illustration.

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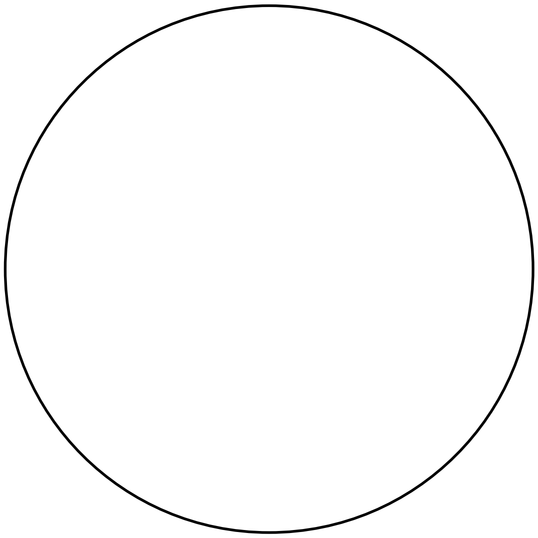


Plate

Student activity sheet
Activity 1.1

Name: ____________________________

Mysterious M&M's (*continued*)

Questions you could investigate

The color of M&M's, how many are in the plate, the temperature of the water, and the type of liquid the M&M's are placed in are variables that can be changed to do new experiments.

4. Look at the variables below. These variables can be changed to learn more about M&M colors in water. Write at least one question for each variable.

***Example*:**

***A. Variable*—**Color

***Question*—**Do certain M&M colors dissolve in water faster than others?

***B. Variable*—**Number of M&M's

***Question*—**

***C. Variable*—**Temperature of water

***Question*—**

***D. Variable*—**Type of liquid

***Question*—**

E. What other variables and questions can you investigate?

What's next?

It is interesting to see how the colored coating from an M&M dissolves and moves in water. But it will be more interesting to see how changing different variables will affect how the color is going to move. You will have the chance to investigate some of these questions.

Activity 1.2
Racing M&M colors

Do some M&M colors dissolve in water faster than others?

Students often want to know whether the coatings of certain colored M&M's dissolve in water faster than others. In order to investigate this, students will have to design a fair race. As students discuss how to compare the speed at which each colored coating dissolves in water, they will begin to identify possible variables and suggest ways to control them. Once the races are complete, students should compare results and decide whether they are conclusive enough to answer the question.

Materials needed for each group

6 Different colors of M&M's
6 White plastic or foam dessert plates
Room-temperature water
Round film canister lid or a quarter
1 Plastic cup, 3½ ounces
Crayons or colored pencils
Permanent marker
Bucket or large bowl
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.

Preparing materials

- You may wish to draw concentric circles in the center of plates ahead of time. Or students can draw them as part of the activity. The procedure for drawing these is described on p. 30.

Activity sheet

Copy *Activity sheet 1.2—Racing M&M colors*, p. 32, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 1.2
Racing M&M colors

Question to investigate

Do some M&M colors dissolve in water faster than others?

1. Ask students how they might design an experiment to answer the question.

Distribute *Activity sheet 1.2—Racing M&M colors*. In groups, have students plan how they might investigate the question. As you go around to groups and listen to their discussions, ask students what they are doing to keep the experiment as fair as possible. Students should have a plan to control variables such as type of plate, amount of water, temperature of water, how and where the M&M's are placed on the plate, when the M&M's are placed in water, and the amount of time the M&M's are in the water. Students should record their plans along with possible variables and ideas of how they will control them on the activity sheet.

As a whole class, share group plans, drawing attention to methods of controlling variables. Tell students that for a scientific investigation to be valid or fair, all variables need to be kept the same except for the one being tested: In this case, it is the color of the M&M.

Once the groups develop their experimental designs, you may choose to have them follow their own procedures. If you would like to give groups more guidance, you could have a whole class discussion to develop a procedure that all groups will follow.

2. Have students compare how fast different color M&M coatings dissolve in water.

The following procedure is an example of one way students can investigate whether color affects the rate at which an M&M coating dissolves in water. Because student suggestions are incorporated as they plan the procedure that they will follow, procedures will vary. The following procedure is one example of an experimental design that investigates the question.

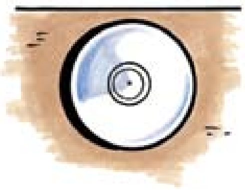
Procedure

1. Draw two concentric circles and a dot on each plate so that you can better compare how fast the coating from each color M&M dissolves in water. You will need one targeted plate for each color M&M you plan to race.

    - Use a permanent marker to trace around the top of a 3½-ounce cup to draw a circle in the center of a plate.

    - Place a quarter, film canister lid, or other similar-sized circular object in the center of the circle you just drew. Trace this object with a permanent marker.

    - Make a dot in the center of the circles on each plate.



2. Pour enough water into each plate so that the bottom of the plate is completely covered.

3. With the help of your lab partners, place a different-colored M&M in the center of each plate at the same time. Observe for 1 minute.

4. On *Activity sheet 1.2*, describe the way you set up your experiment, what you did to make it a fair test, and what you observed.

3. Have students share their observations.

Ask students questions such as the following:

- Does one color seem to move faster/slower than the others?
- Did other groups have similar results?
- Is there enough evidence from your experiments to conclude that a particular color of M&M moves faster in water than the others?

Point out to students the importance of replicating experiments. If students conclude that a certain color coating dissolves faster than others, ask them whether repeating the experiment and getting the same result might make the results more convincing. If all groups had the same result they could be more certain that the result was valid. In this activity, results may be inconsistent and students may not be able to definitively conclude that a particular color moves faster or slower than others.

***Expected results*: When racing M&M's, our results have been inconclusive. The colors seem to move at similar rates with no definitive fastest dissolver. It is possible that you and your students observe that certain colors dissolve faster or slower than the others.**

When discussing their results, help students review the variables they tried to control so that the experiment was as fair as possible. Were there any variables that may not have been controlled? For example: Were all the plates level? Was each M&M placed in the center of each plate at exactly the same time? It could be possible that the experimental design is not sensitive enough to discern the differences in the rate of dissolving. Perhaps the experiment would need to be redone with more-precisely marked plates. Students need not try the activity over and over, but discussing the validity of their experiments and ways to possibly create an even fairer test is an excellent exercise.

Student activity sheet
Activity 1.2

Name: ______________________________

Racing M&M colors

Do some M&M colors dissolve in water faster than others?

Plan your experiment

1. Plan an experiment you could do to find out whether some M&M colors dissolve in water faster than others. Write about your plan in the space below.

    ____

    ____

    ____

    ____

2. What will you do to make sure that your test is fair?

    ____

    ____

    ____

Conduct your experiment

3. Do certain colors seem to move faster or slower than others?______________________

4. If so, which ones? If not, what did you observe? ________________________________

    ____

    ____

    ____

Explain your observations

5. Did other groups have similar results?____

6. Is there enough evidence from your experiments to conclude that a particular color of M&M moves faster in water than the others?____________________________________

    ____

    ____

Activity 1.3
Colors collide or combine?

What would the colors look like if we placed two or more M&M's in a plate of water?

When students do this activity, they may be surprised by the way an additional M&M affects the movement of color in the plate. Often students expect the colors from each M&M to blend when they come together, but instead the colors remain separate along a defined border. In *Activity 1.3*, students will explore how the areas of color change shape as M&M's are placed in different positions in the plate. In *Activity 1.4*, students will explore why the areas of color from different M&M's seem to stay separate.

Materials needed for each group

Different colored M&M's
1 White plastic or foam dessert plate
Room-temperature water
Crayons or colored pencils
Bucket or large bowl
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.

Activity sheet

Copy *Activity sheet 1.3—Colors collide or combine?*, p. 36, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 1.3
Colors collide or combine?

Question to investigate

What would the colors look like if we placed two or more M&M's in a plate of water?

1. Ask students to predict what might happen with two M&M's in a plate of water.

Ask students what might happen if they placed two different-colored M&M's in a plate of water at the same time. For example, if they placed a yellow M&M and a blue M&M near the center of a plate somewhat close to each other, what would they expect to see? Would the yellow and blue combine to make green? Ask students to test two different colored M&M's in one plate of water.

2. Have students place two M&M's in a plate of water.

Have each group select two different-colored M&M's. Distribute *Activity sheet 1.3—Colors collide or combine?* and have students follow the procedure described below.

Procedure

1. Pour enough room-temperature water into a white plastic or foam plate so that it covers the bottom of the entire plate.
2. Once the water has settled, place 2 M&M's about 2 centimeters apart near the center of the plate. Be careful to keep the water and M&M as still as possible. Observe for about 1 minute.
3. Record your observations with a colored drawing.
4. Empty the plates of water and M&M's into a bucket, bowl, or sink, and dry them with a paper towel.

3. Have students share their observations.

Expected results: **The colors will flow in a circular pattern around each M&M until the color from one M&M approaches the color from the other M&M. The colors will not blend but instead will appear to form a distinct "line" between them.**

Note: There may be a small amount of mixing of colors. In some cases, it may also appear that one color has flowed over or under another.

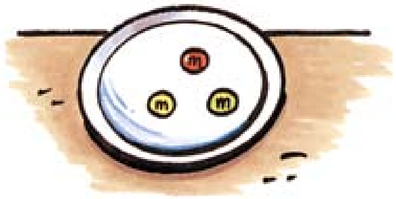
Ask each group to share which colors of M&M's they used and what they observed. After sharing results and referring to drawings when necessary, students should agree that no matter which two colors they use, the colors tend to stay separate.

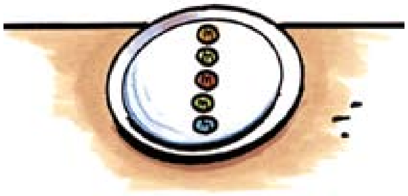
4. Have student groups discuss what they might try next, predict what might happen, and then try it.

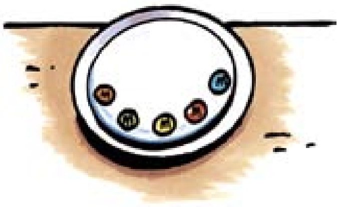
Ask students what shapes of color they might see if three or more M&M's are placed in a plate of water at the same time. Ask them how they would like to position the M&M's and what they would expect to see. Give students a chance to think about what they might like to try on their own and record these ideas on the activity sheet. Once students have considered possible plans on their own, have them discuss their ideas with their groups. Groups can decide what to try and in what order, make informal predictions, conduct the experiments, and record their observations.

5. Ask students to share their observations.

Have groups report on the different arrangements of M&M's they tested and ask the class to guess what happened. Students should then reveal their results. Encourage students to refer back to *Activity sheet 1.3* as they discuss different groups' results.







Student activity sheet
Activity 1.3

Name: ______________________________

Colors collide or combine?

What would the colors look like if we placed two or more M&M's in a plate of water?

Procedure

1. Pour room-temperature water into a white plastic or foam plate so that it covers the bottom of the entire plate.

2. Once the water has settled, place 2 M&M's about 2 centimeters apart near the center of the plate. Be careful to keep the water and M&M's as still as possible. Observe for about 1 minute.

3. Record your observations with a colored drawing.

4. Empty the plates of water and M&M's into a bucket, bowl, or sink, and dry them with a paper towel.

Plate

---

1. What combinations of M&M's would you like to test? Draw where you would like to place the M&M's. You will share these drawings with your group later.

---

2. Once your group decides which M&M arrangements to test, predict what the colors will look like in the plate. Then conduct the experiment and draw your results in the circles below.

Activity 1.4
Investigating the line

Is the “line” that forms when two colors meet a special property of M&M’s?

Students are often intrigued by the apparent “line” that forms where colors from M&M coatings meet but do not mix. Perhaps the most surprising aspect of this non-mixing is that it is actually quite common anytime similar liquids come together. For example, when mixing yellow and blue paint together to make green, you wouldn’t place the yellow and blue next to each other and expect them to mix on their own. You would physically stir the paints together to speed up the mixing process. In this activity, students will discover that this non-mixing of colored solutions is not unique to M&M’s.

Materials needed for each group

2 Different colors of M&M’s
Room-temperature water
Clear plastic container
Crayons or colored pencils
Bucket or large bowl
Paper towels
Dropper with red corn syrup
Dropper with blue corn syrup

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.

Preparing materials

- The following procedure will make enough colored corn syrup to supply all groups with the amount needed for the activity.
- Place 2 tablespoons of corn syrup into each of two small cups.
- Add 3 drops of red food coloring to one cup and 3 drops of blue food coloring to another.
- Use a separate spoon or popsicle stick to mix the corn syrup and coloring well.
- Distribute the corn syrup in the droppers that the students will use. You will need two droppers for each group—one with red syrup and the other one with blue syrup.

Activity sheet

Copy *Activity sheet 1.4—Investigating the line*, pp. 40–43, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 1.4
Investigating the line

Question to investigate

Is the "line" that forms when two colors meet a special property of M&M's?

1. Have students observe the M&M's in a clear plastic container.

Suggest to students that it might be interesting to take a better look at the "line" that forms between M&M colors. Instead of using a plate, tell students that they will use a clear plastic container with slightly deeper water than they used in the plate.

Distribute *Activity sheet 1.4—Investigating the line*. Students will follow the procedures on this activity sheet, record their observations, and hypothesize whether this property of non-mixing is unique to M&M's.

Procedure

1. Place a clear plastic container with a flat bottom on a white sheet of paper. Then pour water into the container to a depth that would cover the M&M's.

2. Once the water settles, place 2 different-colored M&M's in the water about 2 centimeters apart.
3. Observe for about 1 minute. Look from the side and describe what you see.
4. Empty the water and M&M's into a bucket or sink and dry the clear plastic container with a paper towel.
5. Record your observations on the activity sheet.

Expected results: **The color will be along the bottom of the container only. The two colors will spread along the bottom in a circular pattern. The two colors will not mix, but instead will remain separate. A "line" will form where the colors meet.**

2. Have students share their observations.

Remind students that the colored coating on M&M's also contains sugar. Ask students whether they think that M&M coatings are special or that any sugar and color mixture would form a line when colors meet. Students may think of placing different types of colored candies, like Skittles® or gumballs, in water to see whether their colors collide or combine. The can try this experiment in the *Science in Action* activity, pp. 57–58.

3. Have students test two different-colored sugar solutions in water.

The following procedure investigates whether colored sugar solutions, in general, will collide or combine. Based on the results, students can reason that the "line" is a property of any two colored sugar solutions coming together. Have students conduct the procedure on *Activity sheet 1.4*, p. 41.

Distribute the colored corn syrup in the droppers that students will use. You will need two droppers for each group—one with red syrup and the other one with blue syrup.

Follow a procedure similar to the one you used with two M&M's.

Procedure

1. Place a clear plastic container with a flat bottom on a white sheet of paper. Then pour water into the container until it is about as deep as the water in which you tested the M&M's.

2. Once the water settles, hold the droppers with the red and blue sugar solutions upright in the container of water about 2 centimeters apart. Then gently add about 5 drops of each solution directly beneath each dropper. When you are done, carefully remove the droppers from the water.

3. Observe for about 1 minute. Look from the side and describe what you see.

4. Empty the clear plastic test container and dry it with a paper towel.

4. Have students share their observations.

Expected results: **Like the M&M's, the color will spread along the bottom of the container and form a distinct "line" where the colors meet.**

Ask students: Is the "line" that forms where two colors meet a specific property of M&M's? Students should conclude that it is not but that it appears to be a characteristic property of colored sugar solutions, no matter where they come from.

Student activity sheet
Activity 1.4

Name: ______________________________

Investigating the line

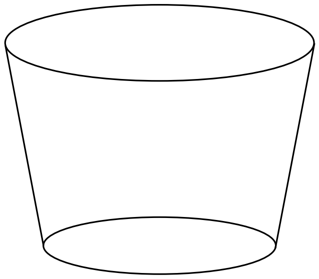
Is the “line” that forms when two colors meet a special property of M&M’s?

Before we explore the main question, let’s take a better look at the “line” that forms between M&M colors.

Procedure

1. Place a clear plastic container with a flat bottom on a white sheet of paper. Then pour water into the container to a depth that would cover the M&M’s.
2. Once the water settles, place two different-colored M&M’s in the water about 2 centimeters apart.
3. Observe for about 1 minute.

1. Draw a side view of the M&M’s and their dissolved colors and write what you see.



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2. The way the colored sugar solutions from M&M’s don’t mix could be something that happens only with M&M’s. But it might also happen with other candies or colored substances. What else could you test to find out if non-mixing happens with other colored substances?

____

____

Empty the water and M&M’s into a bucket or sink and dry the clear plastic container with a paper towel.

Student activity sheet
Activity 1.4

Name: ______________________________

Investigating the line (*continued*)

In the following activity, you will use colored corn syrup in water the way you tested M&M's. Like the M&M coating, the colored corn syrup is made with food coloring and sugar. Using this basic sugar solution will help you find out whether non-mixing is a property of colored sugar solutions or whether non-mixing is something that happens only with M&M's in water.

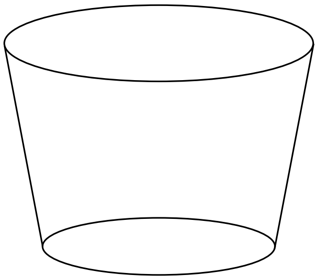
Procedure

1. Place a clear plastic container with a flat bottom on a white sheet of paper. Then pour water into the container until it is about as deep as the water was when you tested the M&M's.

2. Once the water settles, hold the droppers with the red and blue sugar solutions upright in the container of water about 2 centimeters apart. Then gently add about 5 drops of each solution directly beneath each dropper. When you are done, carefully remove the droppers from the water.

3. Observe for about 1 minute. Look from the side and describe what you see.

3. Draw a side view of the colored corn syrup in water and write what you see.



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Empty the clear plastic container and dry it with a paper towel.

Name:______________________________

Investigating the line (*continued*)

4. Is the line that forms when two colors meet a special property of M&M's?__________

5. How do you know? ____

6. Do you think that the dissolved coating from gumballs or other candies with colored sugar coatings would form a line when the colors meet? __________________________

   What makes you think that?

Activity 1.5
M&M's in different temperatures

Does the temperature of the water affect how fast the colored coating dissolves from an M&M?

In this activity, students will discuss variables and ways to control them as they design an experiment to investigate the question. When they conduct their experiments, students will discover that the color moves somewhat faster in hot water than in room-temperature water and much faster in hot than in cold. Since the temperature of water is the only difference between the plates, students can conclude that temperature does make a difference in how fast the colored coating dissolves from an M&M.

Materials needed for each group

3 Same-color M&M's
3 White plastic or foam dessert plates
Room-temperature water
Hot tap water
Cold water
Round film canister lid or a quarter
1 Plastic cup, 3½-ounce
Crayons or colored pencils
Permanent marker
Bucket or large bowl
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.
- **Students should use care when handling hot tap water**.

Preparing materials

- This activity uses cold, room-temperature, and hot water. For best results use ice water, water that is about 20 °C, and water that is about 45 °C.
- You may wish to draw concentric circles in the center of plates ahead of time. Or students can draw them as part of the activity. The procedure for drawing these is described in *Activity 1.2*, p. 30.

Activity sheet

Copy *Activity sheet 1.5—M&M's in different temperatures*, p. 46, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 1.5
M&M's in different temperatures

Question to investigate

Does the temperature of the water affect how fast the colored coating dissolves from an M&M?

1. Have groups suggest experimental designs.

Have students form small groups and discuss how they might investigate the question and record an initial plan on *Activity sheet 1.5—M&M colors in different temperatures*. Students should also think about and list the variables that need to be controlled in this experiment.

As you visit the groups and listen to their discussions, check to see if students are thinking about variables: the kind of plate, the amount of water in each plate, the color of the M&M's, and the placement of the M&M's at the same time in each plate. All these variables should be kept the same. Students should realize that the only variable that should be changed is the temperature of the water.

2. As a whole class, finalize the experimental design.

Have students share their plans with the whole class. Discuss the students' list of variables and ask them how their plans control these variables.

Some groups may have planned to test M&M's in hot and cold water but didn't consider using room-temperature water, too. Encourage all groups to test an M&M in all three temperatures of water. The room-temperature water serves as a control and can help students see the difference in how much cold and hot water affects the movement of M&M color.

Tell students that they will use plates with concentric circles to help compare the amount the color spreads in each plate.

3. Have groups conduct the experiment.

Your class procedure will probably be similar to the following.

Procedure

1. Use small pieces of paper to label each of three plates **cold**, **room-temp**, and **hot**.

2. Pour cold, room-temperature, and hot water into their labeled plates so that the water covers the bottom of the entire plate.

3. With the help of your partners, place a same-colored M&M in the center of each plate.
   Observe for 1 minute.

4. Record your observations on the activity sheet.

4. Have students share their observations.

Ask students whether they noticed a difference in the movement of color in the different temperatures of water.

Expected results: **The sugar and color dissolve and spread out fastest in the hot water and slowest in the cold water. The sugar and color in the room-temperature water dissolve and spread out somewhere between the cold and hot water, but are more similar to the cold than the hot.**

5. Ask students to answer the question to investigate.

Ask students if, based on their observations, they could answer the question to investigate: *Does the temperature of the water affect how fast the colored coating dissolves from an M&M?*

Students may have noticed a greater difference in the circle of color between the hot and the room-temperature water than between the room-temperature and the cold water. You could ask students for a possible explanation for this. Suggest to students that there is probably a greater difference in temperature between the hot and the room-temperature water than between the cold and the room-temperature water.

Student activity sheet
Activity 1.5

Name: ______________________________

M&M's in different temperatures

Does the temperature of the water affect how fast the colored coating dissolves from an M&M?

1. Talk with your group about how you might design an experiment to investigate the question above. Describe your basic plan below.

   ____

   ____

   ____

   ____

2. One variable that you should change in each plate is the temperature of the water. All other variables should be kept the same, or controlled. Make a list of variables that you will control in your experiment.

   ____

   ____

   ____

   ____

3. After conducting your experiment, describe your observations with basic illustrations and captions, and answer the question: Does the temperature of the water affect how fast the colored coating dissolves from an M&M?

Activity 1.6
M&M's in different sugar solutions

Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves?

In previous activities in this investigation, students explored different factors that affect the speed of dissolving—namely, the color of the M&M and the temperature of the water. Students also looked at the movement of dissolved M&M coatings in water. The sugar and color dissolve, sink, and move along the bottom of the container. In this activity, students will investigate whether having sugar already dissolved in water affects the speed of dissolving and the movement of sugar and color through the water.

Materials needed for each group

3 Same-color M&M's
3 White plastic or foam dessert plates
Room-temperature water
Round film canister lid or a quarter
3 Plastic cups, 3½ ounces
2 Plastic cups, 9 or 10 ounces
Crayons or colored pencils
Permanent marker
Sugar
Teaspoon
Bucket or large bowl
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles**.

Preparing materials

- You may wish to draw concentric circles in the center of plates ahead of time. Or students can draw them as part of the activity. The procedure for drawing these is described in *Activity 1.2*, p. 30.

Activity sheet

Copy *Activity sheet 1.6—M&M's in different sugar solutions*, pp. 50–51, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 52–53. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 1.6
M&M's in different sugar solutions

Question to investigate

Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves?

1. Ask students to design an experiment to investigate the question.

Ask students to predict what might happen if they place an M&M in sugar water instead of plain water. Would the sugar and color dissolve as quickly from the M&M as they do in plain water? Would the sugar and color from the M&M flow through the water as quickly or in the same way? Then ask students how they could set up an experiment to find out whether the amount of sugar already in water affects how fast the color coating dissolves from an M&M. Students should recognize that they will need to test the same-color M&M in water with different amounts of sugar. They should talk about testing a range of sugar concentrations and begin to talk about variables that must be kept the same.

2. Identify variables and how they are controlled in the procedure provided.

Distribute *Activity sheet 1.6—M&M's in different sugar solutions*. Direct students to think about the procedure they discussed and look at the procedure on the second page of *Activity sheet 1.6* as they identify the variables in the experiment. Students should recognize that the only variable that will be different in each plate is the amount of sugar dissolved in the water. Everything else, including the size and type of plate, amount and temperature of water, and color of M&M, should all be kept the same. The M&M's should also be placed in the plates at the same time and in the same position.

3. Have student groups conduct the experiment and record their observations.

As students conduct the procedure written on *Activity sheet 1.6*, they should be sure to compare both the amount of color left on the M&M and the size of the circle of color around each M&M. The amount of color left on the M&M is an indicator of how much of the coating has dissolved. The size of the circle of color can be attributed to the amount of the coating that has dissolved, but also how readily the dissolved sugar and color are flowing through the water.

Procedure

1. Use small pieces of paper to label each of three cups and three plates **no sugar**, **1 teaspoon sugar**, **3 teaspoons sugar**.

2. Pour ¼ cup of water into each cup.

3. Add 1 teaspoon of sugar and 3 teaspoons of sugar to their labeled cups. Stir until the sugar in each cup dissolves.

4. Pour the water and the sugar solutions into their labeled plates. The water should be deep enough that an M&M would be completely submerged in the water.

no sugar **1 teaspoon sugar** **3 teaspoons sugar**

5. With the help of your partners, place each of the same-color M&M's in the center of each plate at the same time. Wait about 1 minute.

6. Record your observations on *Activity sheet 1.6—M&M colors in sugar solutions.*

Expected results: **The M&M coating will dissolve most quickly from the M&M placed in plain water and least quickly from the M&M placed in the most concentrated sugar solution. The circle of color will also be the largest in the plain water and the smallest in the most concentrated sugar solution.**

4. Discuss student observations.

Ask students what they think about the prediction they recorded on *Activity sheet 1.6* at the start of this activity. Ask them: Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves? Using observations from this activity, how do you know?

Explain to students that dissolving sugar in water makes the solution more dense. When an M&M is placed in a sugar solution, the dissolved sugar and color from the M&M cannot push this more-dense solution out of the way. This keeps the circle of color smaller and more color remains on the M&M.

Student activity sheet
Activity 1.6

Name: ______________________________

M&M's in different sugar solutions

Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves?

1. You've seen that when an M&M coating dissolves in water, the sugar and color dissolve, sink, and then move along the bottom of the container through the water. Do you think the sugar and color will dissolve and move as freely in water that already has some sugar dissolved in it? __________________

2. What makes you think that?

____

____

____

Look at the procedure written on the next page as you answer the following questions about variables.

3. Which is the variable that is different in each plate?

____

____

4. How does the procedure control the other variables? In other words, what is purposely kept the same in each plate?

____

____

____

Conduct the experiment and then answer the following questions.

5. Does having sugar already dissolved in water affect how fast an M&M coating dissolves? ____

What makes you think that?

____

____

Student activity sheet
Activity 1.6

Name: ______________________________

M&M's in different sugar solutions (*continued*)

Try the following procedure to find out how the sugar and color from an M&M dissolve and move in sugar water. In this procedure you will use water with different amounts of sugar dissolved in it.

Procedure

1. Use small pieces of paper to label each of three cups and three plates **no sugar**, **1 teaspoon sugar**, **3 teaspoons sugar**.

2. Pour ¼ cup of water into each cup.

3. Add 1 teaspoon of sugar to the cup labeled **1 teaspoon sugar** and 3 teaspoons of sugar to the cup labeled **3 teaspoons sugar**. Stir until the sugar in each cup dissolves.

4. Pour the water and the sugar solutions into their labeled plates. The water should be deep enough that an M&M would be completely submerged in the water.

5. At the same time, place the same-color M&M in the center of each plate. Wait about 1 minute.

6. What do you observe about the coloring on the M&M and in the water? Describe your observations with basic illustrations and captions.

Investigation 1—Scientific questions and their investigation

Assessment rubric

What happens when the colored coating of an M&M gets wet?

Activity 1.1—Mysterious M&M’s

What happens when one M&M is placed in water?

G S N
☐ ☐ ☐ Describes characteristics of an M&M with words and drawings
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records observations with words and drawings
☐ ☐ ☐ Writes scientific questions about M&M coatings dissolving in water

Circle one: Good Satisfactory Needs Improvement

Activity 1.2—Racing M&M colors

Do some M&M colors dissolve in water faster than others?

G S N
☐ ☐ ☐ Plans experiment to answer question
☐ ☐ ☐ Identifies variables and controls them
☐ ☐ ☐ Conducts experiment
☐ ☐ ☐ Records observations
☐ ☐ ☐ Considers evidence from own experiment and those of others when answering the question

Circle one: Good Satisfactory Needs Improvement

Activity 1.3—Colors collide or combine?

What would the colors look like if we placed two or more M&M’s in a plate of water?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Plans related experiments
☐ ☐ ☐ Conducts at least three experiments
☐ ☐ ☐ Records observations with drawings

Circle one: Good Satisfactory Needs Improvement

Activity 1.4—Investigating the line

Is the “line” that forms when two colors meet a special property of M&M’s?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations with drawings and words
☐ ☐ ☐ Considers other tests to answer the question
☐ ☐ ☐ Considers evidence from experiments to answer the question
☐ ☐ ☐ Makes a prediction

Circle one: Good Satisfactory Needs Improvement

Investigation 1—Scientific questions and their investigation

Assessment rubric (*continued*)

Activity 1.5—M&M's in different temperatures

Does the temperature of the water affect how fast the colored coating dissolves from an M&M?

G	S	N	
☐	☐	☐	Plans experiment with group
☐	☐	☐	Identifies and controls variables
☐	☐	☐	Conducts the experiment
☐	☐	☐	Describes observations with drawing and captions
☐	☐	☐	Answers the question to investigate based on evidence from experiment

Circle one: Good Satisfactory Needs Improvement

Activity 1.6—M&M's in different sugar solutions

Does the amount of sugar already dissolved in water affect how fast an M&M coating dissolves?

G	S	N	
☐	☐	☐	Makes a prediction based on observations during previous M&M experiments
☐	☐	☐	Explains reasoning
☐	☐	☐	Identifies and controls variables
☐	☐	☐	Follows given procedure
☐	☐	☐	Answers the question using evidence from experiment

Circle one: Good Satisfactory Needs Improvement

Overall grade

To earn a "**B**", a student must receive a "Good" in each activity.

To earn an "**A**", a student must also exhibit some of the following qualities throughout this investigation.

- ☐ Develops reasonable well-written questions
- ☐ Creates outstanding drawings and written explanations
- ☐ Possesses a well-developed understanding of possible variables
- ☐ Participates well in class discussions
- ☐ Participates well in group work
- ☐ Uses scientific thinking
- ☐ Consistently exhibits exceptional thought and effort in tasks
- ☐ Other ____

Review and apply

The following section, titled *Review and apply*, contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 1*, they will reflect on their learning, apply what they learned about experimental design to a new activity, and identify how variables were controlled in a historic experiment. An optional reading explains, on the molecular level, why sugar dissolves in water. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**.

Let's review

1. Review with students what they learned in the M&M investigation.

Distribute *Review and apply: Let's Review*, p. 56, and give students an opportunity to respond to the prompts on their own. Once students think about and write their ideas, discuss what students learned about controlling variables and about the dissolving of the colored sugar coating of M&M's during *Investigation 1.*

Science in action!

2. Have each student design and conduct an experiment with a colored sugar-coated candy.

Ask students to name other candies that have sugar coatings. Then ask if they think the colored sugar coatings from these candies would dissolve in water like M&M's. Explain that each student will conduct an experiment based on one of the questions explored during the M&M investigation—except this time, with a different type of candy. Students may select the candy they will use and the experiment they will do. This activity and the corresponding *Review and apply* worksheet can serve as a summative assessment, evaluating students' skills in developing a question, identifying and controlling variables, and interpreting results.

Distribute activity sheet, *Review and apply: Science in action!*, pp. 57–58. This activity may be conducted either at home or in class.

3. When students have completed their experiments, compare experimental designs and results.

Have students join small groups and describe their experiments and their results. With the whole class, ask students to describe any similarities or differences between their experiment and someone else's. For example: If one student tested Skittles in cold, room-temperature, and hot water and another tested gumballs, did both students observe faster dissolving in the hot water than in the cold water? Were the results similar to what was observed with the M&M's in different temperatures of water? What were some differences? After hearing a few examples ask the general question: Does the coating from other candies seem to dissolve in water the way it does with M&M's?

Think about it

4. Have students read about a historical experiment and then answer questions.

Distribute *Review and apply: Think about it*, pp. 59–62. Tell students that most juice and milk sold in this country is *pasteurized*. This means that the drink was heated to kill disease-causing bacteria. This process is named after its inventor, Louis Pasteur. Before Pasteur's experiments, people did not know that something in the air (germs, bacteria, spores, etc.) could make them sick or make food spoil. But after learning about his experiments, people began to change their minds. Tell students that they will read about a famous experiment Louis Pasteur conducted and then answer some questions.

5. Discuss the experimental design Louis Pasteur used to prove that the theory of spontaneous generation was not true.

Discuss student responses to the questions on the *Review and apply* worksheet. Be sure students understand what Pasteur did to make his experiment fair.

For additional information about Louis Pasteur, go to **www.inquiryinaction.org**.

What's going on here? *(optional)*

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about the process of dissolving on the molecular level and answer questions about the reading.

Distribute *Review and apply: What's going on here?*, pp. 63–65. This reading describes the structure of the water molecule and explains how this structure helps it to dissolve sugar. This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about protons, electrons, and the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level. Discuss with students the process of dissolving based on the reading to help them understand.

Material to support this reading can be found at **www.inquiryinaction.org**.

Name: ____________________________

Let's review

At the beginning of this investigation a student noticed that the colored coating from an M&M dissolves in water. Like the student, you also investigated the way the colored coating dissolves and moves through water.

1. Describe an activity you did where you had to control variables. Explain what you did to control them.

2. Write one or two things you discovered about the way the colored coating from an M&M dissolves and moves in water.

Review and apply worksheet Name: ______________________________

Science in action!

Does the coating from another type of candy dissolve in water like M&M's?

Plan your experiment

Examples of candies with colored sugar coatings like M&M's are Skittles, Reese's Pieces, gumballs, etc. You may also choose to experiment with different types of M&M's, perhaps using holiday colors, mini or mega M&M's, peanut M&M's, etc.

1. Which type of candy will you use in your experiment? ____________________________

2. Next select your question to investigate. Base your question on something you investigated with M&M's in water. Write what you plan to investigate in question form.
____
____
____
____

3. How will you set up your experiment?
____
____
____
____
____
____
____
____
____
____

Conduct your experiment!

Name: ______________________________

Science in action! (*continued*)

Does the coating from another type of candy dissolve in water like M&M's?

Record your observations

Describe your observations with words and colored illustrations. What did you observe?

Explain your observations

How is this similar to or different from what you observed with M&M's?

Name:____________________________

Think about it

Vocabulary

variable
predict
spontaneous generation
pasteurize

Louis Pasteur and the theory of spontaneous generation

A historical account of identifying and controlling variables

Some people used to think that flies, worms, bacteria, and other unwanted organisms actually came from rotten food, liquid, or other substances. They thought that somehow the food actually turned into these organisms. This idea—that nonliving substances could turn into living organisms—is called *spontaneous generation*. Spontaneous means "to happen suddenly without anyone or anything trying to make it happen". Generation means "to come into being" or "to be born".

In the 1860s, the French scientist Louis Pasteur designed and conducted a scientific investigation to test whether the idea of spontaneous generation was true. Pasteur did not think that food or drink could somehow turn into living organisms. Instead, he thought that the organisms came from somewhere else and got into the food from the air or in some other way. He knew it was important to design a fair experiment to test whether spontaneous generation was true or false.

Pasteur decided to concentrate on the problem of bacteria causing certain liquids to spoil. His question to investigate was: *Do bacteria from the air cause food to spoil?*

In designing his experiment, Pasteur decided to use two containers of broth (a clear soup). He knew that he needed to keep everything about these two containers exactly the same except for the one thing he was trying to test. Both needed the same type of broth, both had to be open to the same air, and both needed to be exposed to the same light and temperature. Pasteur had to set up the experiment so that the only difference between the two containers was that bacteria could get into one container but not the other. If the broth spoiled in the container that allowed the bacteria to enter, it had to be the bacteria that caused it. Nothing else could have caused it because everything else about the containers was the same.

Pasteur predicted that the broth in which bacteria could enter from the outside would soon become filled with bacteria and would spoil. He also predicted that the broth that bacteria could not enter would not spontaneously produce bacteria but would remain clear and unspoiled. Pasteur believed that this experiment could show that the idea of spontaneous generation was not true.

Think about it (*continued*)

Here's what he needed to do

Pasteur needed to figure out a way to let bacteria get into one container but not into the other. He could not simply leave one open and the other closed because then one container would be getting air and the other would not. This difference between the two containers Pasteur knew would make the experiment unfair. The only difference between them could be that bacteria could get into one but not the other. Pasteur needed to figure out a way to do this while leaving both containers open to the air.

Here's how he did it

Pasteur got two glass containers for holding the broth. One of the containers had a neck that went straight up and was open at the end. When air passed over the opening, bacteria in the air could fall down into the broth.

The other container had a curved neck that was open at the end. When air passed over this opening, bacteria would fall into the curve in the neck and become trapped, never able to reach the broth. Using this method, Pasteur found a way to expose both samples of broth to the air but allowed bacteria to get into the broth in only one.

Pasteur then put the same kind and same amount of broth into both containers. He heated each container, in the same way, at the same temperature, for the same length of time, to kill any bacteria that may have been in the broth already.

After only a few days, the broth in the straight-necked container, in which bacteria could enter from the outside, was cloudy and spoiled. The broth in the curved-necked container, in which bacteria could not reach, stayed clear. The experiment proved that broth doesn't somehow spontaneously turn into bacteria on its own. Rather, for broth to spoil, bacteria need to get into it from the outside.

Pasteurization

Louis Pasteur conducted many experiments and solved many problems. One of the techniques he developed was named after him and is still commonly used today—it's *pasteurization*. Look on containers of juice and milk. Many of them say that they are pasteurized. What this means is that the drink was heated to kill bacteria that might make people sick. Then it was cooled quickly so that the flavor would not change much. Since pasteurization kills much of the bacteria in drinks, it also keeps them fresher longer. So, Louis Pasteur's work still affects us today.

Name: ____________________________

Think about it (*continued*)

1. What is the main idea of the reading about Louis Pasteur?
   a. Louis Pasteur wanted to test ideas in a laboratory.
   b. Louis Pasteur designed and conducted an experiment to test the theory of spontaneous generation.
   c. Louis Pasteur was the inventor of pasteurization.
   d. Louis Pasteur was a scientist.

2. The term *spontaneous generation* means:
   a. to suddenly catch on fire.
   b. to have a large and complicated family tree.
   c. a living thing can come from a non-living thing.
   d. to get power from a generator.

3. Pasteur *predicted* that bacteria from the air caused broth to spoil. What does the word *predicted* mean in this sentence?
   a. expected
   b. exposed
   c. produced
   d. designed

4. In his experimental design, Pasteur kept everything about the containers the same except bacteria could get in one container but not the other. He designed his experiment this way so that it was a *fair* test.
   In a *fair* test:
   a. No variables are used.
   b. There are at least three variables used.
   c. All variables are kept the same except for the one you are testing.
   d. Two variables are changed at the same time.

5. In Pasteur's experiment, he used a curved-neck container and a straight-neck container. Why did he use different shaped containers?
   a. The straight one allowed air to get in.
   b. The curved one prevented the broth from spoiling.
   c. They both allowed air in, but the curved one prevented bacteria from getting in.
   d. He could heat both without the broth boiling over.

6. If you were to come up with a title for this reading, it might be:
   a. Louis Pasteur solves many problems.
   b. Louis Pasteur likes milk.
   c. Louis Pasteur experiments with broth.
   d. Louis Pasteur tests the theory of spontaneous generation.

Name: ____________________________

Think about it (*continued*)

7. In Louis Pasteur's experiment to disprove the theory of spontaneous generation, what were some of the variables that he needed to keep the same so that his experiment was fair?

8. In Pasteur's experiment, what was the one variable that was different between the two containers?

9. If Pasteur wanted bacteria to get into one container of broth but not the other, why didn't he just leave one open and put a lid on the other?

10. In your own words, explain how the careful setup of Pasteur's experiment added evidence to the case that the theory of spontaneous generation is not true.

Review and apply worksheet Name: ____________________________

What's going on here?

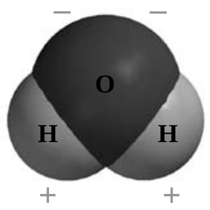
Water and the process of dissolving

In this investigation, you saw that sugar and color dissolve from an M&M when the M&M is placed in water. Dissolving seems like a pretty simple process, but you can learn a lot if you look at dissolving closely, VERY closely.

The first thing to understand about dissolving is that you have to look at the liquid doing the dissolving (solvent) as well as the substance being dissolved (solute). Dissolving depends on the interaction between the molecules of the solvent and the molecules of the solute. Since dissolving sugar happens way down on the molecular level, you have to know something about the water molecules and the sugar molecules.

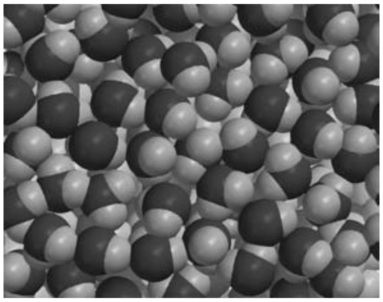
Water molecules

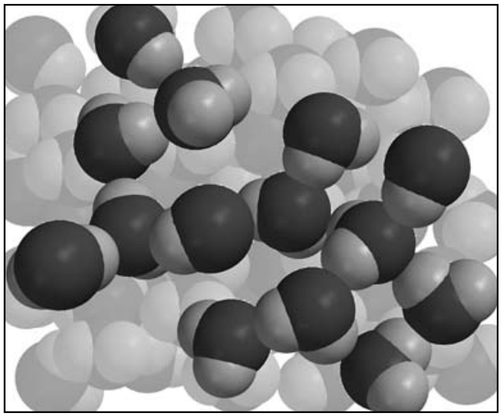
A water molecule is made of two hydrogen atoms bonded to one oxygen atom. All atoms, including hydrogen and oxygen, have one or more protons in the center, or nucleus, of the atom. Atoms also have electrons that move around the nucleus. Protons have a positive electric charge and electrons have a negative electric charge. An atom has the same number of electrons as it has protons. Here is a model of a water molecule. Scientists use models to represent objects or processes that are difficult to actually see. In this model of a water molecule, the space taken up by the dark ball (oxygen) and the lighter balls (hydrogen) represent the area in those atoms where the electrons would be. The nucleus of each atom would be much smaller and in the center of each ball but is not shown in this type of model. Actual water molecules don't really look like these balls stuck together but this is a useful model to help understand more about how water molecules behave.



Because of the characteristics of oxygen and hydrogen and how they are bonded together in the water molecule, there is a slight positive charge near the hydrogen atoms and a slight negative charge near the oxygen atom.

The smaller illustration to the right shows that the molecules in liquid water associate very closely with one another. The larger illustration shows how the water molecules tend to orient themselves according to their opposite charges. Notice how the positive area of one water molecule is attracted to the negative area of another.





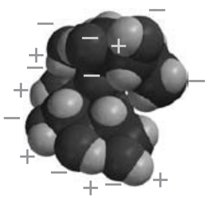
Name: ___________________________

What's going on here? (*continued*)

But these positive and negative areas on water molecules are also attracted to the positive and negative areas of the molecules of other substances. This is the key to water's great ability to dissolve certain substances, including sugar.

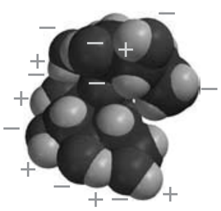
Sugar

There are many different kinds of sugar. The common sugar that we use in foods and drinks is called sucrose. Sucrose is a pretty big molecule compared to water. Its chemical formula is $C_{12}H_{22}O_{11}$. One reason why water can dissolve sucrose is because it has areas on it that are slightly positive and slightly negative. Look at the illustration of the sucrose molecule. It has many places on it where a hydrogen atom is bonded to an oxygen atom. This is very similar to the oxygen and hydrogen in a water molecule. In the sucrose molecule, the area near the hydrogen is slightly positive and the area near the oxygen is slightly negative.



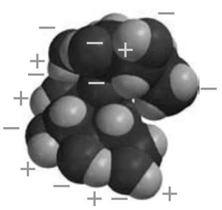
Sucrose molecule

Sucrose molecules are attracted to other sucrose molecules and join together because of the attraction of opposite charges. This is what keeps sucrose molecules together in a piece of sugar.



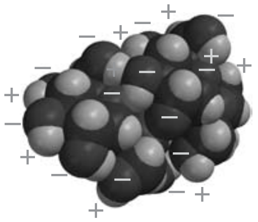
Sucrose molecule

+



Sucrose molecule

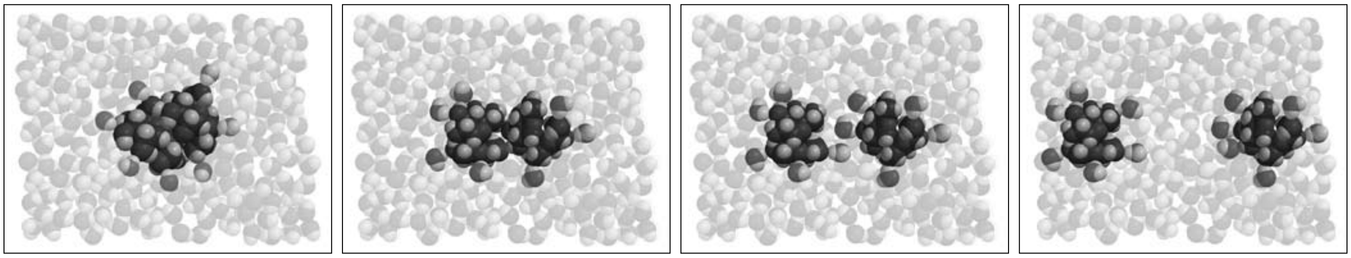
=



Two sucrose molecules closely associated due to oppositely charged polar areas

Why does water dissolve sucrose?

The positive and negative ends of the water molecules attract the negative and positive parts of the sucrose molecule. When the attractions that the water molecules have for the sucrose molecule become stronger than the attractions the sucrose molecule has for the other sucrose molecules that surround it, the sucrose molecule is pulled away and surrounded by water molecules. At that point it is dissolved.



Name: ____________________________

What's going on here? (*continued*)

1. What atoms is water made of? **Hint**: The chemical formula for water is H_2O.

____

____

____

____

2. Why are water molecules attracted to each other?

____

____

____

____

3. Why is water able to dissolve sucrose?

____

____

____

____

Cool factoid

The drawings and models of water molecules that you see or build are millions of times larger than the actual size of real water molecules. To get an idea of how small they are, consider this: Let's say you had about a tablespoon of water and wanted to count all the water molecules in that amount of water. Assume you were a very fast counter and could count 1 million water molecules every second. Even at your very fast counting speed, it would take you over 190 million centuries to count all the water molecules in that small amount of water. WOW!

Investigation 2

Physical properties and physical change in solids

How can you tell if crystals that look the same are really the same or different?

Summary

In this investigation, students compare the properties of four different household crystals to the properties of an unknown crystal. This unknown crystal is chemically the same as one of the known crystals, but does not appear the same. Students conduct tests for appearance, “crushability”, solubility, and recrystallization to help them identify the unknown crystal. The activities emphasize solubility as a characteristic property of a solid, identifying and controlling variables to design fair tests, making observations, and analyzing results.

Investigation 2: Physical properties and physical change in solids

Key concepts for students

- Solubility is a characteristic property of a substance.
- To measure equal amounts of different solids for a solubility test, it is better to use mass than volume.
- When comparing solubilities of different solids, all variables should be kept the same except for the type of solid used.
- The way a substance recrystallizes is a characteristic property of that substance.
- Solubility and recrystallization can be used to help identify an unknown substance.

Learning objectives

Students will be able to:

- Develop an understanding of the meaning of characteristic properties of substances by testing and comparing different household crystals.
- Recognize that solubility is a characteristic property of a substance.
- Identify an unknown crystal by comparing its characteristic physical properties with those of four known crystals.
- Measure equal amounts of crystals by mass rather than volume.
- Identify possible variables and suggest ways to control them as they help design valid scientific investigations.

Investigation questions

How can you tell if crystals that look the same are really the same or different?

- Can you identify an unknown crystal by comparing its appearance to other known crystals?
- Can you identify the unknown crystal by crushing the different crystals and comparing them?
- Do some of the crystals dissolve more or less than others?
- What is the best way to measure equal amounts of crystals?
- Can you identify the unknown crystal by the amount that dissolves in water?
- Can you identify the unknown crystal by the way it looks when it recrystallizes?

Assessment

The assessment rubric *Physical properties and physical change in solids*, pp. 108–109, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section on pp. 110–124.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties, including size, weight, shape, and color.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Types of investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

Substances have characteristic properties, such as density… and solubility.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

2.1 Curious crystals
2.2 Crushing test
2.3 Solubility test
2.4 Recrystallization test

Each group will need

	Activities			
	2.1	2.2	2.3	2.4
Salt in cup	●	●	●	
Epsom salt in cup	●	●	●	
MSG (Accent®) in cup	●	●	●	
Sugar in cup	●	●	●	
Kosher salt in cup (unknown)	●	●	●	
Black construction paper, ½ piece	●	●		
Magnifying glass	●			
Masking tape	●		●	
Pen	●		●	
Ruler			●	
Permanent marker			●	●
Clear plastic cups			5	
Small plastic cups, 3½ ounces			6	
Plastic teaspoon	●	●	●	
Hot tap water			●	
Paper clips			10	
Cotton swabs				●
Crystal solutions from *Activity 2.3*				●

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Students should use care when handling hot tap water.**
- Standard metal paper clips weigh about 0.4–0.5 grams each. Students should use 10 identical paper clips to measure either 4 or 5 grams of each crystal. Either 4 or 5 grams of each crystal is enough to observe differences in solubility.
- Additional materials will be required for the *Review and apply: Science in action!* activity, pp. 113–115. These include potassium chloride which can be purchased under the brand name Nu-Salt®.

Materials chart for teacher demonstrations

2a. Solubility is a characteristic property
2b. Measuring equal amounts of crystals for the solubility test

	Demo 2a
Overhead projector	●
Transparency	●
Transparency marker	●
Clear plastic cups	2
Salt	●
Sugar	●
Hot tap water	●
Teaspoon	●
Scale to weigh 5 grams	●

	Demo 2b
Primary balance	●
Clear plastic cups	2
Zip-closing plastic bag, quart-sized	●
Ball-shaped cereal	●

Notes about the materials

- If you do not have a scale that can weigh 4 or 5 grams, build a balance using a ruler, pencil, tape, cups, and 10 paperclips as described in *Activity 2.3—Solubility test*, p. 95.

- You will need enough ball-shaped cereal to completely fill two plastic cups.

Science background information for teachers

The physical properties of a solid are characteristics such as shape, color, size, and texture. Some other physical properties that are not as readily observable are density and hardness.

Sometimes, these physical properties can change. A physical change is a change that alters the form or appearance of a substance without changing the chemical composition. One example of physical change is melting: A substance changes from a solid to a liquid. Another is breaking apart and dissolving in a liquid to become part of a solution. In both cases, the substance changes its form or size but does not change its identity. The physical properties of substances, like the crystals examined in this investigation, and the way they undergo physical change are characteristic properties and can be used to distinguish one substance from another.

For videos, animations, and other information related to this investigation,
go to **www.inquiryinaction.org**

Chemistry concepts

- A water molecule has an area of positive charge and an area of negative charge.
- Salt (sodium chloride) is made up of positive and negative ions.
- Dissolving salt depends on the interaction between water molecules and the sodium and chloride ions.
- If the attraction the water molecules have for the sodium and chloride ions overcomes the attractions these ions have for each other, dissolving can take place.
- The solubility of a substance depends on the ions or molecules it is composed of, how strongly they are attracted to each other, and how they interact with water molecules.

Activity 2.1—Appearance test

There are two main reasons why the various types of crystals look different from one another. One reason is that the crystals are made of different atoms and molecules. Since the atoms and molecules are different, the way in which they bond together to form the crystal varies. This atomic and molecular structure affects the crystal's overall shape, color, texture, and other features. The other factor that can affect the appearance of the crystals is the way they are processed and packaged for sale. The table salt (sodium chloride) and the kosher salt (sodium chloride) are chemically the same but look different because of the way they are processed. Both salts are produced by pumping water into rock salt deposits and then collecting the salty water and evaporating it. To make kosher salt, the salty water is continuously raked during the evaporation process, which results in less uniform and flakier salt crystals.

Activity 2.2—Crushing test

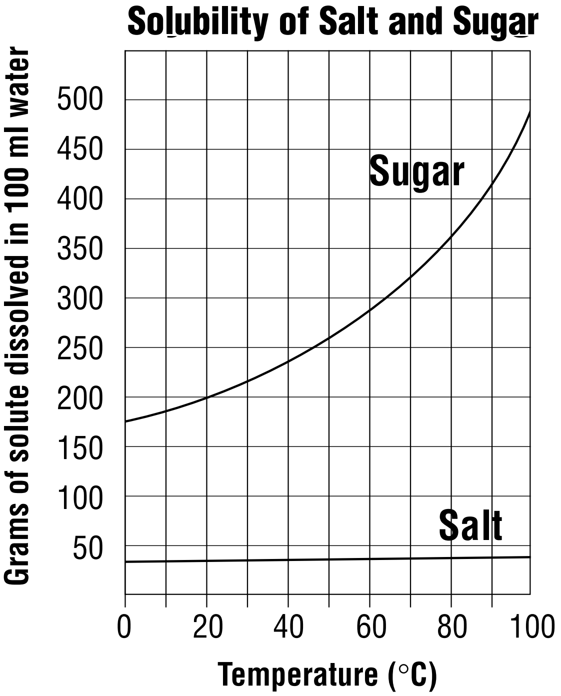
The hardness of the crystals is mostly dependent on their atomic and molecular structure. But, as mentioned above, the processing of the crystals may also have an impact on their properties, including hardness. This crushing test is not the classic hardness test that geologists use to help them identify minerals. It is a much more subjective test that has several variables that are difficult to control, which makes it a fairly unreliable test. It is included as an activity mainly because students may suggest crushing the crystals as a way to help identify them. Also, a discussion that identifies variables and considers why they are hard to control can help students better appreciate the issues involved in designing a valid experiment. The main variables that are difficult to control here are the crystal size and the force applied to the crystals. After doing the test and discussing the problems concerning certain variables, students will probably not be able to conclusively identify the unknown, or even eliminate any crystals based on this test.

Demonstration 2a—Solubility is a characteristic property

Solubility is usually expressed as the maximum number of grams of a substance that can be dissolved in 100 ml of water at a certain temperature. Since this number is unique for each substance, solubility is a characteristic property of a substance. In this demonstration, you will show students that more sugar than salt will dissolve in the same amount and temperature of water. Once students see that sugar is more soluble than salt, they will realize that dissolving each of their crystals in water may reveal distinct enough differences to help them identify the unknown crystal.

The graph at the right shows the solubility curves for salt (sodium chloride) and sugar (sucrose) over a range of temperatures. Solubility, as shown on the graph, is measured as the maximum number of grams of a substance that will dissolve in 100 ml of water at a given temperature. This is the saturation point of a substance. So, each point on the graph shows the saturation point of salt or sugar at a given temperature. For example, at room temperature (20 °C) about 37 grams of salt and about 195 grams of sugar can be dissolved in 100 ml of water. Since solubility is a characteristic property, every substance has its own unique solubility curve.

An interesting thing to note about the solubility of salt is that it does not increase very much as the temperature is increased. In *Demonstration 4a—Temperature affects the solubility of salt and sugar*, pp. 196–201, students will compare the amounts of salt and sugar that dissolve in cold and hot water.



Demonstration 2b—Measuring equal amounts of crystals for the solubility test

For a dissolving test it is important to use the same amount of each type of crystal. Students may suggest using a volume measure, like a teaspoon, or weighing the crystals. This demonstration shows that measuring the mass of the crystals is better than measuring the volume.

Using volume to measure the crystals is problematic. The size and shape of the crystals will affect how much room they take up in the spoon. If one type is very small and well-packed in the spoon and the other is larger and packed more loosely, it is likely that a level teaspoon of each could contain a very different amount of crystal.

Mass is a better way to measure the same "amount" of each crystal. Used in this way, "amount" refers to the quantity of matter that makes up the crystals, rather than the space or volume the crystals take up. The amount of matter that makes up a substance is measured by its mass.

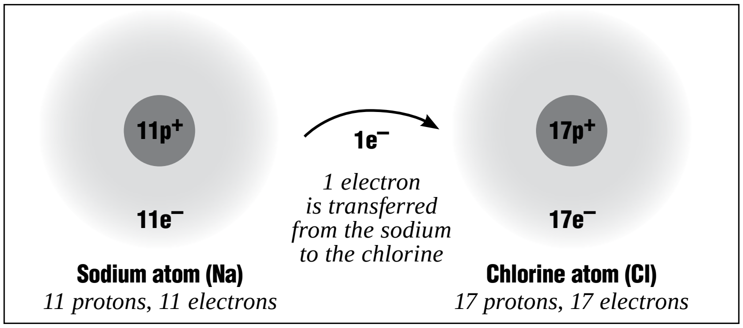
Activity 2.3—Solubility test

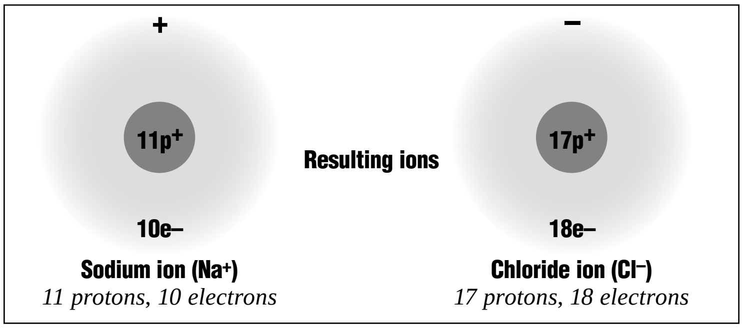
The reason why the different crystals dissolve differently has to do with the different size, weight, strength of attraction, and packing together of the ions or molecules that make up the crystal. The amount of attraction that the water molecules have for the particles of the substance compared to the attraction the particles of the substance have for each other determines the *solubility* of the substance. For the purpose of this activity, the solubility of a crystal is measured by the amount that dissolves in a teaspoon of hot water in about 1 minute.

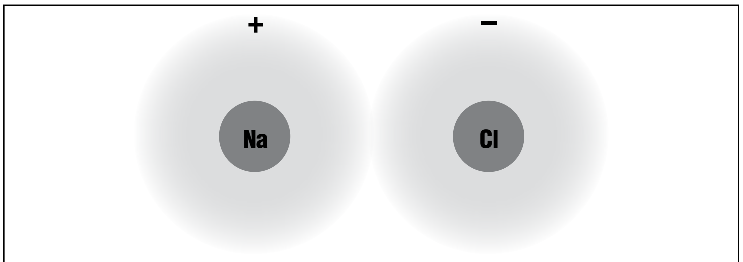
Salt is made from positive and negative ions

Regular table salt is sodium chloride. Its chemical formula is NaCl. *Na* stands for sodium and *Cl* stands for chlorine. The sodium and the chlorine in salt are bonded to each other in a special way. In a reaction between a chlorine atom and a sodium atom, an electron is transferred from the sodium to the chlorine. Since electrons have a negative charge, this gives the chlorine a net negative charge because it gained an electron. Losing an electron gives the sodium a net positive charge. This is because it has the same number of positive protons it had before but one fewer electron. When an atom gains or loses one or more electrons and then has a negative or positive charge, it is called an *ion*. Since positive and negative attract, positive sodium ions and negative chloride ions attract each other and bond together. This is what keeps the sodium and chloride ions together within a salt crystal.

The illustrations below show a salt crystal dissolving in water. Notice how the negative chloride ions are attracted by the positive ends of the water molecules (near the hydrogen atoms). And the positively charged sodium ions are attracted by the negative ends of the water molecules (near the oxygen atoms).

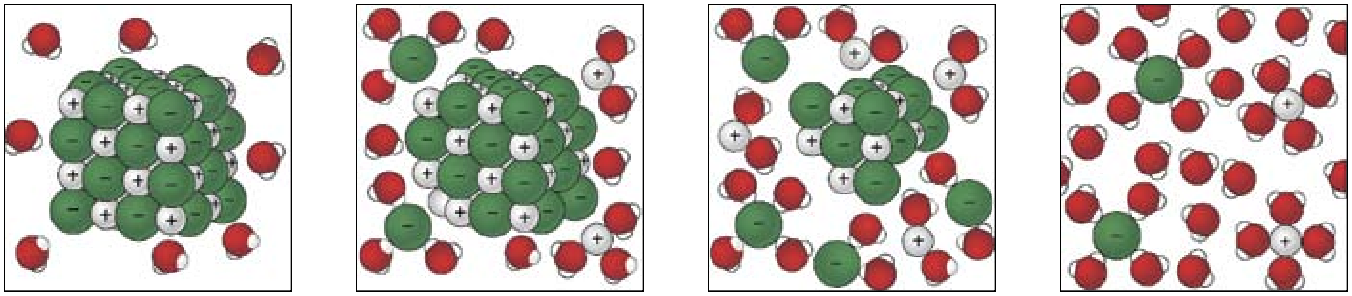






Na^+ and Cl^- form an ionic bond to make
Sodium chloride (NaCl)

The relative sizes of the atoms and ions in the graphic above are not drawn to scale. Also, a single sodium ion would not actually be found bonded to a single chloride ion as shown. The relative sizes and the ions bonding in a crystal lattice are shown in the dissolving drawings below. These simplified drawings are used as a model to help illustrate the process of ionic bonding.



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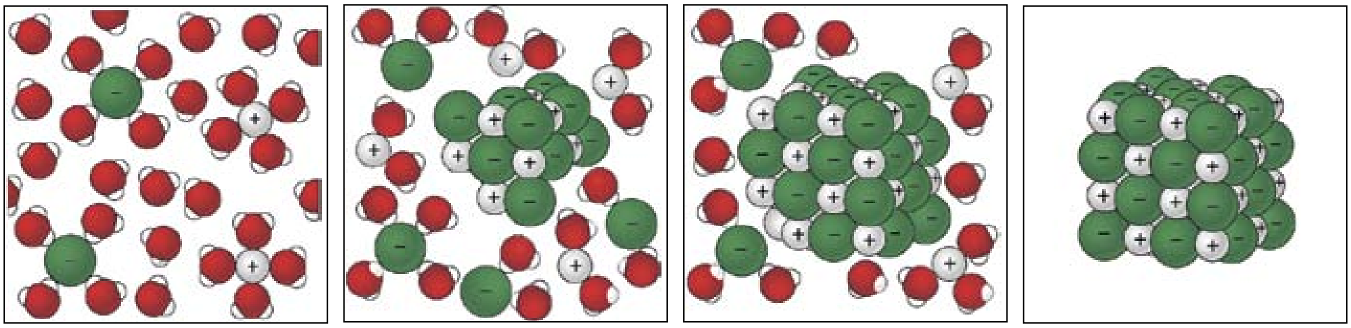
If students use the same mass of each crystal, the same amount and temperature of water, and swirl the solution in the same way for the same length of time, this should be a pretty fair test of the differences in solubility between the crystals. But there is still one variable that has not been controlled: the size of the crystals. The more surface area that is in contact with the water, the faster the crystal should dissolve. So for a given amount of crystal, the smaller it is crushed up to begin with, exposing a lot of surface area, the faster it will dissolve. Technically, to help reduce the effect of this variable, all crystal samples would have to be crushed to the same size. We do not recommend this step because of logistical difficulties in crushing the crystals to the same size.

Activity 2.4—Recrystallization test

The recrystallization test is like a “reverse-dissolving” test. When the different substances dissolve, their ions or molecules are surrounded by water molecules. This makes it hard for the ions or molecules to come together to begin to form a crystal again. But as the water evaporates, there are fewer water molecules surrounding the ions or molecules. Evaporation causes the concentration of the water to go down and the concentration of the solute to go up. This makes it easier for the ions or molecules to come together and bond according to their positive and negative charges, forming crystals.



Once the solutions have evaporated, the resulting crystals look different from one another. This is because they are made of different ions with different structures and sizes that bond together in different arrangements. Both the unknown (coarse kosher salt) and the table salt look alike when they recrystallize because they are both sodium chloride.

The sugar solution may not recrystallize even after a long period of time. One reason for this is that each substance has its own level of concentration it has to reach before it will recrystallize. Water takes a long time to evaporate from a sugar solution, so it takes a long time for the sugar to reach this concentration.

Activity 2.1
Curious crystals

Can you identify an unknown crystal by comparing its appearance to other known crystals?

In this activity, students will carefully look at four known household crystals. After observing and describing the crystals, students will be given an unknown crystal, which is chemically the same as one of the four known crystals but looks different. When students realize that they cannot identify this crystal by its appearance alone, they will suggest other tests and ways to compare the crystals to eventually identify the unknown crystal. The other activities in this investigation are examples of tests students can conduct on the crystals. After a series of these tests, students will gather enough evidence to identify the unknown crystal.

Materials needed for each group

Salt
Epsom salt
MSG (Accent®)
Sugar in cup
Kosher salt in cup (unknown)
5 Small cups
Black construction paper, ½ piece
Magnifier
Masking tape
Pen
Plastic spoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- The piece of black construction paper, and crystals poured on it, will be used in both *Activities 2.1* and *2.2*.

Preparing materials

- Use a permanent marker to label five small cups **salt**, **Epsom salt**, **MSG**, **sugar**, and **unknown**.
- Place at least 2 teaspoons of each crystal in its labeled cup.
- These source cups and crystals will be reused in *Activities 2.2* and *2.3*.

Activity sheet

Copy *Activity sheet 2.1—Curious crystals*, pp. 79–81, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 2.1
Curious crystals

Question to investigate

Can you identify an unknown crystal by comparing its appearance to other known crystals?

Take a closer look

1. Have students read the introductory story on *Activity sheet 2.1* and examine the crystals.

Introduce students to the four household crystals they will be examining. Then have students follow the procedure below and record their observations about the crystals on the activity sheet. Let students know that they can look at the crystals and touch them but they should not taste them!

Procedure

1. Use masking tape and a pen to label four corners of a piece of black construction paper: **sugar**, **salt**, **Epsom salt**, and **MSG**. Label the center **unknown**.
2. Place small samples of Epsom salt, table salt, sugar, and MSG on the labeled areas of the construction paper.
3. Use a magnifier to look carefully at each type of crystal.
4. Describe some characteristics of each crystal. Include any similarities and differences you notice among them.

2. Have students discuss their observations.

Students should describe physical properties such as the size, shape, color and texture. They should also describe whether the crystals are shiny, dull, transparent, or opaque.

Try this!

3. Introduce the "unknown crystal" and have students compare it to the four known crystals.

Give students a sample of the unknown crystal and tell them that this unknown is chemically the same as one of the other crystals they just looked at. Have them compare this unknown to the others as described in the following procedure.

Procedure

1. Place a sample of the "unknown crystal" in the center of your piece of black construction paper.
2. Use a magnifier to help you compare this crystal to each of the four crystals you just examined.

4. Discuss student observations.

Expected results: **The unknown will not look identical to any of the other crystals.**

Ask students for their ideas about what the unknown might be based on the way the crystals look. (Don't tell students yet that the unknown is coarse kosher salt.) Ask students to identify crystals they think the unknown might be. Then ask them how certain they are that this is the identity of the unknown. Students should not have enough evidence to correctly identify the unknown at this point.

What's next?

5. With the whole class, have students suggest tests they could do that might help them identify the "unknown crystal".

Tell students that the appearance test did give some information about the crystals, but not enough to identify the unknown. Ask students for their ideas about other tests they could conduct that might reveal the identity of the unknown. One example of a test would be to crush each type of crystal to see if the unknown breaks in a way that is similar to one of the known crystals. Students might also suggest dissolving each of the crystals in water. Perhaps the unknown will dissolve as much as one of the known crystals. Tell students that in the next few activities they will help design tests and gather evidence to discover the identity of the unknown.

Student activity sheet
Activity 2.1

Name: ____________________________

Curious crystals

I woke up the other day and went into the kitchen to get some breakfast. I usually make a waffle or cereal, and my dad usually makes eggs and coffee. My dad added some sugar to his coffee and put a little salt on his eggs. I saw that a few tiny bits of sugar and salt had dropped onto the table. I'd never really thought about it, but I noticed how similar the sugar and salt looked even though I know how different they taste. Anyway, I couldn't think about sugar and salt too much because I had to catch the bus to school. At lunch that day, I had some pretzels and a sugar cookie and it happened again. There they were. I looked very closely at the salt granules on the pretzel and the sugar granules on the cookie. They almost looked like tiny crystals. When I got home that night, I took a little salt and sugar from the cabinet and looked at them with a magnifying glass. While I was at it, I asked if I could look at some other stuff that also looked like crystals. My mom gave me some MSG from the kitchen cabinet and some Epsom salt from the bathroom closet. I looked at all these with a magnifying glass and saw some pretty interesting things.

Take a closer look

Look at a few household crystals to see what you notice about them.

What do Epsom salt, table salt, sugar, and MSG crystals look like?

Procedure

1. Use masking tape and a pen to label four corners of a piece of black construction paper **Epsom salt**, **salt**, **sugar**, and **MSG**. Label the center **unknown**.

2. Place small samples of Epsom salt, table salt, sugar, and MSG on the labeled areas of the construction paper. (Be sure not to taste the crystals.)

3. Use a magnifier to look carefully at each type of crystal.

4. Describe some characteristics of each crystal in the chart on the following page. Include any similarities and differences you notice about them.

Student activity sheet
Activity 2.1

Name: ____________________________

Curious crystals (*continued*)

Epsom salt	Salt	Sugar	MSG

Try this!

Your teacher gave you a crystal sample labeled **unknown**. This crystal is chemically the same as one of the four known crystals.

Can you identify the unknown crystal by comparing its appearance to other known crystals?

Procedure

1. Place a sample of an “unknown crystal” in the center of your piece of black construction paper.

2. Use a magnifier to help you compare this crystal to each of the four crystals you just examined.

1. What similarities do you notice between the unknown and any of the known crystals?

____

____

____

2. Based on your observations, what do you think the identity of the unknown might be?

____

3. How certain are you that your guess is correct?

____

Student activity sheet
Activity 2.1

Name: ______________________________

Curious crystals (*continued*)

What's next?

The appearance test gave you some information about the crystals, but probably not enough to identify the unknown for sure. So you will need to conduct a few other tests. One test could be to crush each type of crystal to see if the unknown breaks in a way that is similar to one of the known crystals. You may also try dissolving each of the crystals in water. Maybe the unknown will dissolve as much as one of the known crystals does. In the next few activities you will help design these types of tests as you try to discover the identity of the unknown.

Activity 2.2
Crushing test

Can you identify the unknown crystal by crushing the different crystals and comparing them?

A hardness test is used to identify rock samples, so a similar test may provide some information about the crystals. In this activity, students will try to design a crushing test and discover that identifying and controlling the variables may be difficult. Although the crushing test will not give conclusive results, it is a good opportunity to discuss variables and why they are sometimes difficult to control. This crushing test is also a good example of how a particular test does not always give enough information to answer a question.

Materials needed for each group

Salt in cup
Epsom salt in cup
MSG (Accent®) in cup
Sugar in cup
Kosher salt in cup (unknown)
Black construction paper, ½ piece
Plastic teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Use the crystals in labeled cups from *Activity 2.1.* These will be reused again in *Activity 2.3.*
- Use the piece of black construction paper labeled in *Activity 2.1.*

Activity sheet

Copy *Activity sheet 2.2—Crushing test*, pp. 85–86, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 2.2
Crushing test

Question to investigate

Can you identify the unknown crystal by crushing the different crystals and comparing them?

1. Have students help design a fair test.

In *Activity 2.1*, students may have suggested crushing the crystals. Distribute *Activity sheet 2.2—Crushing test* so students can plan a crushing test. Then lead a class discussion so that students can suggest ways to compare the “crushability” of the crystals. Important considerations to elicit from students involve controlling variables such as using the same object to crush each pile of crystals and trying to use the same amount of force for the same length of time. Discuss the importance of keeping variables the same in an experiment so that the test is fair. As a class, decide on the materials and procedure the groups will follow. You and the students can, of course, decide to use a can, a rolling pin, or any other safe object and a safe method to apply a consistent amount of force to the crystals in the same way. The procedure below is just one possible experimental design. Be sure students wear safety goggles when crushing the crystals.

2. Have students conduct the experiment.

Students may use the crystals they placed on the black construction paper from *Activity 2.1.* If they do, they can skip Steps 1 and 2.

Procedure

1. Use masking tape and a pen to make a small label for each of the five crystals as shown.

2. Spread a little of each of the five crystals in their labeled areas on the black paper.
3. Use your thumb in the bowl of a plastic spoon to press down on each pile of crystals, as shown. Rock the spoon back and forth to help crush the crystals.
4. Listen to the sounds the crystals make as they break. Notice any difference in the way the crystals feel when they break. Compare the residue left behind on the black paper.

3. Have students share and interpret their results.

Have students record their ideas about the identity of the unknown on *Activity sheet 2.2—Crushing test.*

Ask the following questions:

- Can you single out any crystal that is definitely *not* the unknown?
- Are any crystals similar enough to the unknown that they might be the unknown?
- Do you have enough information from this crushing test to say that you definitely know the identity of the unknown?

Expected results: **Although students may have detected slight differences in the crystals during the crushing test, they probably cannot identify the unknown at this point.**

Ask students whether comparing the sound, feel, or residue from each crystal is the best way to identify the unknown. Students should recognize that problems using a consistent amount of force to crush each crystal would make this test inconclusive. Students should conclude that they need more information to identify the unknown.

Student activity sheet
Activity 2.2

Name: ____________________________

Crushing test

Can you identify the unknown crystal by crushing the different crystals and comparing them?

If you were going to test and identify rock samples, you might use a hardness test. In a hardness test, you scratch a rock sample with different substances. If the rock gets scratched it means that it is not as hard as that substance. Hardness is a characteristic property of a rock. So knowing a rock's hardness can help you identify it.

Since the household crystals you are working with are so small, they would be difficult to scratch. But you can crush the crystals and compare how they break. Are they easy to break? Do they make a certain cracking sound? Do they leave a certain mark on a surface? Do the crushed pieces look a certain way? If "crushability" is a characteristic property of a substance, you may get some information that could help you identify the unknown crystal.

Plan your crushing test

1. What is one way you could crush samples of crystals?

____

____

____

____

2. What would you do to make sure that you crush each crystal with the same amount of force so that the test is fair?

____

____

____

____

Conduct your crushing test

Student activity sheet
Activity 2.2

Name: ______________________________

Crushing test (*continued*)

Interpret your observations

After you have conducted the crushing test, answer the following questions.

3. Can you single out a crystal that is definitely *not* the unknown?

   ____

4. Which crystal or crystals might be the unknown?

   ____

   ____

5. Do you have enough information from this crushing test to say that you know the identity of the unknown for sure?

   ____

   ____

   ____

Demonstration 2a
Solubility is a characteristic property

Do some of the crystals dissolve more or less than others?

In this demonstration, students are introduced to the term *solubility* and the idea that solubility is a characteristic property of a substance. First, students will see that sugar is more soluble than salt. They can then reason that other crystals may also have different solubilities. In fact, a solubility test on all of the crystals may help them identify the unknown. Students begin to consider how they might conduct this solubility test using all of the crystals. However, they will encounter a problem when addressing how to the measure equal amounts of each crystal: Should they use a volume measure like a teaspoon or weigh the crystals? *Demonstration 2b* resolves this issue.

Materials needed for the demonstration

Overhead projector
Transparency
Transparency marker
2 Clear plastic cups
Salt
Sugar
Hot tap water
Teaspoon
Scale to weigh 5 grams

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**

Preparing materials

- Use a sensitive scale to measure 5 grams each of salt and sugar.
- If you do not have a scale that can weigh 5 grams, build a balance using a ruler, pencil, tape, cups, and 10 paperclips as described in *Activity 2.3*, p. 95. Ten paperclips typically weigh between 4 and 5 grams.
- Place a transparency on the overhead projector and label one area **salt** and another **sugar**.

Activity sheet

Copy *Demonstration sheet 2a—Solubility is a characteristic property*, p. 90, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Demonstration 2a
Solubility is a characteristic property

Question to investigate

Do some of the crystals dissolve more or less than others?

1. Discuss the variables in a solubility test.

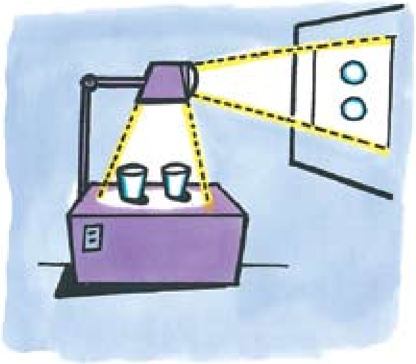
Tell students that salt and sugar are both crystals that dissolve in water. Ask them how they might design an experiment to compare how well sugar and salt dissolve. Use the following questions to get students to identify the variables in this demonstration:

- In order to have a fair comparison, should we use the same amount of water in both cups when we try to dissolve the crystals?
- What about the temperature of the water? Why is that important?
- Should we use the *same* amount of each crystal? Why?
- Should the cups be swirled in the same way and for the same length of time?

2. As a demonstration, dissolve salt and sugar in water.

Follow the procedure below while pointing out to students that you are using the same amount of water at the same temperature, and the same amount of crystal, swirled in the same way for the same length of time.

Procedure



1. Using identical clear plastic cups, place 1 teaspoon of hot tap water into each cup and place them on the overhead.

2. Place equal preweighed samples (about 5 grams) of salt and sugar into the cups of water at the same time. Swirl each cup at the same time and in the same way for about 20 seconds. Be sure to keep both cups on the overhead.

3. Ask students whether one substance seems to dissolve more than the other.

4. Swirl again for 20 seconds and observe. Then swirl for 20 more seconds and have students make their final observations.

5. Slowly and carefully pour the solution from each cup back into the empty labeled cups. Try not to let any undissolved crystal go into these cups. Place the clear plastic cups on the overhead so that students can compare the amount of undissolved crystal remaining.

Expected results: **Much more sugar will dissolve than salt. There will be more salt than sugar left in the cup.**

3. Discuss the results of the demonstration.

Ask students questions such as the following:

- Are the amounts left over the same?
- Which crystal has more left over?
- Where did the missing crystal go?
- Which dissolved better, salt or sugar?
- Do you think dissolving the five crystals in water might show differences between them?
- What makes you think that?
- How would you know which crystal is the same as the unknown?

Students should conclude that more sugar dissolved than salt when they compared the amount of each crystal left behind after three cycles of swirling. Since there was less sugar than salt left in the cup, this means that more sugar dissolved. Since different amounts of salt and sugar dissolved, students should recognize that this test might be useful in identifying the unknown. If the amount of the unknown left in the cup is about the same as the amount left behind by another crystal, then it's reasonable to conclude that the unknown is that crystal.

4. Introduce the term "solubility" and plan a solubility test.

Distribute *Demonstration sheet 2a—Solubility is a characteristic property*. Explain that the ability of a substance to dissolve in water is a characteristic property called *solubility*. For example, sugar is a white substance that forms crystals and is more *soluble* than salt.

Ask students to think about how they might conduct a solubility test on salt, Epsom salt, MG, sugar, and the unknown. Have students work in groups to discuss their ideas and record a simple plan on the activity sheet.

5. Discuss student plans and introduce the idea of how to measure equal amounts.

Ask a few students to share their plans to dissolve each of the crystals in water. Ask students how each of the plans controls variables to make the test as fair as possible. When students bring up using equal amounts of crystals, ask them how they could measure equal amounts. Students may suggest using a volume measure like a teaspoon or weighing the crystals. Tell students that you will do another demonstration to help them decide how to measure equal amounts of the crystals. (*Demonstration 2b—Measuring equal amounts of crystals for the solubility test*, p. 92.)

Student activity sheet
Demonstration 2a

Name: ______________________________

Solubility is a characteristic property

Do some of the crystals dissolve more or less than others?

1. More salt was left in the bottom of the cup than sugar. What does this tell you about the *"dissolve-ability"* of salt compared to sugar?

____

____

Scientists use the word *solubility* when they are talking about the amount that a substance dissolves. Solubility is a characteristic property of a substance. Different substances are going to be more or less soluble than others.

This means that you could use a solubility test to notice differences in each of the crystals and to identify the unknown. If the amount of the unknown left in the cup is about the same as the amount left in a cup by another crystal, then it's reasonable to conclude that the unknown is that crystal.

2. How could you conduct a solubility test to compare how well salt, Espom salt, sugar, MSG, and the unknown dissolve in water? Write a simple plan below.

____

____

____

____

____

3. List the variables you would need to control.

____

____

____

____

____

Demonstration 2b
Measuring equal amounts of crystals for the solubility test

What is the best way to measure equal amounts of crystals?

In *Demonstration 2a*, students saw that comparing the solubility of different substances requires testing *equal amounts* of each substance. In this demonstration students will see that to measure equal amounts, measuring by mass is better than measuring by volume.

Materials needed for the demonstration

Primary balance scale
2 Clear plastic cups
Zip-closing plastic bag, quart-size
Ball-shaped cereal

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**

Preparing materials

- Fill two clear plastic cups to the top with cereal balls. Place both filled cups on a simple balance to see whether the cereal in each cup weighs the same. If needed, adjust the amount of cereal until the cups balance.

Activity sheet

Copy *Demonstration sheet 2b—Measuring equal amounts of crystals for the solubility test*, p. 93, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Demonstration 2b
Measuring equal amounts of crystals for the solubility test

Question to investigate

What is the best way to measure equal amounts of crystals?

1. Show students two identical cups, each containing the same amount of cereal balls.

Hold the cups filled with cereal up so that students can see that both have about the same amount of cereal in them. Prove to your students that both contain the same amount of cereal by placing the cups on either end of a simple balance. Ask students how the height of the cereal in a cup will change if you smash the cereal balls from that cup. Students will probably suggest that the smashed cereal will not take up as much room in the cup.

2. Crush the cereal from one cup.

Pour the cereal from one of the cups into a storage-grade, zip-closing plastic bag. Get as much air out as possible and seal the bag. Place it on the ground, and smash the contents thoroughly with your foot. Once the cereal is pulverized, open the bag, and pour the crushed cereal bits back into the cup.

3. Prove that the amount of cereal in each cup is the same.

Hold both cups up and ask students which cup contains more cereal. Ask them if any cereal was added or removed from either cup. Point out that even though the crushed cereal takes up less space, it is still the same amount of matter (cereal) as was in the cup before it was crushed. Ask students how they could prove that these two cups actually contain the same amount of matter. They should suggest placing the cups on a balance scale as you did before. Do this so that students can see that the cups still balance.

Expected results: **The cups should balance on the scale.**

4. Compare this example to large and small crystals.

Tell students to imagine that the cereal balls are crystals. The large cereal balls represent large crystals and the crushed cereal represents small crystals. Ask students if each cup has the same amount of crystal in it. Students may be tempted to say that the cup with the small crystals has less crystal in it. Point out to students that the cups have the same amount of matter in them. Explain that the size and shape of the crystals may be different, but the balance shows that their mass is the same.

5. Conclude that, in order to measure equal amounts, it is better to weigh substances than to measure by using volume.

Distribute *Activity sheet 2b—Measuring equal amounts of crystals for the solubility test.* Tell students that in the solubility test they will do, they will need to measure equal amounts of the five crystals. Ask students what they think would be the best way to measure equal amounts. After this demonstration, students should realize that weighing is better than measuring by volume. In order to make sure that all students understand the important concept demonstrated, have them answer the questions on the activity sheet.

Student activity sheet
Demonstration 2b

Name: ______________________________

Measuring equal amounts of crystals for the solubility test

What is the best way to measure equal amounts of crystals?

1. Even though the mass of cereal in each cup is the same, after crushing the balls in one of the cups, the volume looks different. How do you know that the amount of cereal in each cup is actually the same?

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2. Using evidence from the demonstration, explain why it is best to weigh the crystals instead of using a volume measure like a teaspoon for your solubility test.

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3. Why would accidentally using different amounts of substances make the solubility test unfair?

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Activity 2.3
Solubility test

Can you identify the unknown crystal by the amount that dissolves in water?

In *Demonstration 2a*, students saw that more salt is left behind than sugar when both crystals are mixed with the same amount of water. Students can apply this same dissolving test to their known crystals and to the unknown. Since the unknown is chemically the same as one of the known crystals, it should dissolve similarly. By dissolving each of the crystals in the same amount of water and comparing the amount of crystal left behind, students will gain some information about the possible identity of the unknown.

Materials needed for each group

Salt in cup
Epsom salt in cup
MSG (Accent®) in cup
Sugar in cup
Kosher salt in cup (unknown)
Masking tape
Pen
Ruler
Permanent marker
5 Clear plastic cups
6 Small plastic cups, 3½-ounce
Plastic teaspoon
Hot tap water
10 Paper clips

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Students should use care when handling hot tap water.**
- Standard metal paper clips weigh about 0.4–0.5 grams each. Students should use 10 identical paper clips to measure 4 to 5 grams of each crystal. About 4 or 5 grams of each crystal is enough to observe differences in solubility.
- The labeled cups and the solutions made during this activity will be used again in *Activity 2.4.*
- *Activity 2.4—Recrystallizing test* should be done immediately after *Activity 2.3—Solubility test.*

Preparing materials

- Use the crystals in the source cups from *Activities 2.1* and *2.2*. If necessary add about 2 teaspoons of each crystal to its labeled cup.

Activity sheet

Copy *Activity sheet 2.3—Solubility test*, pp. 98–100, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 2.3
Solubility test

Question to investigate

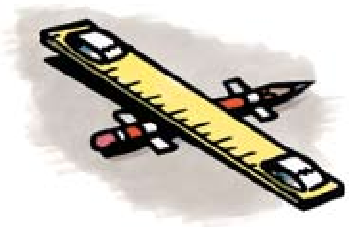
Can you identify the unknown crystal by the amount that dissolves in water?

1. Have students weigh equal amounts of the crystals.

The amounts of crystal and water used in this solubility test are specific and should be used because they give clear results. There are a variety of methods students could use to weigh equal amounts of each crystal. They could construct a balance themselves, like the one described below, or they could use any scale that can weigh 4–5 grams.

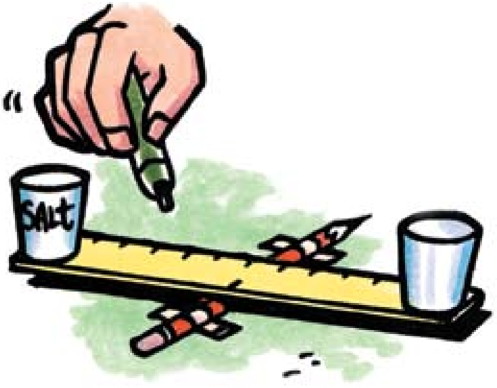
Procedure

1. Use your masking tape and pen to label five small cups **salt**, **sugar**, **epsom salt**, **MSG**, and **unknown**. Label five larger clear plastic cups in the same way. You should have two labeled cups for each type of crystal.



2. Tape the pencil down as shown. Roll two small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite end of the ruler. Place the small empty **salt** cup on one piece of tape so that the edge of the cup bottom is right at the end of the ruler. Place a small unlabeled cup on the other piece of tape in the same way.

3. Lay the ruler on the pencil so that it is as balanced as possible. Use a permanent marker to make a mark on the ruler at the point where it is balanced on the pencil. This is your *balance point*.



Note: Students may find it difficult to get the ruler to balance perfectly. Reassure them that if they get the ruler close to balancing, it will be accurate enough.

4. Carefully place 10 paper clips in the unlabeled cup. Slowly add salt to the **salt** cup until the cup with the paper clips just barely lifts from the table. Remove the **salt** cup from the ruler and set it aside.

5. Weigh the other four crystals in the same way so that you have equal amounts of all five crystals in their small labeled cups.

2. Discuss the variables that need to be controlled in the solubility test.

Ask students how they might mix the crystals into water to compare how they dissolve. You could ask questions such as the following to bring attention to the variables in this test.

- How many cups do we need?
- Should the cups all have the same amount of water?
- What else about the water should be the same? (same temperature)
- What is a good way to mix the crystals into water in each cup?

3. Have students dissolve the crystals in water.

The following procedure is also listed on *Activity sheet 2.3—Solubility test*. The amount of water used in the procedure is specific and should be used because it gives clear results. Swirling the crystals in water is a good way of mixing them to help them dissolve. Lead the class so that all groups pour their crystal samples into the water at the same time. Also tell students when to swirl the water and crystals and when to stop and observe. There will be three 20-second intervals.

Procedure

1. Place 1 teaspoon of hot tap water into each empty clear plastic cup.

2. Match up each pair of cups so that each cup of crystal is near its corresponding cup of water. With the help of your lab partners, listen for your teacher's instructions, and pour the weighed amount of each crystal into its cup of water at the same time.

3. With the help of your lab partners, swirl each cup at the same time and in the same way for about 20 seconds and observe. Swirl again for 20 seconds and observe and then for 20 more seconds and make your final observations.

4. Slowly and carefully pour the solution from each clear plastic cup back into its small empty cup. Try not to let any undissolved crystal go into the small cup. Compare the amount of crystal remaining in each clear plastic cup.

Students should use their observations during the solubility test to help them answer the questions about the possible identity of the unknown on the activity sheet.

4. Have students discuss their observations.

Ask students questions such as the following:

- Do you have enough information to identify the unknown?
- Are there any crystals that you could rule out as probably *not* the unknown?
- What do you think is the identity of the unknown?
- What evidence do you have to support your conclusion?
- If someone in the class had a very different conclusion and had very different observations, what do you think may have led to these differences?

Students should mention possible errors in weighing the crystals, in measuring the amount of water used, the amount and type of stirring, or accidentally pouring the crystals into the wrong cups.

***Expected results*: Results may vary somewhat depending on the temperature of the water. However, Epsom salt and sugar should dissolve the most. MSG should appear to dissolve more than salt and the unknown. The salt and the unknown should appear to dissolve to a similar degree.**

Based on their observations, students are most likely to eliminate Epsom salt and sugar as the possible identity of the unknown. They might conclude that the unknown is salt, but in some cases might think it could also be MSG. Since they may have some doubt, students will do a recrystallization test with the crystal solutions from this solubility test.

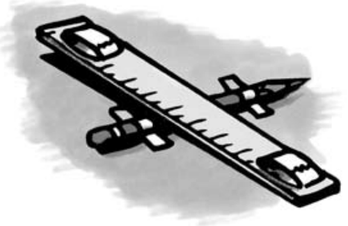
Note: *Activity 2.4—Recrystallization test* should be done immediately after the solubility test with the solutions made during this activity.

Student activity sheet
Activity 2.3

Name: ______________________________

Solubility test

Build your own balance



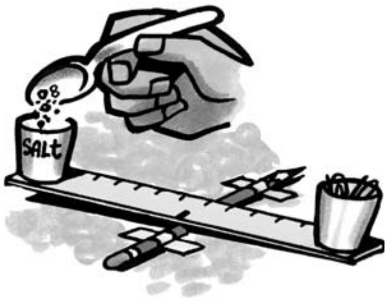
Procedure

1. Use your masking tape and pen to label five small cups **salt**, **Epsom salt**, **MSG**, **sugar**, and **unknown**. Label five larger clear plastic cups in the same way. You should have two labeled cups for each type of crystal.

2. Tape the pencil down as shown. Roll two small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite end of the ruler. Place the small empty salt cup on one piece of tape so that the edge of the cup bottom is right at the end of the ruler. Place a small unlabeled cup on the other piece of tape in the same way.

3. Lay the ruler on the pencil so that it is as balanced as possible. Use a permanent marker to make a mark on the ruler at the point where it is balanced on the pencil. This is your balance point.

   Don't worry if you cannot get the ruler to balance perfectly. If you get the ruler close to balancing, it will be accurate enough.



4. Carefully place 10 paper clips in the unlabeled cup. Slowly add salt to the salt cup until the cup with the paper clips just barely lifts from the table. Remove the salt cup from the ruler and set it aside.

5. Weigh the other four crystals in the same way so that you have equal amounts of all five crystals in their small labeled cups.

Name: ______________________________

Solubility test (*continued*)

Can you identify the unknown crystal by the amount that dissolves in water?

Use the procedure below to compare the solubilities of salt, Epsom salt, MSG, sugar, and the unknown.

Procedure

1. Place 1 teaspoon of hot tap water into each empty clear plastic cup.
2. Match up each pair of cups so that each cup of crystal is near its corresponding cup of water. With the help of your lab partners, listen for your teacher's instructions, and pour the weighed amount of each crystal into its cup of water at the same time.
3. With the help of your lab partners, swirl each cup at the same time and in the same way as your teacher counts for 20 seconds. When your teacher tells you to stop, compare the amount of crystal left behind in each cup. Listen for your teacher's instructions and swirl again for 20 seconds and observe. Swirl again for 20 seconds and make your final observations.

4. Slowly and carefully pour the solution from each clear plastic cup back into its small empty cup. Try not to let any undissolved crystal go into the small cup. Compare the amount of crystal remaining in each clear plastic cup.

Student activity sheet
Activity 2.3

Name: ____________________________

Solubility test (*continued*)

Can you identify the unknown crystal by the amount that dissolves in water?

1. Draw your observations. Try to show the difference in the amount of crystal remaining in each cup.

Salt Epsom salt MSG Sugar Unknown

2. Based on the amount of crystal remaining in each cup, do you have enough information to identify the unknown?

____

____

____

3. Which crystals are probably *not* the unknown? ______________________________
Explain how your observations lead you to this conclusion.

____

____

____

4. Based on what you saw in the appearance test, crushing test, and this solubility test, do you have enough information to identify the unknown? ____________________

With the information you have so far, what might be the identity of the unknown?

____

Activity 2.4
Recrystallization test

Can you identify the unknown crystal by the way it looks when it recrystallizes?

The way a substance dissolves in water is a *characteristic property* of that substance. Similarly, the way a substance “un-dissolves”, or *recrystallizes*, is also a characteristic property of the substance. The following recrystallization tests provide another clue that can help confirm the identity of the unknown. In this activity, students will allow each sample of crystal solution made in *Activity 2.3* to recrystallize. The crystals that form appear different enough that students will be able to positively identify the unknown. Two different methods for recrystallization are provided in this activity.

24-Hour method
The 24-hour method may be preferable since the solutions are left overnight to recrystallize and show clear differences when students view them the next day.

Same-day method
If you need results within 1–3 hours, you may want to try the same-day method. Since the testing surface will be paper and characteristics of paper vary, this test is not as reliable as the 24-hour method. The absorbency of the papers affects the quality of the crystals and the ability to observe them on the surface of the paper. Test one sheet of paper according to the instructions on p. 103 before trying this method with your students.

Materials needed for each group

24-Hour method
5 Labeled clear plastic cups from *Activity 2.3*
Crystal solutions from *Activity 2.3*

Same-day method
Crystal solutions from *Activity 2.3*
Permanent marker
Cotton swabs

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- *Activity 2.4—Recrystallizing test* should be done immediately after *Activity 2.3—Solubility test* using the crystal solutions made during the activity.

Activity sheet

Copy either *Activity sheet 2.4—Recrystallization test, 24-hour method*, pp. 104–105, or *Activity sheet 2.4—Recrystallization test, same-day method*, pp. 106–107, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 108–109. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 2.4
Recrystallization test

Question to investigate

Can you identify the unknown crystal by the way it looks when it recrystallizes?

24-Hour method

1. Students will reuse the large clear plastic cups and solutions from *Activity 2.3* according to the procedure below.

Procedure

1. Rinse each large clear plastic cup with water to remove any remaining crystal. Dry each with a paper towel.

2. Carefully pour the solution from each small cup into its corresponding large clear plastic cup.

3. Allow the solutions to sit overnight.

2. The next day, have students observe the crystals.

Distribute *Activity sheet 2.4—Recrystallization test*, p. 104–105. You may want to have students use a magnifying glass so that they can better see details of the crystals. Have students observe the crystals from the top and bottom of the cup and describe what they see in each cup.

Expected results: **Salt and the unknown look very similar. Epsom salt, MSG, and sugar look different from each other and different from salt and the unknown. The sugar may not have recrystallized yet, but given more time it will form large clear crystals.**

When students have completed the activity sheet, ask them questions like the following:

- What do you think is the identity of the unknown?
- Do you have enough information to be sure?

Students should be able to determine that the identity of the unknown is salt. Tell students that the unknown is coarse kosher salt. It is chemically the same as regular salt, but the process for making each is different and that is why they look different.

Same-day method

1. Have students apply the solutions to the activity sheet.

Distribute *Activity sheet 2.4—Recrystallization test*, pp 106-107. Tell students that they will apply some of each solution to the circles on the activity sheet. When the water evaporates, crystals will re-form.

Procedure

1. Although the circles are already black, use a black permanent marker to completely cover each circle with a layer of marker.
2. Dip a cotton swab into one of the solutions. Apply the solution in a circular motion to its labeled area on the activity sheet. Repeat until as much of the circle is covered with the solution as possible.
3. Using clean cotton swabs, repeat Step 2 for the other four solutions. Set the paper aside and check it in about an hour. If not much crystal has formed; check it again in another hour.
4. Compare the unknown to the other crystals.

2. Have students discuss their observations.

Students can use a magnifying glass to better see details of the crystals. Ask students what they see on each circle.

Expected results: **Salt and the unknown look very similar. Epsom salt, MSG, and sugar look different from each other and different from salt and the unknown. The sugar may not have recrystallized yet.**

When students have completed the activity sheet, ask them questions like the following:

- What do you think is the identity of the unknown?
- Do you have enough information to be sure?

Students should be able to determine that the identity of the unknown is salt. Tell students that the unknown is coarse kosher salt. It is chemically the same as regular salt, but the process for making each is different and that is why they look different.

Student activity sheet
Activity 2.4

Name: ______________________________

Recrystallization test, 24-hour method

Can you identify the unknown crystal by the way it looks when it recrystallizes?

Procedure

1. Rinse each large clear plastic cup with water to remove any remaining crystal. Dry each with a paper towel.
2. Carefully pour the solution from each small cup into its corresponding large clear plastic cup.
3. Allow the solutions to sit overnight.
4. Use a magnifier to observe the crystals from the top and bottom of the cup. Compare the crystals in each cup.

1. What do you think is the identity of the unknown?

____

2. What evidence do you have to support your conclusion?

____

____

Recrystallization in nature

Recrystallization doesn’t only happen in a cup. Stalactites and stalagmites in caves are another example of recrystallization. *Stalactites* form at the ceiling of the cave and point down. *Stalagmites* form on the floor of the cave directly beneath stalactites and point up.

Water that is slightly acidic seeps through tiny cracks in the ceiling of the cave and dissolves some of the limestone rock. If the drop of water hangs from the ceiling long enough, the water evaporates and the limestone recrystallizes. If this happens over and over again for hundreds of thousands of years, a stalactite is formed.

3. Why do you think stalagmites form directly underneath stalactites?

____

____

Student activity sheet
Activity 2.4

Name: ____________________________

Recrystallization test—24-hour method (*continued*)

Salt and kosher salt are both made of sodium chloride. The reason the crystals look different has to do with the way they are processed. Regular salt and kosher salt are both made by allowing salt water to evaporate. But the solution used to make kosher salt is constantly raked while the water is evaporating. This interferes with the way the crystals would ordinarily develop, causing them to come together in an irregular way. In this super-magnified view of a piece of kosher salt, you can recognize the cubic shape you ordinarily see in a single crystal of table salt.

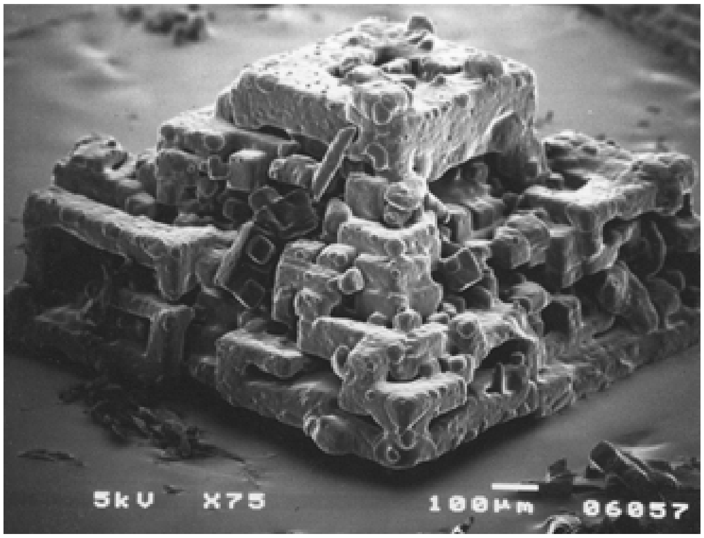


Photo courtesy of the the Museum of Science, Boston.

Student activity sheet
Activity 2.4

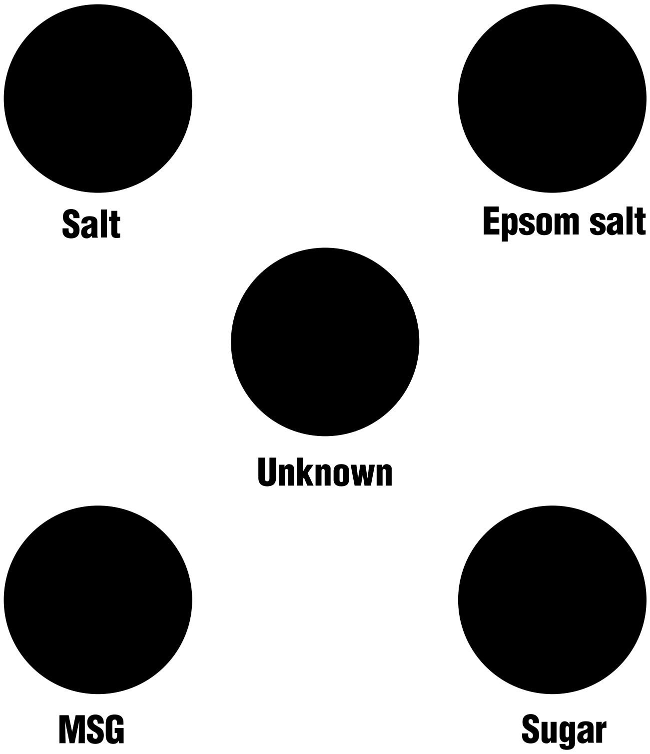
Name: ______________________________

Recrystallization test—same-day method

Can you identify the unknown crystal by the way it looks when it recrystallizes?

Procedure

1. Although the circles are already black, use a black permanent marker to completely cover each circle with a layer of marker.
2. Dip a cotton swab into one of the solutions. Apply the solution in a circular motion to its labeled area on the activity sheet. Repeat until as much of the circle is covered with water as possible.
3. Using clean swabs, repeat Step 2 for the other four solutions. Set the paper aside and check it in about an hour. If not much crystal has formed; check it again in another hour.



Compare the unknown to the other crystals

1. What do you think is the identity of the unknown? ____________________________
2. What evidence do you have to support your conclusion?

____

____

Student activity sheet
Activity 2.4

Name: ____________________________

Recrystallization test—same-day method (*continued*)

Recrystallization in nature

Recrystallization doesn't only happen on paper. Stalactites and stalagmites in caves are another example of recrystallization. *Stalactites* form at the ceiling of the cave and point down. *Stalagmites* form on the floor of the cave directly beneath stalactites and point up.

Water that is slightly acidic seeps through tiny cracks in the ceiling of the cave and dissolves some of the limestone rock. If the drop of water hangs from the ceiling long enough, the water evaporates and the limestone recrystallizes. If this happens over and over again for hundreds of thousands of years, a stalactite is formed.

3. Why do you think stalagmites form directly underneath stalactites?

____

____

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____

Salt and kosher salt are both made of sodium chloride. The reason the crystals look different has to do with the way they are processed. Regular salt and kosher salt are both made by allowing salt water to evaporate. But the solution used to make kosher salt is constantly raked while the water is evaporating. This interferes with the way the crystals would ordinarily develop causing them to come together in an irregular way. In this super-magnified view of a piece of kosher salt, you can recognize the cubic shape you ordinarily see in a single crystal of table salt.

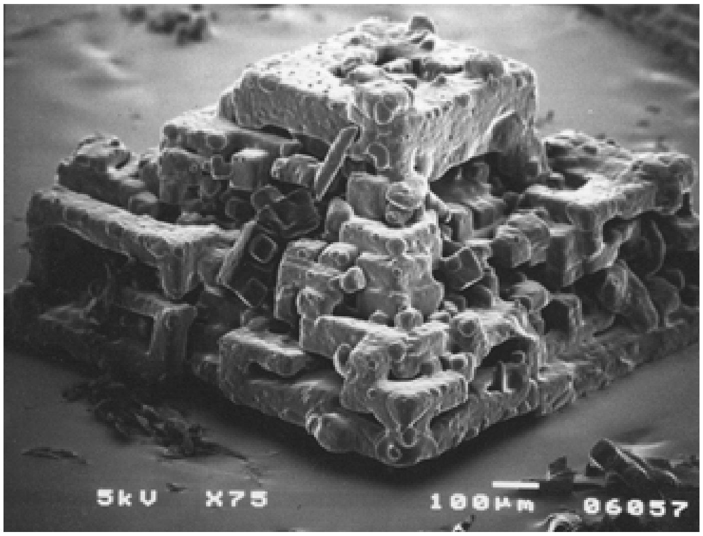


Photo courtesy of the the Museum of Science, Boston.

Investigation 2—Physical properties and physical change in solids

Assessment rubric

How can you tell if crystals that look the same are really the same or different?

Activity 2.1—Curious Crystals

Can you identify the unknown crystal by comparing its appearance to other known crystals?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Describes characteristics of crystals with words and/or drawings
☐ ☐ ☐ Observes and describes similarities between crystals
☐ ☐ ☐ Determines whether or not there is enough information to identify the unknown
☐ ☐ ☐ Suggests tests that might help identify the unknown crystal

Circle one: Good Satisfactory Needs Improvement

Activity 2.2—Crushing test

Can you identify the unknown crystal by crushing the different crystals and comparing them?

G S N
☐ ☐ ☐ Plans experiment with group
☐ ☐ ☐ Identifies and controls variables
☐ ☐ ☐ Conducts the experiment
☐ ☐ ☐ Determines whether or not there is enough information to identify the unknown

Circle one: Good Satisfactory Needs Improvement

Demonstration 2a—Solubility is a characteristic property

Do some of the crystals dissolve more or less than others?

G S N
☐ ☐ ☐ Participates in discussion about how to best design a solubility test
☐ ☐ ☐ Compares the solubility of salt and sugar based on the demonstration
☐ ☐ ☐ Plans a fair solubility test
☐ ☐ ☐ Identifies variables that will need to be controlled

Circle one: Good Satisfactory Needs Improvement

Demonstration 2b—Measuring equal amounts of crystals for the solubility test

What is the best way to measure equal amounts of crystals?

G S N
☐ ☐ ☐ Explains why the cups in the demonstration contained the same mass of cereal, even though the volumes appear different
☐ ☐ ☐ Explains why mass is better than volume when designing a fair test

Circle one: Good Satisfactory Needs Improvement

Investigation 2—Physical properties and physical change in solids

Assessment rubric (*continued*)

Activity 2.3—Solubility test

Can you identify the unknown crystal by the amount that dissolves in water?

G S N
☐ ☐ ☐ Follows given procedure to weigh crystals
☐ ☐ ☐ Discusses the variables that need to be controlled in the solubility test
☐ ☐ ☐ Works with group to follow given procedure
☐ ☐ ☐ Considers the possible identity of the unknown
☐ ☐ ☐ Uses results from the appearance, crushing, and solubility tests to explain reasoning

Circle one: Good Satisfactory Needs Improvement

Activity 2.4—Recrystallization test

Can you identify the unknown crystal by the way it looks when it recrystallizes?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Considers whether there is enough information to identify the unknown
☐ ☐ ☐ Uses evidence from recrystallization test to identify the unknown
☐ ☐ ☐ Extends observations to explain the formation of stalagmites in caves

Circle one: Good Satisfactory Needs Improvement

To earn a “**B**”, a student must receive a “Good” in each category.

To earn an “**A**”, a student must also exhibit some of the following qualities throughout this investigation.

- ☐ Writes outstanding explanations
- ☐ Possesses a well-developed understanding of possible variables
- ☐ Participates well in class discussions
- ☐ Participates well in group work
- ☐ Uses scientific thinking
- ☐ Consistently exhibits exceptional thought and effort in tasks
- ☐ Other ____

Teacher instructions

Review and apply

The following section contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 2*, they will reflect on their learning, apply what they learned about experimental design to a new activity, and read about the importance of salt. An optional reading explains, on the molecular level, what happens when different crystals dissolve and recrystallize. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned in the crystals investigation.

Distribute *Review and apply: Let's Review*, p. 112, and give students an opportunity to respond to the prompts on their own. Once students think about and write their ideas, discuss what students learned about controlling variables in the solubility and recrystallization tests.

Science in action!

2. Have each student conduct the appearance, crushing, solubility, and recrystallization tests to compare sodium chloride to potassium chloride.

Show students containers of salt and salt substitute made from potassium chloride. Tell them that the salt that is often added to their food has a chemical name—sodium chloride. Salt substitute is chemically different, it's potassium chloride. Explain that some people need to limit the amount of sodium in their diet, so are encouraged to use potassium chloride instead. Challenge students to conduct all of the tests they conducted on the crystals during this investigation on both the sodium chloride and the potassium chloride. This activity and the corresponding *Review and apply* worksheet can serve as a summative assessment, evaluating the students' ability to control variables and conduct all of the tests introduced in this investigation.

Distribute *Review and apply: Science in action!*, pp. 113–114. This activity may be conducted either at home or in class.

3. Have each student design and conduct a test to compare how sodium chloride and potassium chloride solutions absorb into a surface.

After students complete their appearance, crushing, solubility, and recrystallization tests, they will design an absorption test. First, students will need to make solutions using potassium chloride and sodium chloride. Variables should be controlled when making the solutions. Students should use the same amount and temperature of water and the same mass of sodium chloride and potassium chloride and should stir for the same length of time. Students will also need an absorbing surface, like a brown paper towel or a coffee filter. Students may choose to place a small amount of each liquid on the paper or to dip strips of paper into the solutions. Either way the solutions will absorb into the paper at different speeds.

Distribute activity sheet *Review and apply: Science in action! continued*, p. 115. This activity may be conducted either at home or in class. Make a variety of materials available. You might supply water, clear cups, brown paper towels or coffee filters, droppers, or some other suitable materials. Also give each group about 1 teaspoon each of sodium chloride (table salt) and potassium chloride (Nu-Salt®).

This activity and the corresponding activity sheet can serve as a summative assessment, evaluating students' skills in designing a fair test, identifying and controlling variables, and recording observations.

4. When students have completed their experiments, compare experimental designs and observations.

Have students join small groups and describe their experiments and their results. With the whole class, ask students to describe any similarities or differences between their experiment and someone else's. If the design of the experiment was similar, did students have similar results? Did students notice a difference in the way potassium chloride and sodium chloride absorbed into a particular surface?

Think about it

5. Have students read about salt and then answer questions.

Distribute *Review and apply: Think about it*, pp. 116–119. Tell students that salt (sodium chloride) is pretty inexpensive and is available in just about any store that sells food. But once it was very expensive and hard to come by. Students will read about salt, find out why people and animals need it, learn how it's used, and discover where it comes from. Then they will answer questions about the reading.

For additional information about salt, go to
www.inquiryinaction.org

What's going on here? (*optional*)

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about dissolving and recrystallization on the molecular level and answer questions about the reading.

Distribute *Review and apply: What's going on here?*, pp. 120–124. This reading describes the structure of the water molecule and explains how this structure helps it to dissolve sugar, salt, and the other ionic substances used in this investigation. It also explains the process of recrystallization.

This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level. Discuss the process of dissolving and recrystallization with students based on the reading.

Material to support this reading can be found at
www.inquiryinaction.org

Name: ____________________________

Let's review

At the beginning of this investigation a student noticed that salt and sugar look pretty similar. She decided to look at them and at Epsom salt and MSG with a magnifier. You did the same thing and did other tests to discover the identity of an unknown crystal.

1. One of the tests you did to learn about and compare the crystals was a dissolving test. Describe how you conducted the dissolving test. Explain what you did to control variables that might affect dissolving such as amount of water, temperature of water, amount of swirling, etc.

2. You also did a recrystallization test. Explain what you did to control the variables in this test.

Name: ___________________________

Science in action!

How does potassium chloride compare to sodium chloride?

When we think of salt, we usually think of the salt we sprinkle on our french fries, eggs, or other food. This salt is sodium chloride. For a long time, sodium chloride was the only salt you could buy to use on your food. But people with high blood pressure or certain other medical conditions are supposed to limit the amount of sodium in their diet. So food scientists tried a different kind of salt called *potassium chloride* to see if it could be used instead of sodium chloride. These days, you can find potassium chloride in most grocery stores where it is sold as a salt substitute.

In order to compare potassium chloride to sodium chloride, you will need to conduct several tests on each of the crystals. First, conduct the appearance, crushing, solubility, and recrystallization tests on potassium chloride and sodium chloride. Then explain your test and record your observations using the chart on the next page.

Review and apply worksheet

Name: ______________________________

Compare potassium chloride to sodium chloride

Test	How did you conduct the test?	What did you observe?
Appearance		
Crushing		
Solubility		
Recrystallization		

Name: ____________________________

Science in action! (*continued*)

How does potassium chloride compare to sodium chloride?

Design your own absorption test

The way a potassium chloride or a sodium chloride solution absorbs into a particular surface might show some interesting similarities or differences. Develop an absorption test of your own. You might use water, clear cups, food coloring, paper towels, coffee filters, droppers, or some other materials available in your classroom or home.

1. Describe what your absorption test might be like.

____

____

____

____

2. How will you control variables in your absorption test?

____

____

____

Conduct your absorption test

Record your observations

Potassium chloride	Sodium chloride

Review and apply worksheet Name: ____________________________

Think about it

Vocabulary	
volume	recrystallize
absorb	evaporate
excrete	preservative
dissolve	dilute

Salt

Salt (sodium chloride) is a lot more interesting than we give it credit for. Did you know that salt wasn't always so easy to get and used to be very valuable? In fact in ancient Rome, soldiers used to be paid with an amount of salt called a *salarium*. This is where the word "salary" comes from. Salt was considered so precious that kings and queens had elaborate silver containers, called *salt cellars*, specially made to hold salt at the table. In fact, the expression "salt of the earth" describes a particularly kind and good person.

Who needs salt?

Humans and other animals need salt. Animals in the wild who find a salt deposit will travel back to it over and over again to lick up some salt. In the past, animals have created paths that people also followed to get the salt. Some of these paths eventually were made into roads, which people used to trade and sell salt. Sometimes whole towns would start because of these salt deposits and roads.

The body requires a certain amount of salt to function properly. Salt plays an important role in helping to maintain the volume of fluid in the blood stream, cells, and tissues. The sodium from salt also plays an important role in nerve function. The digestive, circulatory, and excretory systems help balance the amount of salt taken in and the amount absorbed and excreted. Sometimes this balance can be thrown off by extreme sweating or by not taking in enough fluids.

What happens when there is too much salt?

Some animals have special ways to balance the salt in their bodies. Salt water fish take in salty ocean water but need to get rid of the extra salt in order to survive. They excrete the extra salt in salty urine and through specialized cells in their gills. Freshwater fish have the opposite problem. They take in a lot of water but not much salt. With their kidneys, they excrete large quantities of dilute urine and take in salt through special salt-absorbing cells in their gills.

Name: ___________________________

Sometimes, other animals that live near salt water take in too much salt and it needs to be removed from the body. Sea birds that eat a diet high in salt or drink salt water have large areas near their eyes called *salt glands.* These glands remove the extra salt by secreting a solution through the nose that is very high in salt and low in water. Because these glands are not fully developed in the young, adult birds will sometimes dunk food into freshwater before giving it to their babies.

Reptiles like sea turtles also take in a great deal of salt when they eat and drink. They have salt glands in their eye sockets which allow them to excrete leftover salt. The amount of salt in their tears can be twice as much as found in sea water. When female turtles nest to have babies, it looks like they are crying. Actually, they are excreting salt through their eye glands.

Uses for salt

As you probably know, salt isn't just for making food taste better. One of its main uses in history was as a preservative. Meat and fish were treated with salt, which made it harder for bacteria to live and grow on the food. This allowed food to be transported over greater distances and to last longer while being stored. Salt is also used for purposes that have nothing to do with food. It is used in making soap and detergent, dying fabric, making paper, and in many other products and processes. Thousands of tons of salt are used to make roads safer for driving when there is snow and ice in the winter.

Where does salt come from?

There are two huge sources of salt on Earth. One is the salt that is dissolved in oceans and seas. The other is deposits of solid rock salt called *halite* which is under the earth's surface. To get salt from ocean and sea water, the water is placed in large open pools and allowed to evaporate. This allows the sodium ions and the chloride ions dissolved in the water to recrystallize to form salt crystals.

There are two different methods for getting salt from beneath the earth. One technique is to drill down into a salt deposit and pump in large amounts of water to dissolve some of the salt. This salty water is then pumped up to the surface and allowed to evaporate, allowing the dissolved salt to recrystallize.

The other method is like underground mining where long mine shafts and tunnels are built to get down into the salt deposit. Machinery is used to blast, scrape, and dig the solid salt out of the ground. This salt is then sent up to the surface where it is crushed and processed.

Think about it (*continued*)

1. The reading suggests that salt deposits could have caused entire towns to be built. This is because…
    a. Where there is salt, there is water.
    b. Where there is salt, it is easier to grow crops.
    c. Animals like salt.
    d. Salt was very useful and valuable.

2. In history, salt has been used as a preservative. Re-read the "Uses for salt" section. What is the main reason for using a preservative?
    e. Makes food taste better
    f. Makes it harder for bacteria to live and grow
    g. To help make roads safer in winter
    h. To make soap and detergent

3. Salt is found dissolved in the oceans. In this sentence, what does the word "dissolve" mean?
    a. Water and salt are completely mixed, making salt water.
    b. Salt is found on the shore line.
    c. Salt is found in the ocean.
    d. Salt is also found in the body systems, including the digestive system.

4. What is the most likely reason that the author included the information about salt?
    a. To tell readers how much salt should be used on their food
    b. To explain to readers where they can find salt
    c. To teach readers about the importance of salt
    d. To encourage readers to put more salt on their foods

5. There are two places we can find salt on the earth. The type of salt that is found in solid rock is called…
    a. halite.
    b. halitosis.
    c. heme.
    d. Rockis saltis.

6. According to the details in the passage, what do sea turtles do to eliminate extra salt from their bodies?
    a. They remove the salt through their salt gills.
    b. They remove the salt through their tears.
    c. They remove the salt through their nose.
    d. They leave the extra salt in their bodies.

Name: ___________________________

Think about it (*continued*)

7. People like the taste of salt, but we also need to have a certain amount of it in our bodies to keep us healthy. What is one of the roles of sodium in our bodies?

8. Animals that live in salt water need to get rid of excess salt. What is one way they do this?

9. Salt makes food taste better. Name at least two other uses for salt.

10. What are the two main sources of salt on Earth?

Review and apply worksheet Name: ____________________________

What’s going on here?

In this investigation, you saw that the amount of a substance that dissolves in water is different for different substances. You can begin to understand why this is by looking at both water and the substances being dissolved on the molecular level.

Dissolving

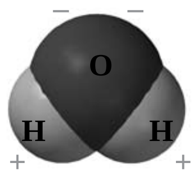
The first thing to understand about dissolving is that you have to look at the liquid doing the dissolving (*solvent*) as well as the substance being dissolved (*solute*). Dissolving depends on the interaction between the molecules of the solvent and the molecules of the solute.

Since you used water to dissolve the different substances and since dissolving occurs on the molecular level, you need to first look at the molecular structure of water.

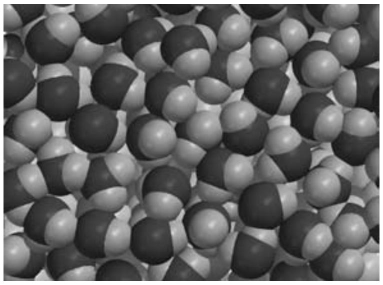
Water molecules

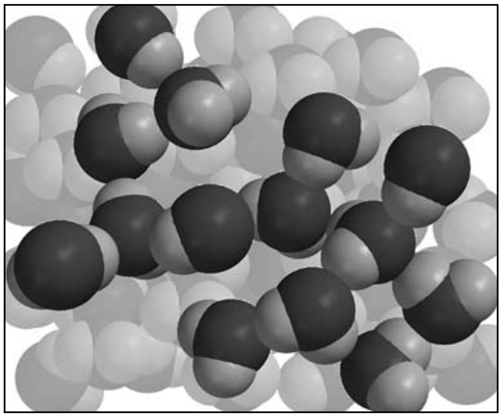
A water molecule is made of two hydrogen atoms bonded to one oxygen atom. All atoms, including hydrogen and oxygen, have one or more *protons* in the center, or *nucleus*, of the atom. Atoms also have *electrons* that move around the nucleus. Protons have a positive electric charge, and electrons have a negative electric charge. An atom has the same number of electrons as it has protons.

Because of the characteristics of oxygen and hydrogen and how they are bonded together in the water molecule, there is a slight positive charge near the hydrogen atoms and a slight negative charge near the oxygen atom.



The smaller illustration to the right shows that the molecules in liquid water associate very closely with one another. The larger illustration shows how the water molecules tend to orient themselves according to their opposite charges. Notice how the positive area of one water molecule is attracted to the negative area of another.





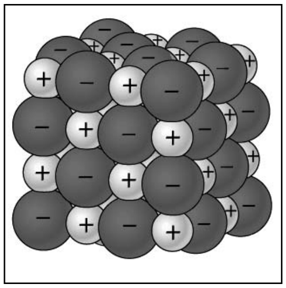
Review and apply worksheet

Name: ___________________________

Salt is made from positive and negative ions

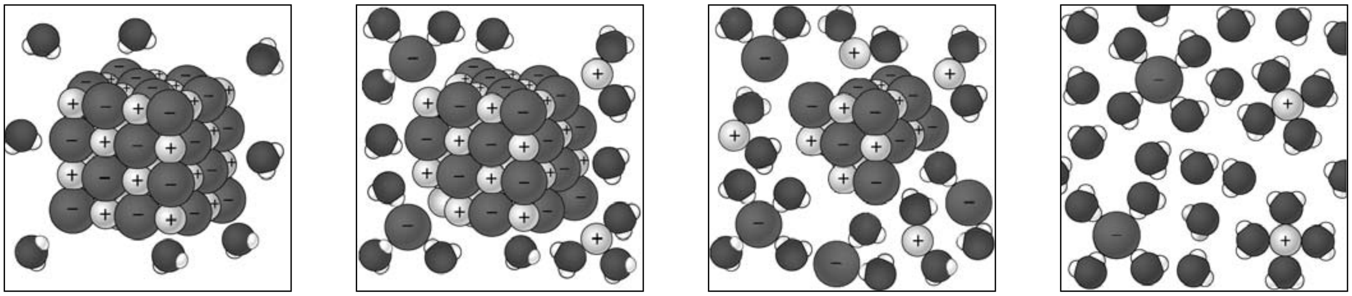
Regular table salt is called sodium chloride. Its chemical formula is NaCl. *Na* stands for sodium and *Cl* stands for chlorine. When the sodium atom and the chlorine atom react, the sodium ends up with a positive charge and the chlorine ends up with negative charge. The positive sodium and the negative chloride are called *ions*. Because positive and negative attract, the sodium (Na^+) and chloride (Cl^-) ions attract each other and bond together. This is what keeps the sodium and chloride ions together to make a piece of salt.

This illustration is a model of a salt crystal drawn to give you a basic idea of what a salt crystal looks like. However, you should know that there are far more ions in a single salt crystal than this picture shows. The approximate number of sodium (Na^+) and chloride (Cl^-) ions in a typical crystal of ordinary table salt is actually around 1 million trillion of each.



How water dissolves salt

When salt is placed in water, the positive and negative ends of the water molecules are attracted to the negative chloride and positive sodium ions. When the attraction that the water molecules and an ion have for each other overcomes the attraction that the ion has for the other ions in the salt, that ion is pulled away and dissolves. So when water dissolves salt, it pulls away individual sodium and chloride ions.



Sodium chloride dissolving in water

Water can dissolve many substances made from ions

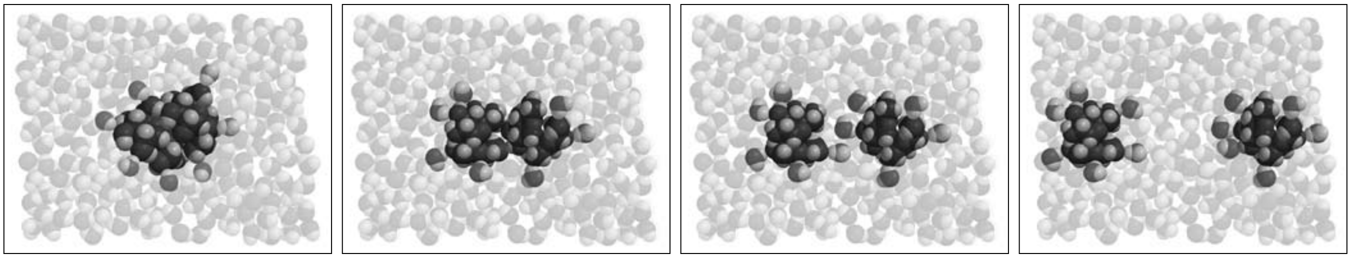
MSG and Epsom salt are also made of ions with a positive and negative charge. The ions that make up these different substances all have a different size, weight, strength of attraction, and overall structure. Because of this, they pack together differently to form their crystal shape. When water molecules interact with these substances, all these differences make it either easier or harder for the water molecules to pull the ions away and dissolve them. That's why these substances dissolve to different extents and why you see some differences in how much is left undissolved of each substance.

Review and apply worksheet

Name: ____________________________

Dissolving sugar

The kind of sugar you used in the activities is called *sucrose*. The chemical formula for sucrose is $C_{12}H_{22}O_{11}$. In the sucrose molecule, there are many positive and negative areas. Sucrose molecules are attracted to other sucrose molecules and line up next to each other because of the attraction of opposite charges. This is what keeps sucrose molecules together in a piece of sugar.



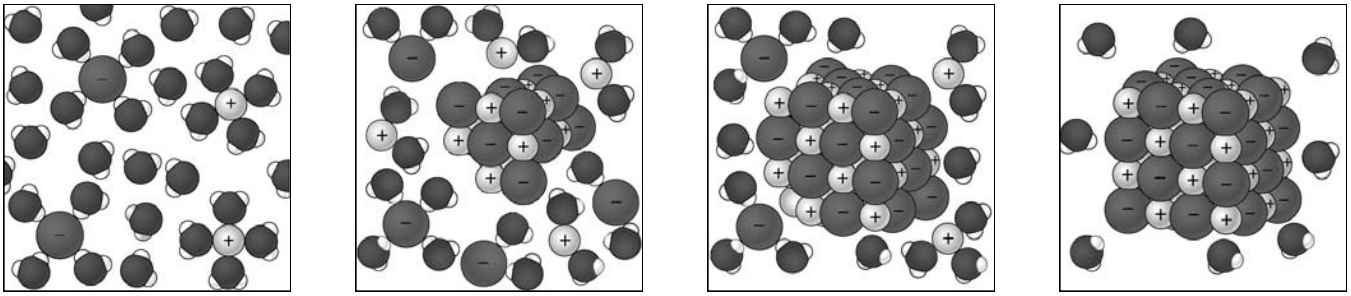
When sucrose is placed in water, the positive and negative ends of the water molecules attract the negative and positive parts of the sucrose molecule. When the attractions that the water molecules have for the sucrose molecule become stronger than the attractions the sucrose molecule has for the other sucrose molecules, the sucrose molecule is pulled away and surrounded by water molecules. At that point it is *dissolved*. So, when water dissolves sucrose, entire sucrose molecules are pulled away from each other. But, when water dissolves salt, Epsom salt, or MSG, individual ions are separated from each other.

Review and apply worksheet

Name: ____________________________

Recrystallizing

Another test you did to identify the unknown was the recrystallization test. You saw that as the water evaporated, some of the original substances recrystallized. You also saw that the different substances looked different when they recrystallized.



Sodium chloride recrystallizing from salt water

When the different substances dissolve, their ions or molecules are surrounded by water. This makes it hard for them to come together to begin to form a crystal. But as the water evaporates, there are fewer water molecules surrounding the ions or molecules. This makes it easier for them to come together and bond according to their positive and negative charges, or to recrystallize.

Once the solutions have evaporated, the resulting crystals look different from one another. This is because they are made of different ions with different structures and sizes that bond together in different arrangements. Both the unknown (coarse kosher salt) and the table salt look alike when they recrystallize because they are both sodium chloride.

Name: ____________________________

What’s going on here? (*continued*)

1. Explain why water is able to dissolve salt (sodium chloride).

2. Explain why the amount of salt and kosher salt that dissolved was so similar.

3. Why do you think the salt and kosher salt looked similar when they recrystallized but looked different from the other substances?

Cool factoid

In the *Think about it* section, you read that salt is a good preservative for food. Well it’s also a good preservative of people. Ancient Egyptians used sodium chloride and other types of salt to make a paste for preparing mummies. Also, well-preserved bodies of people who lived over 2,000 years ago have been found in salt deposits in different parts of the world.

Investigation 3

Physical properties and physical change in liquids

How can you tell if liquids that look the same are really the same or different?

Summary

Even though different liquids may look similar, they act differently when placed on various surfaces. Students will compare the way four known liquids and an unknown liquid bead up, spread out, or absorb into different surfaces. They will use their observations to identify the unknown liquid. Students will then conduct another test by comparing how each known liquid (colored yellow) combines with water (colored blue). Students will discover that each liquid has its own characteristic way of combining with water. Then, as a culminating challenge, students will use this characteristic property to identify yellow liquids, each of which will be re-labeled **A**, **B**, **C**, and **D**. The activities throughout the investigation emphasize the characteristic properties of liquids, identifying and controlling variables, making observations, and analyzing results to answer a question.

Investigation 3: Physical properties and physical change in liquids

Key concepts for students

- Different liquids have different characteristic properties
- A solution made from water and another substance will have characteristics based on the interaction between water and the other substance.
- The way a liquid behaves on a surface depends on the characteristics of the liquid and the characteristics of the surface.
- The way a liquid combines with water depends on the characteristics of the liquid and the characteristics of water.

Learning objectives

Students will be able to:

- Recognize that different liquids have unique characteristic properties.
- Identify and control variables as they design and conduct tests on each of the liquids.
- Identify unknown liquids based on the results of their tests.
- Understand that the way liquids behave on a surface has to do with the interaction between the characteristics of the liquid and the characteristics of the surface.
- Understand that the way liquids combine with water has to do with the interaction between the characteristics of the liquid and the characteristics of water.

Investigation questions

How can you tell if liquids that look the same are really the same or different?

- Can you distinguish between four clear colorless liquids based on the way they look on a brown paper towel?
- How can you identify an unknown liquid based on the way it behaves on different paper surfaces?
- Can you tell a difference between liquids by the way they look when they combine with water?
- How can you use the characteristic way each liquid combines with water to identify the unknown liquids?

Assessment

The assessment rubric *Physical properties and physical change in liquids*, pp. 153–154, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and Apply* section, pp. 155–168.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Types of investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

3.1 Look-alike liquids
3.2 Developing tests to distinguish between similar-looking liquids
3.3 Using color to see how liquids combine
3.4 Using the combining test to identify the unknown liquids

Each group will need

	Activities			
	3.1	3.2	3.3	3.4
Tap water in cup	Colorless ●	Colorless ●	Yellow ●	Yellow ●
Isopropyl rubbing alcohol, 70%, in cup	Colorless ●	Colorless ●	Yellow ●	Yellow ●
Detergent solution in cup	Colorless ●	Colorless ●	Yellow ●	Yellow ●
Salt water in cup	Colorless ●	Colorless ●	Yellow ●	Yellow ●
Unknown in cup		Colorless ●		
4 Yellow solutions in cups labeled A, B, C, D				●
Blue tap water in cup			●	●
Labeled droppers	●	●	●	●
Droppers labeled A, B, C, D				●
Plastic bag	●			
Brown paper towel	●	●		
Wax paper		●		
Notebook paper, copy paper, or newspaper		●		
Construction paper		●		
Crayons or colored pencils			●	●
Toothpicks			●	●
Pencil	●	●		
Paper towels			●	●

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- The same solutions are used in all four activities in this investigation. However, in *Activities 3.1* and *3.2* they are colorless. In *Activities 3.3* and *3.4*, the solutions are colored yellow so that students can observe the movement of the solutions when combined with water, which will be colored blue.
- Teachers will need yellow and blue food coloring to prepare the solutions for *Activities 3.3* and *3.4*.
- You will need a total of three sets of water, isopropyl alcohol, detergent solution, and salt water to conduct all of the activities. The instructions for making these solutions are on pages 133, 143, and 149.
- You could use small plastic containers with lids, like fast food restaurant condiment cups, as source cups for the solutions. Use a push pin to make a hole in each lid so that a dropper can be inserted through the lid. Small cups without lids are also fine. However, lids help prevent spilling and help conceal the identity of the unknown.
- Mineral oil will be required for the *Review and apply: Science in action!* activity, pp. 159–160.

Science background information for teachers

The *physical properties* of a liquid are characteristics such as color, density, and surface tension. Some other physical properties of liquids that are not as readily observable are viscosity and how easily the liquid dissolves a particular solid.

Sometimes, these physical properties are able to change. A physical change is a change that alters the form or appearance of a substance without changing the chemical composition. One example of physical change is when a liquid changes to a solid by freezing. Other examples are evaporating, absorbing into another material, or mixing with another liquid or solid to become part of a solution. In all of these cases, the substance changes but does not change its identity. The physical properties of a liquid and the way it undergoes physical change are characteristic properties that can be used to distinguish the liquid from other liquids.

For videos, animations, and other information related to this investigation, go to
www.inquiryinaction.org

Chemistry concepts

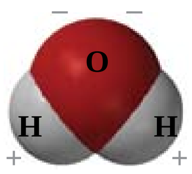
- A water molecule has an area of positive charge and an area of negative charge.
- Water molecules attract each other based on the attraction of these oppositely charged areas.
- The attractions among water molecules contribute to water's strong surface tension.
- The way water behaves on a surface is determined by water's surface tension and the way water interacts with the molecules of the surface.
- A solution made of water and another substance has characteristic properties based on the interaction between water molecules and the molecules of the substance.
- The way a solution behaves on a surface is determined by the solution's surface tension and the way it interacts with the molecules of the surface.
- The way a solution mixes with water is determined by the densities of the solutions and the water, and by the way the molecules or ions in the solution interact with water molecules.

3.1 Look-alike liquids
3.2 Developing tests to distinguish between similar-looking liquids

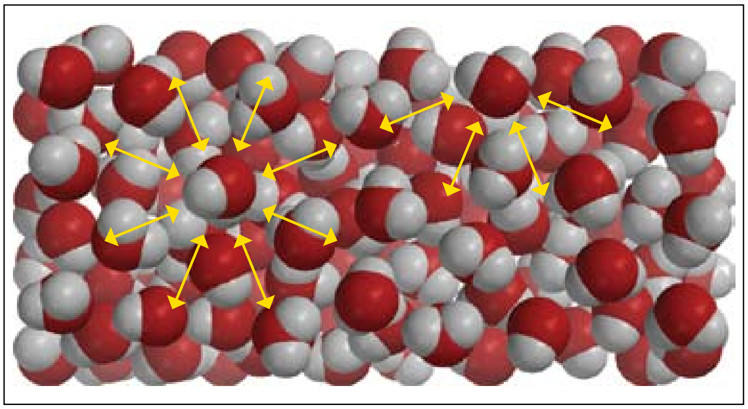
On the wax paper, water and salt water both bead up while isopropyl alcohol and detergent solution both spread out. This beading up or spreading out is influenced to a large degree by the surface tension of the different liquids and also by the way they interact with the molecules of the different surfaces. Since all the liquids contain water, it's important to understand water's *surface tension* before looking at how other substances in the water might affect this surface tension.

Water's surface tension

Because of the characteristics of oxygen and hydrogen and how they are bonded together in the water molecule, there is a slight positive charge near the hydrogen atoms and a slight negative charge near the oxygen atom making water a polar molecule. Water molecules associate with each other based on the attraction of these opposite charges. For a more detailed explanation of the polarity of water, see pp. 18–19.



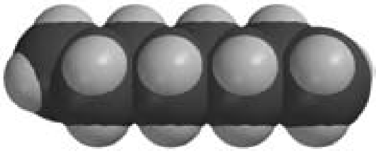
Water



Surface tension

Water molecules within a sample of water are in constant motion and are closely associated with one another based on their polar attractions. Since water molecules in the interior of a sample of water are surrounded by other water molecules, they can be attracted in every direction. But water molecules at the surface have no water molecules attracting them from above. These surface molecules can only be attracted down and in. Since they are attracted in a more uniform or consistent direction, they form a more stable arrangement at the surface called *surface tension*.

Water on wax paper



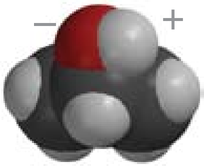
Carbon–hydrogen Chain

Water beads up on wax paper. This is due to the attraction of water molecules to each other and water's strong surface tension. The wax on wax paper is made up of carbon and hydrogen atoms like in this space-filing model. When carbon and hydrogen bond to each other, there is only a very slight positive and negative charge. Therefore, water molecules are more attracted to each other than they are to the surface of wax paper. This, plus water's strong surface tension, makes the water bead up.

Salt water on wax paper

Saltwater beads up on wax paper the way water does. Salt water has negative chloride ions and positive sodium ions dissolved among the water molecules. These positive and negative ions are attracted to the negative and positive areas of water molecules. This interaction of the ions with the water molecules doesn't interfere with water's surface tension allowing the salt water to bead up on the wax paper.

Isopropyl alcohol on wax paper

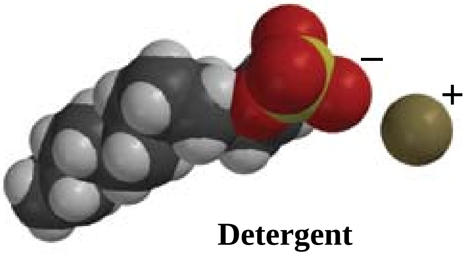


Isopropyl alcohol

The isopropyl alcohol you get in most stores is a solution of alcohol in water. A common mixture is 70% alcohol and 30% water. As you can see in this space-filling model of the alcohol molecule, isopropyl alcohol, like all alcohols, has an oxygen atom bonded to a hydrogen atom. This results in the oxygen having a slight negative charge and the hydrogen having a slight positive charge. This is similar to the oxygen–hydrogen bond in water. But, like wax, the rest of the alcohol molecule is made up of carbon and hydrogen atoms bonded together. These bonded atoms produce only a slight positive and negative charge compared to the positive and negative polar areas in a water molecule.

The alcohol spreads out on wax paper rather than beading up the way water does. This is because alcohol molecules interfere with water's surface tension. The carbon–hydrogen part of the alcohol molecule is not very attracted to water. This interferes with the normal interaction of water molecules at the surface of a drop and disrupts the surface tension.

Detergent on wax paper

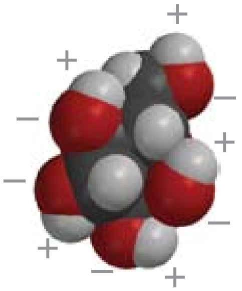


Detergent

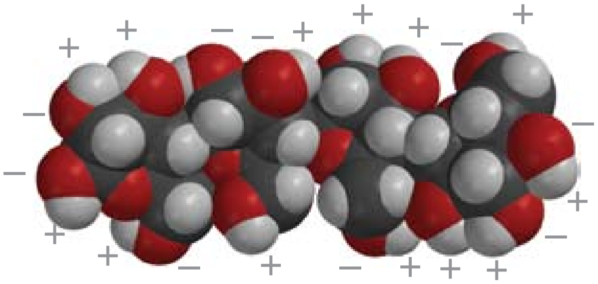
The detergent solution spreads out on the wax paper rather than beading up the way water does. Like alcohol, detergent molecules interfere with water's surface tension. A detergent molecule like the one shown at the right has a negatively charged end which is attracted to water. It also has a long carbon-hydrogen chain which is not particularly attracted to water. The large negatively charged part of the molecule disrupts the orderly arrangement of water molecules at the surface. This interferes with the normal interaction of water molecules at the surface of a drop and disrupts the surface tension.

Liquids on other papers

The degree to which a liquid absorbs into another substance, such as paper, has to do with the properties of the liquid and the properties of the paper. One aspect of absorbing has to do with the physical properties of the paper such as the size and number of pores. In addition to these physical features of the paper, the material that the paper is made of also matters. Paper is made from wood, and wood is made from cellulose. Trees make cellulose from the glucose ($C_6H_{12}O_6$) produced in their leaves.



Glucose



Cellulose

Cellulose is actually a very long molecule made up of a great many individual glucose molecules.

The space-filling model of glucose shows that it has lots of O–H bonds. These O–H bonds produce polar areas with a slight positive and negative charge. Cellulose is made up of glucose molecules. Therefore, the O–H bonds on cellulose also have polar areas of negative and positive charge. Water is attracted to these charged areas of the paper and is also attracted to itself. It is the combination of these attractions that determine water's, or any liquid's, ability to move through the pores of paper by capillary action.

So on the molecular level, a liquid's ability to move into the pore spaces of a material depends on the attraction of the molecules of the liquid for the material and on the attraction of the molecules of the liquid for each other. Based on these characteristics, the different liquids absorb into paper to different extents.

One interesting observation students will make is that the drop of salt water stays in a drop on the different papers (especially construction paper) and doesn't absorb nearly as quickly as water. One possible explanation for this is that water molecules are attracted to the polar areas of the O–H bonds in the cellulose of the paper, but are also attracted to the sodium and chloride ions from the salt. This competition for the attraction of water molecules may interfere with salt water readily absorbing into the paper.

Liquids evaporating from other papers

Students may observe the liquids evaporating at different rates from the different papers. Evaporation of a liquid occurs when molecules of the liquid gain enough energy to break away from the rest of the liquid and move into the surrounding air. One of the main factors that affects the rate of evaporation is the amount of attraction the molecules of the liquid have for each other. When the liquids have absorbed into another material, in this case paper, the attraction between the molecules of the liquid and the molecules that make up the paper will also affect the rate of evaporation. The combination of these factors determines the different rates of evaporation for each liquid.

Activity 3.3—Using color to see how liquids combine
Activity 3.4—Using the combining test to identify the unknown liquids

The yellow liquids each combine with the blue water differently because of the way the molecules that make up the liquids interact with water molecules.

Water combining with water

When the blue water and the yellow water first come into contact, the colors stay mostly separate, but have some green in the middle. The colors slowly combine and will eventually become green throughout. Since the solutions are virtually identical there are no other factors affecting mixing other than random molecular motion. This motion results in the slow mixing of the two solutions.

Salt water combining with water

The yellow salt water and blue water appear to combine quickly, resulting in a green color. The yellow salt water is more dense than the blue water and actually flows beneath it. When looking from the top, the colors appear as if they have combined. Upon closer inspection, the separation can be seen. One way to do this is to take a dropper and carefully remove the uppermost surface of the water: It will be blue! If done carefully enough, most of the blue can be removed leaving a yellow puddle beneath.

Alcohol combining with water

The isopropyl alcohol mixes into water in a unique way. Along the boundary where the two liquids meet, the yellow alcohol and blue water appear to “shake” as they combine. One explanation has to do with the different refraction of light by water and alcohol. Different liquids refract or bend light differently as it passes through the liquid. As the water and alcohol combine, the way the light bends as it passes through the changing mixture also keeps changing and gives the shaky appearance.

Detergent combining with water

When the liquids combine, the blue water seems to flow over the yellow detergent solution. The yellow seems to stay along the bottom. Mixing is slow and there may even be a small area of blue that remains for a while. There are a few possible explanations for this. The layering can be explained by the densities of the liquids: The detergent solution is more dense than the water. This explains why the blue water initially flows over the yellow detergent solution. There are two possible reasons why the yellow doesn’t seem to move much. The carbon–hydrogen chains on detergent molecules tend to orient themselves toward each other with their charged ends facing outward. These detergent molecules form microscopic clumps with water clustered around them. It may be more difficult for these clumps to move throughout the water. Another reason might have to do with the noncharged end of the detergent being more attracted to the plastic surface of the testing sheet than to the water.

Activity 3.1
Look-alike liquids

Can you distinguish between four clear colorless liquids based on the way they look on a brown paper towel?

In this introductory activity, students will compare the way water and isopropyl alcohol appear on different surfaces. After seeing that these liquids behave differently, students will be given two other clear colorless liquids—salt water and detergent solution. Students will then test all four liquids on a brown paper towel to discover the differences between them. Through the activities in this investigation, students will see that liquids have characteristic properties that can be used to identify an unknown.

Materials needed for each group

Tap water
Isopropyl rubbing alcohol (70%)
Detergent
Salt
4 Small cups
4 Droppers
Plastic bag
Brown paper towel
Pencil

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- To prevent spills, tape cups to the desk or table so that the cup and dropper do not fall over.

Preparing materials

- Use a permanent marker to label four small cups **water**, **alcohol**, **detergent**, and **salt water**.
- Use a permanent marker to label four droppers **W**(water), **A**(alcohol), **D**(detergent), and **SW**(salt water).
- Make solutions for the class according to the following procedure. These recipes make ¼ cup of each solution, which is enough for 8 groups to conduct the activity.
  - **Water**—Use ¼ cup regular tap water.
  - **Salt water**—Add 1 tablespoon salt to ¼ cup tap water.
  - **Alcohol**—Use ¼ cup 70% isopropyl alcohol. This is a common household strength.
  - **Detergent**—Add 1 teaspoon clear, colorless, liquid hand soap or detergent to ¼ cup tap water. Stir gently.
- Place about 1 teaspoon of each solution into its labeled cup. These solutions will be reused in *Activity 3.2*. Cover the solutions to store them between activities.
- Cut pieces of brown paper towel into approximately 10 × 15 cm pieces. You will need two pieces for each group.

Activity sheet

Copy *Activity sheet 3.1—Look-alike liquids*, pp. 136–137, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 153–154. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 3.1
Look-alike liquids

Question to investigate

Can you distinguish between four clear, colorless liquids based on the way they look on a brown paper towel?

Take a closer look

1. Have students read the introductory story on *Activity sheet 3.1* and compare the appearance of water and rubbing alcohol.

Distribute *Activity sheet 3.1—Look-alike liquids*. The student in the introductory story notices that although water and alcohol are both clear, colorless liquids, they look different on different surfaces. Give students an opportunity to compare how these liquids look on different surfaces for themselves. They can use the tests described below.

Procedure

1. **Plastic bag test:** Use droppers labeled **W** and **A** to place 1 drop each of *water* and *alcohol* on a plastic bag at the same time. Record your observations.

2. **Side of cup test:** Carefully tilt the cup of water and use the dropper labeled **W** to place individual drops of water along the inside surface of the *water* cup. Then carefully tilt the cup of alcohol and use the dropper labeled **A** to place individual drops of alcohol along the inside surface of the *alcohol* cup. Record your observations.

3. **Brown paper towel test:** Use droppers labeled **W** and **A** to place 1 drop each of water and alcohol on a brown paper towel at the same time. Record your observations.

Expected results:	**Water**	**Alcohol**
Plastic bag	Beads up	Spreads out
Side of cup	Travels down in a bead	Flows down in a flat stream
Brown paper towel	Soaks in	Soaks in and evaporates quickly

Try this!

2. Introduce students to four clear, colorless liquids and test them on a brown paper towel.

Show students samples of each of the four clear, colorless liquids in labeled clear plastic cups. Point out that even though these liquids all look very similar, they have different characteristics and uses. Remind students that they were able to tell the difference between water and rubbing alcohol on a brown paper towel. Then ask them if they think there will be differences in the way the four liquids look on a brown paper towel.

Tell students to use each dropper only with its labeled liquid. Talk about ways to prevent contamination of the liquids in the cups. Students should be careful not to put the same dropper in more than one liquid.

Procedure

1. Use a pencil to label a piece of brown paper towel with the names of each solution.

2. With the help of your partners, use separate droppers to place 1 drop each of water, salt water, alcohol, and detergent solution on the piece of paper towel at the same time.

3. Record your observations.

3. Have students discuss their results.

Ask students: What do you notice about each of the liquids on the paper towel?

***Expected results*: The water absorbs into the paper towel a little faster than the salt water does, which stays beaded up a little longer than the water. After they begin to absorb, the water and salt water appear similar, but the water seems to wet a larger area. The detergent and alcohol leave smaller marks, but the alcohol mark has a smooth edge and the detergent has a more irregular edge. Also, the detergent mark appears darker.**

What's next?

4. Ask students what they might do to identify an unknown liquid.

Ask students questions like the following:

- Let's say that I gave you an unknown liquid that was one of the liquids you tested. Do you think the differences in the way each liquid looks on brown paper towel is great enough that you could identify the unknown liquid?
- Would you be more confident about identifying the unknown liquid if you tested it along with the other liquids on other surfaces in addition to the paper towel?

Tell students that in the next activity, you will give them an unknown sample of one of the liquids they tested, but you won't tell them which one it is. They will decide how to test these liquids on brown paper towel, wax paper, newsprint, and construction paper.

Student activity sheet
Activity 3.1

Name: ______________________________

Look-alike liquids

I had a splinter in my finger the other day. Before I tried to take it out, I held my hand over the bathroom sink and poured a little rubbing alcohol on my finger tip as a disinfectant. I got the splinter out, no problem, and then rinsed my finger off with water. I saw something that I had never noticed before. The water beaded up but the alcohol didn't. They even flowed differently down the inside of the sink and looked weird when they mixed together. There was a plastic bag in the bathroom so I put a drop of alcohol and a drop of water on the bag to see if they would look different on something else, and they did. I used a paper towel to wipe them up and they seemed to even absorb differently in the paper towel. Because water and alcohol normally look so similar, I was surprised that they would look and act differently on different surfaces.

Take a closer look

You can do a similar test with water and rubbing alcohol to see similarities and differences between them.

Can you tell the difference between water and rubbing alcohol by placing drops of each on different surfaces?

1. **Plastic bag test:** Use droppers labeled **W** and **A** to place 1 drop each of *water* and *alcohol* on a plastic bag at the same time. Record your observations.
2. **Side of cup test:** Carefully tilt the cup of water and use the dropper labeled **W** to place individual drops of water along the inside surface of the *water* cup. Then carefully tilt the cup of alcohol and use the dropper labeled **A** to place individual drops of alcohol along the inside surface of the *alcohol* cup. Record your observations.

3. **Brown paper towel test:** Use droppers labeled **W** and **A** to place 1 drop of water and alcohol on a brown paper towel at the same time. Record your observations.

Surface	Water	Rubbing alcohol
Plastic bag		
Side of cup		
Paper towel		

Name: ____________________________

Look-alike liquids (*continued*)

Try this!

You were able to tell the two look-alike liquids apart by the way single drops of each looked on a plastic bag, sliding down the side of a cup, and absorbing into a paper towel.

Can you distinguish among four clear, colorless liquids based on the way they look on a brown paper towel?

Use each dropper only with its labeled liquid. Be careful not to mix up the droppers.

1. Use a pencil to label a piece of brown paper towel with the names of each solution.

2. With the help of your lab partners, use separate droppers to place 1 drop each of water, salt water, alcohol, and detergent solution on the piece of paper towel at the same time.

What do you notice about each of the liquids on the paper towel?

Water ____

Salt water ____

Rubbing alcohol ____

Detergent ____

What's next?

You saw that you could do simple tests to see that similar-looking liquids have different characteristics. Although water and alcohol look pretty much the same, you saw that they act differently on surfaces like a plastic bag, the inside of a cup, and a paper towel. When you tested the four liquids, you controlled variables by placing the same amount of each liquid from the same height onto the paper towel at the same time. This is important when conducting a fair test. In the next activity, you will be given an unknown liquid that is the same as one of the known liquids. Testing it along with the known liquids on a few different paper surfaces and comparing their characteristics will help you identify the unknown.

Activity 3.2

Developing tests to distinguish between similar-looking liquids

How can you identify an unknown liquid based on the way it behaves on different paper surfaces?

In *Activity 3.1* students tested water, salt water, rubbing alcohol, and detergent solution on a brown paper towel. In this activity they will be presented with an unknown, which is one of the four known liquids as well as a variety of paper surfaces. Students will help develop a testing method using these surfaces to identify the unknown. They will realize that by using a combination of results from two or more tests, they can successfully identify the unknown.

Materials needed for each group

Tap water in cup
Isopropyl rubbing alcohol (70%) in cup
Detergent solution in cup
Salt water in cup
1 Additional small cup
5 Droppers (4 labeled droppers from the previous activity + 1 additional)
Construction paper
Notebook paper, copy paper, or newspaper
Brown paper towel
Wax paper
Pencil

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- Use the solutions and droppers from *Activity 3.1.*
- Use regular tap water as the unknown solution.
- Use common inexpensive construction paper. Art-quality or coated construction papers will not work well in this activity.
- To prevent spills, tape cups to the desk or table so that the cup and dropper do not fall over.

Preparing materials

- Use a permanent marker to label one small cup **Unknown**. Then place 1 teaspoon of water in this cup.
- Label one dropper **U** for the unknown liquid.
- Cut construction paper into quarters. Any color of construction paper will do.
- Cut the notebook or copy paper into quarters. If using newspaper, select areas of the paper that are either not printed or are consistently printed like the stock quotes. Avoid portions of the paper with pictures. Cut the newspaper into pieces that are about 10 × 15 cm.
- Cut the wax paper and brown paper towel into pieces that are about 10 × 15 cm.

Activity sheet

Copy *Activity sheet 3.2—Developing tests to distinguish between similar-looking liquids*, p. 141, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 153–154. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 3.2
Developing tests to distinguish between similar-looking liquids

Question to investigate

How can you identify an unknown liquid based on the way it behaves on different paper surfaces?

1. Present the unknown liquid and the other testing surfaces.

Distribute *Activity sheet 3.2—Developing tests to distinguish between similar-looking liquids.* Tell students that the unknown liquid you are giving them is either water, salt water, isopropyl alcohol, or detergent solution. Remind them that these liquids acted differently on brown paper towel, so it is possible that there will be differences on other paper surfaces like wax paper, newsprint, and construction paper.

2. Have students, in groups, develop a method for testing the liquids on the surfaces.

As you listen and talk with groups about their plans, make sure that they plan to test one surface at a time. Also be sure they are planning how they will control variables such as: using the same amount of each liquid, applied to the same surface, in the same way, from the same height, and at the same time. Once groups have had enough time to make initial plans, discuss some of these as a whole class.

Note: Students may want to place one drop of a particular liquid on each of the different testing surfaces and observe how the liquid absorbs into each. But by using the same liquid on different surfaces, it is the *surfaces* that are being compared and not the liquids. To compare the *liquids*, all five liquids must be placed on the *same* surface at the same time. This way each surface serves as its own test with all variables controlled. Any observed differences must be the result of the different characteristics of the liquids. By considering the results of all of these tests, students can identify the unknown.

3. Have students conduct their tests and record their observations.

Remind students to use a different dropper for each liquid. Students should be sure that they do not mix up the droppers.

Procedure

1. Use a pencil to label five areas on a piece of brown paper towel.
2. Pick up a small amount of each liquid in its dropper.
3. At exactly the same time and from the same height, squeeze 1 drop of each liquid into its labeled area. Watch the liquids absorb for about 1 minute.
4. Record any observations that give you information about the possible identity of the unknown.
5. Repeat Steps 1–4 for wax paper, newspaper, and construction paper.

Let students know that they should repeat tests, if necessary, to give them enough information so that they are sure of the identity of the unknown.

After recording their observations, students may notice that the rubbing alcohol has evaporated from the brown paper towel. Students may be interested to see that each liquid has its own characteristic rate of evaporation.

4. Discuss student observations and have them identify the unknown.

Expected results:

The water and salt water will bead up on wax paper, while the detergent and alcohol will spread out and flatten. The drops behave similarly on the other three paper surfaces. The water absorbs into the papers faster than the salt water does, which stays beaded up longer than the water. This difference is most distinct on the construction paper. After the water and salt water begin to absorb into brown paper towel, newsprint, or construction paper, the water seems to wet a larger area. The detergent and alcohol leave smaller marks, but the alcohol mark has a smooth edge and the detergent has a more irregular edge. Also, the detergent mark appears darker.

If allowed to evaporate, the rubbing alcohol evaporates first. Although the water and salt water are similar, the water evaporates before the salt water. The detergent solution evaporates the slowest.

Ask students what they think is the identity of the unknown and have them explain what evidence led them to that conclusion.

Note: Some students may have difficulty deciding if the unknown is water or salt water. However, if they focus on testing the unknown along with water and salt water, students will see differences. Water absorbs into brown paper towel, newsprint, and especially construction paper somewhat faster than salt water does. The salt water stays beaded up longer. In an evaporation test, water will evaporate a little bit more quickly than salt water.

Name: ______________________________

Developing tests to distinguish between similar-looking liquids

How can you identify an unknown liquid based on the way it behaves on different paper surfaces?

Work with your group to plan how you will test the liquids on brown paper towel, wax paper, newsprint, and construction paper so that you can identify the unknown. Write your basic plan here. Remember to say what you will do to make this test as fair as possible.

____

____

____

As you test each paper surface, write what you think the unknown might be and explain why you think so.

	What do you think the unknown might be?	What do you see to make you think this?
Brown paper towel		
Wax paper		
Newsprint		
Construction paper		

Based on your observations, what do you think is the identity of the unknown?

____

Activity 3.3
Using color to see how liquids combine

Can you tell a difference between liquids by the way they look when they combine with water?

In this and the following activity, students will use a different method to observe another characteristic property of water, salt water, alcohol, and detergent solution. The liquids will be colored yellow so that students can observe the different ways they combine with water that has been colored blue. After carefully observing the combining liquids in this activity, students will be able to identify these same yellow liquids, labeled **A**, **B**, **C**, and **D**, in *Activity 3.4.*

Materials needed for each group

Tap water
Isopropyl rubbing alcohol (70%)
Detergent
Salt
5 Droppers (4 labeled droppers from the previous activities + 1 additional)
5 Small cups (4 labeled cups from the previous activities + 1 additional)
Crayons or colored pencils
Toothpicks
Paper towels
Yellow food coloring
Blue food coloring

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- Reuse labeled cups and droppers from *Activities 3.1* and *3.2*.
- Only the teacher will need yellow and blue food coloring when preparing the solutions.
- To prevent spills, tape cups to the desk or table so that the cup and dropper do not fall over.

Preparing materials

- Make new solutions for the class according to the following procedure. These recipes make ¼ cup of each solution, which is enough for 8 groups to conduct the activity.
    - **Water**—Use ¼ cup regular tap water.
    - **Salt water**—Add 1 tablespoon salt to ¼ cup tap water.
    - **Alcohol**—Use ¼ cup 70% isopropyl alcohol. This is a common household strength.
    - **Detergent**—Add 1 teaspoon clear, colorless, liquid hand soap or detergent to ¼ cup tap water. Stir gently.
- Add 2 drops of yellow food coloring to each solution
- Place about 1 teaspoon of each solution into its labeled cup. These solutions will be reused in *Activity 3.4* along with another set of solutions (p. 149). Cover the solutions to store them between activities.
- Add 4 drops of blue food coloring to ½ cup of tap water.
- Label one small cup **water** for each group.
- Label one dropper **W** for the blue water.
- Then place about 2 teaspoons of this blue water into the newly labeled cups.

Testing sheet

Make 3 or 4 copies of *Testing sheet 3.3—Using color to see how liquids combine*, p. 146. (This page contains two testing sheets, and each group will need only one.) Cut along the dotted lines and laminate each testing sheet. If you do not have access to a laminating machine, place each chart in a sandwich-sized zip-closing plastic bag, seal it, and have student groups tape each bag to the desk or table. These testing sheets can be reused.

Activity sheet

Copy *Activity sheet 3.3—Using color to see how liquids combine*, p. 147, and distribute one per student when specified in the activity. Students will refer to this completed activity sheet as they attempt to identify the unknown liquids in *Activity 3.4*.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 153–154. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 3.3
Using color to see how liquids combine

Question to investigate

Can you tell a difference between liquids by the way they look when they combine with water?

1. Have students combine a small amount of each of the yellow liquids with blue water.

As you explain the following procedure, discuss with students the importance of using each dropper for one liquid only so that liquids are not accidentally mixed in the cups. Students should also use a clean toothpick as they combine each pair of liquids. Point out that the test would be most fair if they pulled the blue liquid to the yellow liquid each time.

Distribute *Activity sheet 3.3—Using color to see how liquids combine* along with one laminated *Testing sheet 3.3—Using color to see how liquids combine* for each group. Students should use yellow, blue, and green pencils to record their observations on the activity sheet as each pair of liquids combines. Students should also write a descriptive caption for each drawing that gives information not shown in their drawings, like "the ends stayed yellow and blue for awhile with a green area in the middle and eventually all turned green." The completed activity sheet will be used in *Activity 3.4* as students attempt to identify the four unknown yellow liquids.

Procedure

The procedure below is not provided for students in the activity sheet. Explain to students what they will do by showing them. Demonstrate how to hold the toothpick horizontally to pull one large drop of blue water toward one of the yellow drops. You may use the overhead to show this. Once groups are working, check to see that students add enough liquid to *completely fill* each circle on the chart. Also be sure that students use the toothpick only to move the blue drop of water toward the yellow drop. They should not use the toothpick to stir the liquids.

1. Add drops of each liquid to its labeled circle to completely fill each circle on the chart. Depending on your dropper, you may need to add about 5 drops or more.

2. Then, use a toothpick to pull the blue water toward the yellow water. It may take a few tries to get them to join. Instead of holding the toothpick straight up and down, it is helpful to hold it more horizontally so more of the toothpick touches the blue water. As soon as the two drops meet, lift the toothpick away and discard it. Watch the two drops combine on their own. *Do not stir.*

3. Record your observations.

4. When the drawings and captions are complete for the first pair of liquids, combine the second pair and record your observations.

5. Continue testing the remaining pairs in this manner.

2. Have students discuss their observations.

Ask students to describe what happened as each pair of liquids combined.

***Expected results*:**

- **Water + Water**
  Colors do not combine completely. A region turns green in the middle, while the ends of the merged liquids remain the original yellow and blue.
- **Water +Salt water**
  Colors combine almost immediately as evidenced by the quick change to green throughout.
- **Water + Alcohol**
  The yellow and blue liquids appear to "shake" for a time as they combine.
- **Water + Detergent**
  Colors combine at a medium rate and result in a more spread-out area of light green.

Ask students whether they think they could use this test to identify the four yellow liquids even if they were unknown.

Testing sheet 3.3

Using color to see how liquids combine

1	2	3	4
Blue	Blue	Blue	Blue
Water	**Water**	**Water**	**Water**
○	○	○	○
○	○	○	○
Water	**Salt water**	**Alcohol**	**Detergent solution**
Yellow	Yellow	Yellow	Yellow

Testing sheet 3.3

Using color to see how liquids combine

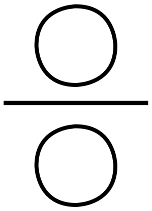
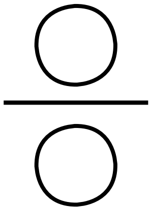
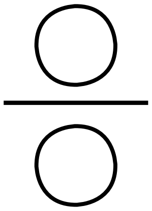
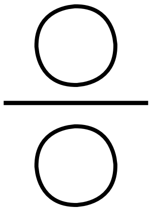
1	2	3	4
Blue	Blue	Blue	Blue
Water	**Water**	**Water**	**Water**
○	○	○	○
○	○	○	○
Water	**Salt water**	**Alcohol**	**Detergent solution**
Yellow	Yellow	Yellow	Yellow

Student activity sheet
Activity 3.3

Name: ______________________________

Using color to see how liquids combine

Can you tell a difference between liquids by the way they look when they combine with water?

Draw what the drops looked like when they joined together.	Describe how the drops combined.
Blue Water Yellow Water 	
Blue Water Yellow Salt water 	
Blue Water Yellow Rubbing alcohol 	
Blue Water Yellow Detergent solution 	

Activity 3.4
Using the combining test to identify the unknown liquids

How can you use the characteristic way each liquid combines with water to identify the unknown liquids?

In this investigation, students have seen that liquids absorb into different surfaces and combine with water in characteristic ways. As a culminating challenge, students will use their recorded observations from *Activity 3.3* as they test four unknowns and try to identify them. The characteristic way each of the household liquids combines with water will allow students to correctly identify these same liquids, relabeled A, B, C, and D.

Materials needed for each group

Colored solutions from *Activity 3.3* (4 yellow + 1 blue)
Tap water
Isopropyl rubbing alcohol (70%)
Detergent
Salt
9 Droppers (5 labeled from *Activity 3.3* + 4 additional droppers)
4 Additional small cups
Crayons or colored pencils
Toothpicks
Paper towels
Yellow food coloring

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- Only the teacher will need yellow food coloring when preparing the solutions.
- To prevent spills, tape cups to the desk or table so that the cup and dropper do not fall over.
- Reuse solutions and droppers from *Activity 3.3.*

Preparing Materials

- Make another set of solutions for the class according to the following procedure. These recipes make ¼ cup of each solution, which is enough for 8 groups to conduct the activity.
    - **Water—**Use ¼ cup regular tap water.
    - **Salt water—**Add 1 tablespoon salt to ¼ cup tap water.
    - **Alcohol—**Use ¼ cup 70% isopropyl alcohol. This is a common household strength.
    - **Detergent—**Add 1 teaspoon clear, colorless, liquid hand soap or detergent to ¼ cup tap water. Stir gently.
- Add 2 drops of yellow food coloring to each solution
- Label 4 cups and 4 droppers **A**, **B**, **C**, and **D**. These will be used with the "unknown" liquids.
- Decide which yellow solutions will be **A**, **B**, **C**, and **D**, and write down your choice. Be sure to keep the identity of each solution a secret until students have completed this activity. The following is an example:
    - **A** = Salt water
    - **B** = Detergent
    - **C** = Alcohol
    - **D** = Water
- Place about 1 teaspoon of each newly made yellow solution into its labeled cup (**A**, **B**, **C**, or **D**) for each group. Make more blue water if necessary.

Testing sheet

Make three or four copies of *Testing sheet 3.4—Using the combining test to identify the unknown liquids*, p. 151. (This page contains two testing sheets and each group will need only one.) Cut along the dotted lines and laminate each testing sheet. If you do not have access to a laminating machine, place each chart in a sandwich-sized zip-closing plastic bag, seal it, and have student groups tape each bag to the desk or table. Students will also need laminated *Testing sheet 3.3* from the previous activity.

Activity sheet

Copy *Activity sheet 3.4—Using the combining test to identify the unknown liquids*, p. 152, and distribute one per student when specified in the activity. Students will need the activity sheet they completed during *Activity 3.3* as they attempt to identify the unknown liquids in this activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 153–154. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 3.4
Using the combining test to identify the unknown liquids

Question to investigate

How can you use the characteristic way each liquid combines with water to identify the unknown liquids?

1. Introduce the unknown liquids and discuss strategies to identify each.

Introduce students to the yellow unknown liquids labeled **A**, **B**, **C**, and **D**. Explain that each of these liquids is one that they combined with blue water in the previous activity. Ask students what they might do to identify each of these unknown liquids. Students might suggest pairing each yellow liquid with blue water and joining each pair with a toothpick as they did in the previous activity. Then they can compare what they see with the results they recorded for *Activity 3.3*. Give groups a few minutes to discuss how they might go about identifying each unknown liquid. Then have groups share basic plans. One plan is described in the procedure below. Let all students know that they may test the liquids more than once, if necessary.

Distribute *Activity sheet 3.4—Using the combining test to identify the unknown liquids* so that students can record the identity of each of the unknown liquids as they discover them. Students will also need laminated *Testing sheets 3.3* and *3.4* along with completed *Activity sheet 3.3*.

2. Have groups test and identify all four unknown liquids.

The following procedure is not provided for students in the activity sheet. Students should have an idea of how they will test each liquid from their group and class discussions. If students need guidance, explain the testing strategy described in the procedure.

Procedure

1. Use drops of yellow liquid labeled **A** to fill its circle and then fill the opposite circle with blue water. Combine this pair with a toothpick the way you did in the last activity.
2. To figure out the identity of unknown **A**, compare the way these two liquids combine to your drawings and captions from the previous activity.

What do you think is the identity of unknown **A**?

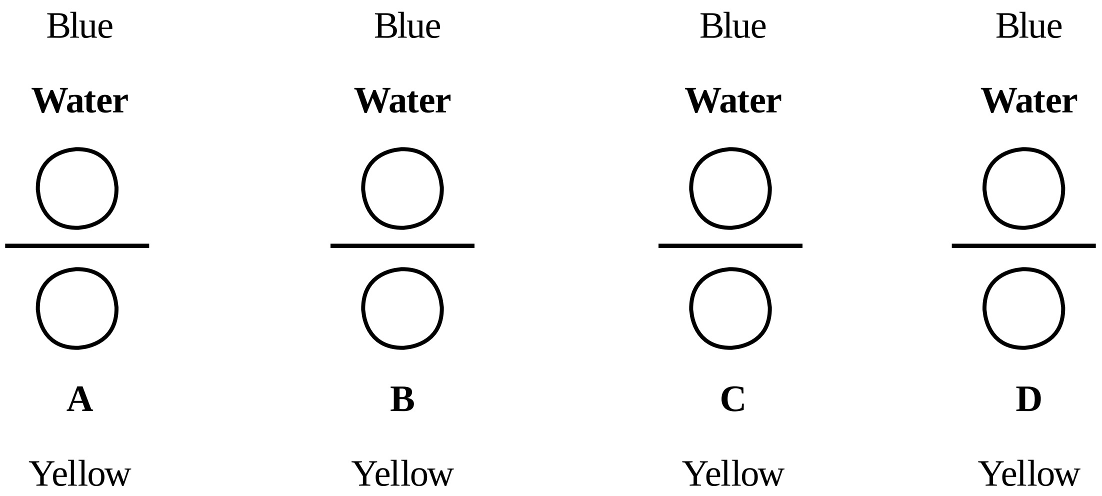
3. When you think you might know, test that liquid with blue water on your other chart and compare it with the way unknown **A** combines with blue water. Conduct the test as many times as you need to.
4. Repeat Steps 1–3 for each of the remaining unknowns. Record the identity of each unknown liquid on your activity sheet and include what made you think that was the identity of the unknown.

3. Have students compare their results and conclusions.

Have students discuss their results and say what they think are the identities of the unknown liquids. Ask students what evidence they used to help them decide the identity of each liquid. Reveal the identities of all four of the unknown liquids.

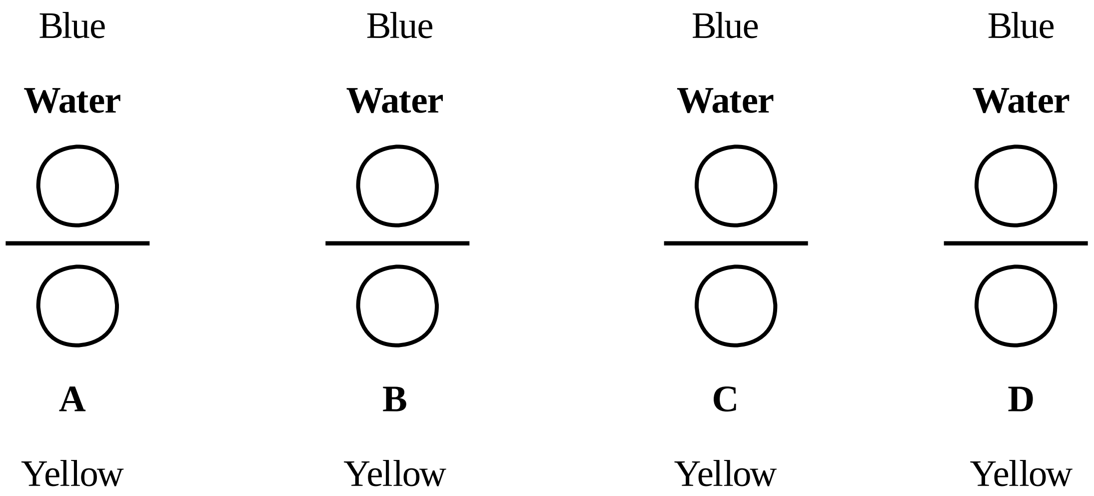
Testing sheet 3.4

Using the combining test to identify the unknown liquids



Testing sheet 3.4

Using the combining test to identify the unknown liquids



Student activity sheet
Activity 3.4

Name: ______________________________

Using the combining test to identify the unknown liquids

How can you use the characteristic way each liquid combines with water to identify the unknown liquids?

What is the identity of each unknown?		What clues helped you identify the unknown?
A		
B		
C		
D		

Investigation 3—Physical properties and physical change in liquids

Assessment rubric

How can you tell if liquids that look the same are really the same or different?

Activity 3.1—Look-alike liquids

Can you distinguish between four clear, colorless liquids based on the way they look on a brown paper towel?

G S N
☐ ☐ ☐ Follows given procedures to compare similar-looking liquids
☐ ☐ ☐ Records observations

Circle one: Good Satisfactory Needs Improvement

Activity 3.2—Developing tests to distinguish between similar-looking liquids

How can you identify an unknown liquid based on the way it behaves on different paper surfaces?

G S N
☐ ☐ ☐ Plans a fair test to identify an unknown liquid
☐ ☐ ☐ Conducts fair tests
☐ ☐ ☐ Uses evidence to identify the unknown liquid
☐ ☐ ☐ Explains reasoning

Circle one: Good Satisfactory Needs Improvement

Activity 3.3—Using color to see how liquids combine

Can you tell a difference between liquids by the way they look when they combine with water?

G S N
☐ ☐ ☐ Controls variables while conducting test
☐ ☐ ☐ Records observations with words and drawings

Circle one: Good Satisfactory Needs Improvement

Assessment rubric (*continued*)

Activity 3.4—Using the combining test to identify the unknown liquids

How can you use the characteristic way each liquid combines with water to identify the unknown liquids?

G S N
☐ ☐ ☐ Controls variables while testing each unknown liquid
☐ ☐ ☐ Refers to recorded observations or conducts additional tests with the known liquids to help identify the unknown
☐ ☐ ☐ Uses evidence to identify the unknown liquids
☐ ☐ ☐ Explains reasoning

Circle one: Good Satisfactory Needs Improvement

To earn a “**B**”, a student must receive a “Good” in each category.

To earn an “**A**”, a student must also exhibit some of the following qualities throughout this investigation.

- ☐ Creates outstanding drawings and written explanations
- ☐ Considers whether an unknown could be identified with a given test
- ☐ Possesses a well-developed understanding of possible variables
- ☐ Participates well in class discussions
- ☐ Participates well in group work
- ☐ Uses scientific thinking
- ☐ Consistently exhibits exceptional thought and effort in tasks
- ☐ Other ____

Teacher instructions

Review and apply

The following section, titled *Review and apply*, contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 3*, they will reflect on their learning, apply what they learned about experimental design to a new activity, and read about the importance of water. An optional reading explains, on the molecular level, the differences in the way liquids behave in the absorption and in the combining-with-water tests. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned in the liquids investigation.

Distribute *Review and apply: Let's review*, p. 158, and give students an opportunity to respond to the prompts on their own. Once students think about and write their ideas, discuss how they conducted fair tests and used their observations to identify an unknown liquid.

Science in Action!

2. Have each student design and conduct two tests that can be used to tell the difference between water and mineral oil.

Explain that water and mineral oil are both clear colorless liquids that look very similar. But like the liquids tested in this investigation, they each have their own characteristic properties. Either provide students with simple materials like clear cups, food coloring, sugar, brown paper towels, brown paper bags, droppers, cotton swabs, etc., or have students gather their own materials. Let students know that their task is to develop two tests that show differences between water and mineral oil. They will likely have to conduct a few tests before they find two that show distinct enough differences between the two similar-looking liquids. This activity and the corresponding *Review and apply* worksheet can serve as a summative assessment, evaluating students' skills at designing a fair test, identifying and controlling variables, and recording observations.

Distribute activity sheet *Review and apply: Science in action!*, pp. 159–160.
This activity may be conducted either at home or in class.

3. When students have completed their experiments, compare experimental designs and observations.

Have students form small groups and describe (using what they drew and wrote on the activity sheet) or demonstrate one of the tests they developed. This test should be one that does an especially good job controlling variables or revealing distinct differences between water and mineral oil. Groups should discuss how variables were controlled in each test.

Think about it

4. Have students read about water and then answer questions.

Tell students that water has some unique properties that make it so special, interesting, and useful. Discuss the following properties of water with students.

Super surface tension
Water molecules are so attracted to each other that water can bead up on certain surfaces. Ask students for examples of water's amazing *surface tension*. They may mention the "dome" of water that forms when adding drops of water on a penny, water striders at the top of water, water beading up on a window when it rains, etc.

Upwardly mobile
The same attractions that give water its amazing surface tension also help it to move up through the tiny tubes in plants. Explain that water is attracted to the sides of the tubes as well as to itself and these attractions help water to move up. Ask students for examples of places they have seen water moving up through tiny tubes or spaces. Students may mention colored water moving through a stalk of celery or a carnation, or water absorbing into a paper towel.

Great dissolver
Tell students that water is especially great at dissolving other substances. Explain that ocean water contains dissolved salt and other minerals. Our blood is made mostly of water and brings dissolved nutrients to our cells. Ask students for examples of dissolving substances in water. Students may mention dissolving sugar and flavoring in water to make drinks, using water-based paint and markers to make artwork, dissolving soap and detergent in water to clean things, etc.

Fantastic freezing
Explain that water does a surprising thing when it freezes; it actually takes up more space as ice than it does as water. Tell students that they can see this for themselves if they completely fill a plastic container with water, place a lid on top, and then place it in the freezer. Once frozen, the lid will either be stretched slightly or pushed up by the ice. A more quantifiable way to show this phenomenon is to partially fill a plastic graduated cylinder with water. Students can measure the volume of water in the cylinder and compare this to the volume of ice that forms. Explain that because the same amount of liquid water actually takes up more space when it freezes, ice is less dense than water and floats. Ask students for examples of floating ice. Students may mention ice cubes floating in a drink, icebergs in the ocean, thin layers of ice that form at the top of puddles in winter, or thick layers of ice on top of ponds and lakes in winter.

Distribute *Review and apply: Think about it*, pp. 161–165. Have students read about the amazing properties of water and answer the comprehension questions.

For additional information about water, go to
www.inquiryinaction.org

What's going on here? (*optional*)

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about the molecular structure of the liquids and answer questions about the reading.

Distribute *Review and apply: What's going on here?* pp. 166–168. This reading describes how the molecular structure of the liquids and papers can help explain why the liquids each have their own characteristic way of absorbing into the papers. It also helps explain how the liquids combine with water the way they do.

This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level. Discuss the five questions and their explanations with students.

- Why do water and salt water bead up on wax paper?
- Why don't isopropyl alcohol and detergent solution bead up on wax paper?
- Why do the liquids absorb into different papers in different ways?
- Why do liquids evaporate at different rates?
- Why do liquids look different when they combine with water?

Material to support this reading can be found at
www.inquiryinaction.org

Name: ____________________________

Let's review

At the beginning of this investigation a student noticed that although water and alcohol look pretty similar, they act differently when placed on different surfaces.

You also tested these liquids and conducted more tests using water, salt water, isopropyl alcohol, and detergent. Since these similar-looking liquids had their own characteristic way of absorbing into different surfaces or combining with water, you were able to identify the unknown liquids.

1. In this investigation you conducted different tests to identify unknown liquids. Describe one of the tests you conducted with the known liquids and the unknown. Be sure to explain what you did to control the variables so that the test was fair.

2. How did you identify the unknown?

Name: ______________________________

Science in action!

What tests could you develop to compare the properties of water and mineral oil?

The best way to tell similar-looking liquids apart is to test them. Sometimes one test is enough to show clear differences in the liquids, but other times more than one test is needed. In the investigation, you used the characteristic way different liquids absorb into surfaces and combine with water to identify unknown liquids. In this activity, you will develop your own tests to compare water and mineral oil.

Water and mineral oil are both clear, colorless liquids that look very similar. But like the liquids you tested in this investigation, they each have their own characteristic properties. Use simple materials like clear cups, food coloring, sugar, brown paper towels, brown paper bags, droppers, cotton swabs, etc., to design and conduct your own tests on these two liquids.

Mineral oil is made from petroleum which comes from the ground. Vegetable oil is made from plants.

Your assignment is to develop at least two tests to compare the characteristic properties of water and mineral oil. First, plan tests you might like to try and describe them in the box below.

Use drawings and captions to describe tests that might show some differences between water and mineral oil.

Experiment with the materials and try some tests. You will likely try more than two tests before you discover two that reveal distinct enough differences between water and mineral oil. After you conduct your tests, answer the questions on the next page.

Review and apply worksheet

Name: ____________________________

Test 1

How did you set up and conduct your test?
Use drawings and brief explanations to describe your test.

What did you observe?

____

____

____

Test 2

How did you set up and conduct your test?
Use drawings and brief explanations to describe your test.

What did you observe?

____

____

____

Name: ______________________________

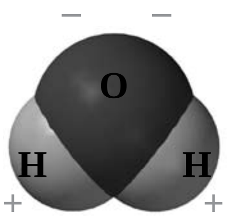
Think about it

Water, water, everywhere…

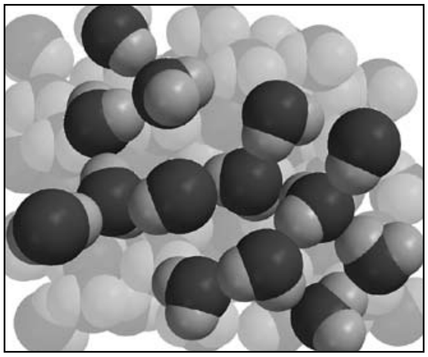
It's just about everywhere! It covers almost ¾ of the Earth's surface. It makes up about ⅔ of your body's weight! Every living thing needs it to survive. It's amazing! It's incredible! It's the one and only, your friend and mine, that multi-talented substance we know and love—**water**!

Vocabulary

atom
molecule
density
evaporation
surface tension
capillary action
dissolve
absorb
adaptation



To understand what makes water so special, it helps to look at the smallest amount of water possible—the water molecule. You may already know that everything in the world is made up of atoms. When two or more atoms join together, they make a molecule. A molecule of water is made up of three atoms: one oxygen atom and two hydrogen atoms. That's why scientists call water "H_2O". A water molecule is shaped kind of like a "V" and has a negative area at one end and a positive area at the other. You can see, in the close-up model of water molecules at right, that the negative end of one water molecule is attracted to the positive end of another water molecule. Also, the positive end of one water molecule is attracted to the negative end of another. These attractions among water molecules give water some of its unique characteristics.



The surface with a purpose

One characteristic of water that we often notice is the way water can bead up or stay together as a drop. You may also have seen a water strider standing on the surface of water, causing the water's surface to "bend" where each leg touches the water. Both these phenomena are caused by water's *surface tension*.

Name: ___________________________

Think about it (*continued*)

The water molecules at the top or surface are attracted to each other and are also pulled down by the molecules beneath them. Because they don't have any water molecules above them, these surface water molecules are attracted only down and in. This results in a tighter, stronger layer of molecules at the surface. Surface tension is what allows water to be poured into a cup until the water level is actually above the rim!

The cold hard facts about ice

Water molecules also act in a special way when water freezes. When most liquids freeze, their molecules get closer together and the substance shrinks or contracts. But when water freezes, water molecules move farther apart as they arrange themselves to form ice. Because water molecules in ice take up more space than they do as liquid water, ice is less dense than water and floats. This is very helpful in nature. When lakes freeze, ice forms on the surface and the water underneath stays liquid. This helps living things in the water survive during the winter.

Making it to the top

The unique characteristics of water molecules also help water move into the roots, stems, and leaves of plants. One of the processes that helps water move up and into the very thin and tiny tube-like cells of plants is called *capillary action*. Water molecules attract each other and are also attracted to the sides of the tube. These attractions help cause the capillary action that plants depend on. Water moving into roots and up the stem to the leaves brings plants the water and nutrients they need to live.

You can't live without it

Water is also an excellent dissolver. The positive and negative areas on water molecules help them attract and eventually dissolve many substances. When we eat, water and other chemicals in our digestive juices help break down and eventually dissolve the food into the nutrient molecules our bodies can use. Water is also a big part of the blood that transports nutrients to the cells of your body. Water is inside and outside the cells helping to regulate the concentration of substances in the cell. In fact, water is involved in many of the chemical reactions that happen in our cells to keep us alive. Water also plays an important role in maintaining the body's temperature within a normal range.

Think about it (*continued*)

Living in the desert

Animals and plants have different adaptations to help them survive when there is little or no water. One of the most amazing survivors is the kangaroo rat found in the desert. This tiny rodent eats only dry seeds, and is never seen drinking water. How does it survive?

When the kangaroo rat, or any animal, breaks down food in its cells to get energy, some water is produced. The kangaroo rat has special structures in its kidneys which help it to conserve more of this water than any other mammal. The kangaroo rat also has other ways of conserving water. During the day, when the temperature is hot, it seals the entrance to its burrow so the cooler moist air stays in. The kangaroo rat also has no sweat glands and has fur that is covered in an oily substance which reduces moisture lost from its skin.

Plants compete for water

The creosote bush competes with other plants for water in the desert. Mature creosote bushes release a nasty chemical and use their extensive roots so that other plants are not able to sprout around them.

Some seeds also rely on chemicals to help them when there is very little water. A covering on the outside seed coat prevents a false start after a single, light rainfall. To make sure there is enough moisture for the young plants' survival, sprouting happens only when there is enough rainfall to wash away these layers of chemicals.

Cacti have another adaptation to help them get and keep water. They develop lots of tiny roots that are shallow in the ground. Cacti are able to quickly absorb water, which they store in their waxy, thick stems. They also have prickly spines instead of leaves to help reduce the amount of water lost due to evaporation.

Water is so important to so many different aspects of life that it is the main substance scientists look for in an environment to see if life itself is possible.

Name: ____________________________

Think about it (*continued*)

1. Look at the picture of water dripping off a leaf. Why does the water droplet hold together?
   a. Water is a molecule.
   b. Water is an atom and atoms are round.
   c. Water molecules are attracted to each other and cling together.
   d. Water molecules have two atoms of hydrogen and one atom of oxygen.

2. According to the details in the reading, what does *capillary action* do for a plant?
   a. Capillary action helps turn the plant towards sunshine.
   b. Capillary action helps make leaves green.
   c. Capillary action helps move water and nutrients into the stems, leaves, and roots.
   d. Capillary action helps bring the plant carbon dioxide.

3. *Surface tension* is a term used to describe…
   a. the number of water molecules on the surface of water.
   b. a water strider or other insect that can stand on the surface of water.
   c. the strength and flexibility of the top layer of water.
   d. the evaporation of water from the surface.

4. What happens to water molecules when they freeze?
   a. Molecules get closer together and the water shrinks when it becomes ice.
   b. Molecules move further apart, and the water expands when it becomes ice.
   c. Molecules slow down but water neither shrinks nor expands when it becomes ice.
   d. Molecules spread out but then get closer together at the end.

5. Which sentence is the best summary of the entire passage about water?
   a. Water is found everywhere.
   b. Water has many unique characteristics that help it cling to itself, be a good dissolver, and keep organisms alive.
   c. Water is a great dissolver.
   d. Water helps keep things alive in the winter.

6. Which detail in the story supports the idea that water is essential to living things?
   a. The kangaroo rat makes its own metabolic water and seals off its home to keep from losing water.
   b. Creosote bushes release a nasty chemical to keep other plants from sprouting around them.
   c. Plants use the characteristics of water to help them move nutrients to their stems and roots.
   d. All of the above.

Name: ____________________________

7. Water molecules tend to cling together. What is it about water molecules that makes them do this?

8. How is frozen water (ice) different from most other liquids when they freeze?

9. What are two ways that water is important in keeping people alive and healthy?

10. Describe one strategy an animal uses and one strategy a plant uses to survive where there is very little water.

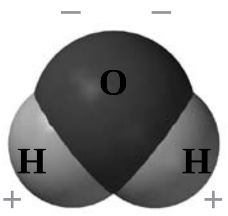
Review and apply worksheet

Name: ______________________________

What’s going on here?

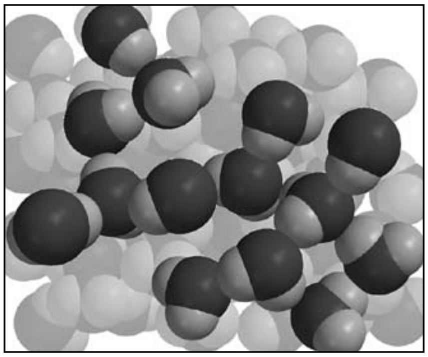
In this investigation you saw that, even though liquids may look very similar, they can act differently when you compare them on different types of paper. You placed the different liquids on wax paper, paper towel, and other papers and saw that you could see some differences between them based on how they clung together and beaded up or absorbed into the paper. You also mixed yellow liquids with blue water and saw differences in the way each liquid mixed with water. To understand why the liquids acted differently from one another, you have to think about them on the molecular level.

Because of the characteristics of oxygen and hydrogen and how they are bonded together in the water molecule, the area around the oxygen atom has a slight negative charge and the area around the hydrogen atoms has a slight positive charge. Since opposite charges attract, the positive part of one water molecule is attracted to the negative part of another water molecule.



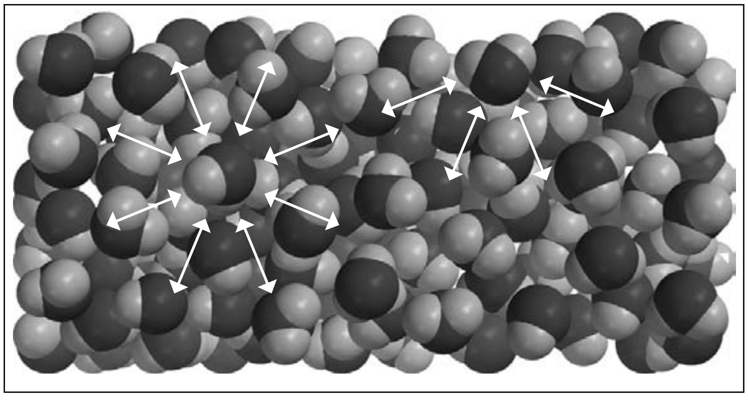
The shape of things to come

In addition to having an area of positive and negative charge, a water molecule also has a very particular shape. It is kind of spread out like a wide “V”. The charged areas of the water molecule and this “V”-like shape allow a single water molecule to attract multiple water molecules at the same time. This allows water molecules to have a lot of attractions for each other. This combination of water’s charged areas, unique shape, and attractions is what gives water some of its very interesting qualities.



Why do water and salt water bead up on wax paper?

Water molecules are attracted in every direction by other water molecules and are more attracted to each other than they are to the wax paper. Also, the water molecules at the surface of a drop have no water molecules attracting them from above. These surface molecules can only be attracted down and in. Since they are attracted in a more uniform or consistent direction, they form a more stable arrangement at the surface called surface tension. Water’s attraction to itself and its strong surface tension causes water to bead up instead of spreading out on the wax paper.



What’s going on here? (*continued*)

Salt water is made up mostly of water molecules, but it also contains dissolved salt. When salt dissolves, it separates into tiny positively and negatively charged particles called *ions*. These ions are very attracted to water. Since salt water beads up on wax paper, we know that the ions do not interfere with water’s surface tension.

Why don’t isopropyl alcohol and detergent solution bead up on wax paper?

The isopropyl alcohol and the detergent solution used in this activity both contain water. Both the alcohol and detergent molecules have parts that are attracted to water. But they also have parts, made up of carbon and hydrogen atoms bonded together, which are not particularly attracted to water. These parts interfere with the interactions water molecules have for each other. This disrupts the water’s surface tension and keeps these solutions from beading up on wax paper the way that water and salt water do.

Why do the liquids absorb into different papers in different ways?

The way a liquid absorbs into a piece of paper has to do with the properties of the liquid and the properties of the paper. For example, one type of paper could have more or bigger pores than another. One reason why water-based liquids absorb into paper is because water is attracted to one of the main substances paper is made of—cellulose. The ability of a liquid to absorb into paper depends on how much the molecules of the liquid are attracted to the paper and how much the molecules of the liquid are attracted to each other. Each of the liquids is made up of different molecules, so they absorb into the papers differently.

Why do liquids evaporate at different rates?

You may have observed the liquids evaporating at different rates from the different papers. Evaporation occurs when molecules of a liquid gain enough energy to break away from the rest of the liquid and move into the surrounding air. One of the main factors that affects the rate of evaporation is the amount of attraction the molecules of the liquid have for each other. When the liquids have absorbed into another material, in this case paper, the attraction between the molecules of the liquid and the molecules that make up the paper will also affect the rate of evaporation. The combination of these factors determines the different rates of evaporation for each liquid. Because each of the liquids is made up of different molecules, they evaporate at different rates.

Why do liquids look different when they combine with water?

There are different reasons why mixing the yellow liquids with blue water looks different for each liquid. The yellow liquids are water, and solutions made from water mixed with salt, alcohol, or detergent. These solutions each have unique characteristics based on the interaction of water with the substance in the solution. They also have their own characteristic densities. When these solutions are then combined with water, they will mix with water in characteristic ways.

Review and apply worksheet Name: ______________________________

What’s going on here? (*continued*)

1. Why does water bead up on wax paper?

2. Why doesn’t detergent solution bead up on wax paper the way that water does?

3. What are some of the factors that affect the rate a liquid evaporates from a surface?

Cool factoid

There is a famous “meeting of the waters” in Brazil where two rivers with very different colors run together for miles without apparently mixing. The faster, more powerful, and more dense brown river slips beneath the black river. The waters of these rivers eventually mix further downstream.

Investigation 4

Dissolving solids, liquids, and gases

Can solids, liquids, and gases all dissolve?

Summary

In this investigation, students will participate in activities that help them better understand the different factors that affect the solubility of solids, liquids, and gases. First, students will add sugar and food coloring to different liquids to discover that substances don't necessarily dissolve in all liquids. Students will then add cocoa mix to hot and cold water, and see that this solute dissolves better in hot water. However, the following teacher demonstration shows that increasing the temperature of water has very little effect on the solubility of salt. Students also experiment with the effect of temperature on carbon dioxide gas dissolved in water. Students should conclude that temperature affects the solubility of substances in different ways. As a culminating challenge, students use their knowledge of dissolving solids, liquids, and gases in water to create a fizzy lemon soda.

Investigation 4: Dissolving solids, liquids, and gases

Key concepts for students

- Dissolving applies to solids, liquids, and gases.
- Dissolving involves the interaction between the solvent and the solute.
- The extent to which a substance dissolves in a liquid is a characteristic property of that substance.
- Heat increases the solubility of most solids.
- Heat does not increase the solubility of all solids by the same amount.
- Heat decreases the solubility of most gases.

Learning objectives

Students will be able to:

- Identify and control variables to design and conduct valid experiments.
- Develop a definition of "dissolve" that applies to solids, liquids, and gases.
- Use observations and results of experiments to develop explanations to answer a question.
- Explain that the solubility of a substance depends on the characteristics of both the solute and the solvent giving each substance a unique solubility.
- Draw pictures and write captions showing the stages of a solid dissolving.
- Explain that heat affects the solubility of solids and gases differently.

Investigation questions

Can solids, liquids, and gases all dissolve?

- How can you tell when a substance is dissolved?
- Does colored sugar dissolve equally well in water, vegetable oil, and alcohol?
- Does cocoa mix dissolve better in hot water or cold water?
- Do salt and sugar dissolve better in hot water than in cold water?
- Do all liquids dissolve in water?
- Can a gas dissolve in a liquid?
- Does temperature have an effect on how quickly dissolved gas escapes from a soda?
- How can you make a lemon soda that keeps as much carbonation as possible?

Assessment

The assessment rubric *Dissolving solids, liquids, and gases*, pp. 218–219, enables teachers to document student progress as they design and conduct activitites and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section, pp. 220–235.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Types of investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties such as…solubility.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

4.1 Defining dissolving
4.2 Dissolving a substance in different liquids
4.3 Temperature affects dissolving
4.4 Dissolving different liquids in water
4.5 Temperature affects the solubilty of gases
4.6 A dissolving challenge

	Activities					
Each group will need	4.1	4.2	4.3	4.4	4.5	4.6
Room-temperature water	●	●		●		
Hot water			●		●	
Cold water			●		●	
Club soda (carbonated water)					●	●
Vegetable oil in cup	●	●		●		
Isopropyl rubbing alcohol, 70%, in cup		●		●		
Corn syrup in cup				●		
Lemon juice in cup						●
Food coloring, any color	●	●				
Powdered cocoa mix			●			
Sugar	● **in cup**	● **in bag**				● **in cup**
Zip-closing plastic bag, sandwich-size		●				
Clear plastic cups	4	3	2	3	4	4
Measuring cup (¼ cup)						
1 Tablespoon	●					
1 Teaspoon	●	●	●			●
Popsicle sticks or stirrers		3	2	3		1
Pipe cleaner						●
M&M's						●

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**
- You will use the same carbonated water for *Demonstration 4b* and *Activity 4.5.* If you have 5 or fewer student groups, use a 1-liter bottle in the demonstration. If you have more, use a 2-liter bottle. Either provide a small bottle of carbonated water for each student group for *Activity 4.6* or pour about 1 cup of carbonated water into a small bottle with a lid for each group.
- Sugar cubes will be needed for the *Review and apply: Science in action!* activity, pp. 225–226.

Materials chart for teacher demonstrations

4a Temperature affects the solubility of salt and sugar
4b Gases can dissolve in liquids

	Demonstrations	
	4a	4b
Hot water	●	
Cold water	●	
Unopened bottle of club soda, 1- or 2-liter		●
Sugar	●	
Salt	●	
Sensitive scale for weighing grams	●	
Plastic graduated cylinders	4	
Small cups	4	
Straws	4	

Science background information for teachers

Solids, liquids, and gases all dissolve. Solubility, or the extent to which a substance dissolves, is a characteristic property of a substance. To understand why substances have unique solubilities, it helps to look on the molecular level. It is important to consider both the substance doing the dissolving, the *solvent*, as well as the substance being dissolved, the *solute*. In this investigation, the main solvent used is water.

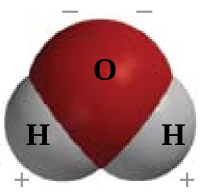
For videos, animations, and other information related to this investigation, go to **www.inquiryinaction.org**

Chemistry concepts

- A water molecule has an area of positive charge and an area of negative charge.
- The interaction between the molecules of a liquid and the molecules of a substance determines the extent to which the substance dissolves.
- Since the molecules that make up liquids are different, the fact that a substance dissolves in one liquid does not necessarily mean the substance will dissolve in a different liquid.
- Like dissolving a solid or a liquid, the dissolving of a gas depends on the interaction between water molecules and the gas molecules.
- Heat increases molecular motion, which tends to increase the solubility of most solids.
- Since different solids are composed of different molecules or ions, adding heat affects their solubilities by different amounts.
- Heat increases molecular motion, which tends to decrease the solubility of gases.

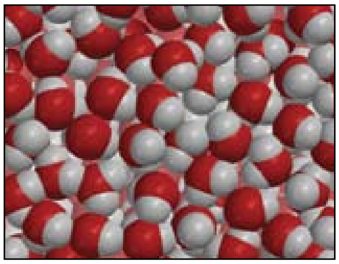
Water molecules

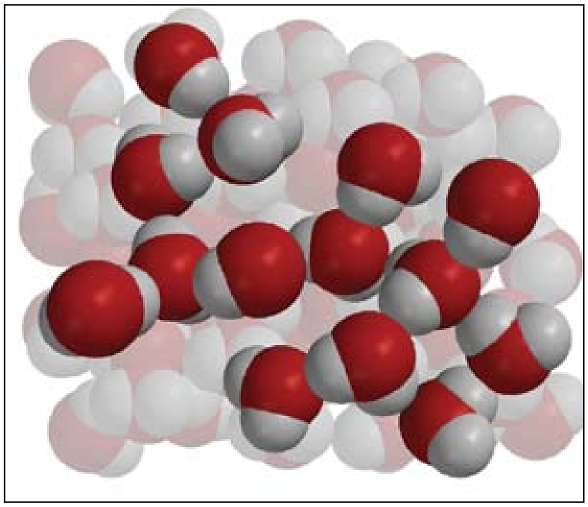
Let's begin by considering the structure of the water molecule and why this structure makes it such a good dissolver. Because of the characteristics of oxygen and hydrogen atoms and the way they bond together to make a water molecule, there is a slight positive charge near the hydrogen atoms and a slight negative charge near the oxygen atom. (For more details, see pp. 18–20.)



Water

The smaller illustration to the right shows that the molecules in liquid water associate very closely with one another. The larger illustration shows how the water molecules tend to orient themselves according to their polarity. Notice how the positive area of one water molecule is attracted to the negative area of another. These positive and negative areas on water molecules are also attracted to the positive and negative areas of other substances. This is the key to understanding why water is such a good dissolver.





Activity 4.1—Defining dissolving
Activity 4.2—Dissolving a substance in different liquids

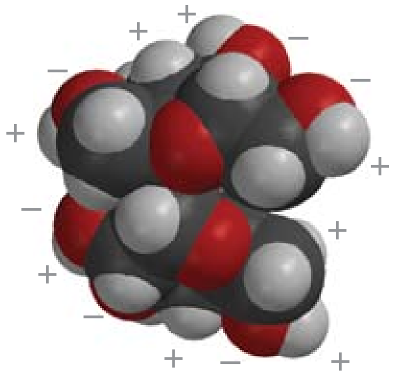
Coloring the sugar

Both the pigment molecules in food coloring and the sucrose molecules in sugar have positively and negatively charged polar areas. (See pp. 19–20 for more information about sucrose.) It is the mutual attraction between these molecules that causes the food coloring to adhere to the sugar.

Colored sugar in water

Both the sugar and color dissolve

The positive and negative polar areas on water molecules are attracted to the oppositely charged polar areas of pigment molecules. The color dissolves in water because there is enough mutual attraction between the water and the pigment to overcome the attraction between the pigment and the sugar. The sugar dissolves in water because there is also enough mutual attraction between the water and the sucrose molecules to overcome the attraction that sucrose molecules have for each other. (See p. 20 for a more detailed explanation.)

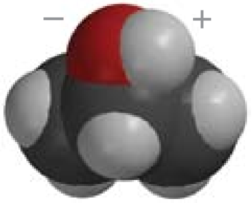


Sucrose molecule showing positive polar areas near the hydrogens and negative polar areas near the oxygens

Colored sugar in isopropyl alcohol

The coloring dissolves but the sugar does not

The isopropyl alcohol you get in most stores is a solution of alcohol in water. A common mixture is 70% alcohol and 30% water. As you can see in this space-filling model of the alcohol molecule, isopropyl alcohol, like all alcohols, has an oxygen atom bonded to a hydrogen atom. This results in the oxygen having a slight negative charge and the hydrogen having a slight positive charge. This is similar to the oxygen–hydrogen bond in water. The rest of the alcohol molecule is made up of carbon and hydrogen atoms bonded together. These atoms have only very slight positive and negative charges compared to the positive and negative polar areas in a water molecule. In isopropyl alcohol, the water and alcohol molecules are attracted to and closely associated with each other.



Isopropyl alcohol

Food coloring dissolves in isopropyl alcohol because of the mutual attraction between the pigment molecules and the water and alcohol molecules. These attractions are strong enough to overcome the attractions between the pigment and the sucrose molecules, causing the pigment to dissolve. There are several reasons that can explain why sugar does not dissolve in alcohol. One has to do with the alcohol molecule itself. Since alcohol molecules do not have as strong of an attraction for sucrose molecules as water does, they are not able to overcome the attractions the sucrose molecules have for one another.

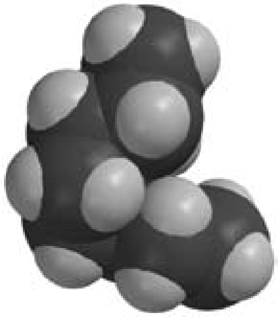
The other reason has to do with the interaction between the water molecules and the alcohol molecules in a 70% isopropyl alcohol solution. As stated earlier, the water and alcohol molecules in isopropyl alcohol are attracted to and closely associated with one another. It is possible that this close association ties up so many water molecules that there are not enough water molecules available to dissolve the sugar.

Another possibility is that the alcohols that do associate with the sugar physically prevent the water from getting close enough to the sugar to dissolve it.

Colored sugar in vegetable oil

Neither the sugar nor the coloring dissolves

Vegetable oil is composed of large molecules that contain long chains of carbon and hydrogen atoms bonded together. These bonded atoms create only a very small amount of positive and negative charge and have very little attraction for the sugar or the coloring. Therefore, neither the sugar nor the coloring dissolves in vegetable oil.



Carbon–hydrogen chain

Activity 4.3—Temperature affects dissolving

Demonstration 4a—Temperature affects the solubility of salt and sugar

Heat increases the solubility of most solids. In the activity, the cocoa dissolves better in hot water. In the demonstration, the sugar and salt both dissolve better in hot water. However, increasing the temperature has a much greater impact on the solubility of sugar than it does on the solubility of salt.

Why does temperature affect dissolving?

Adding heat makes molecules vibrate and move faster. This movement helps disrupt and break the associations holding one molecule to another. In the case of sugar dissolving in water, the heat helps disrupt the associations holding sucrose molecules to one another. It also helps disrupt the associations between water molecules.

But dissolving is more than *breaking* the associations between molecules, new associations must be *formed* between water molecules and sucrose molecules. So even though these molecules are attracted to each other, and will tend to associate with each other, the increased molecular motion at the higher temperature acts to disrupt these associations. So dissolving is a balance between the breaking and forming of associations, which results in sucrose, and every other substance, having a unique solubility at a given temperature.

For certain substances, like sugar, heat tends to increase solubility significantly. For other substances, like salt, heat doesn't have as great an effect on solubility. The reasons for these differences have to do with the characteristic properties of sucrose and sodium chloride:

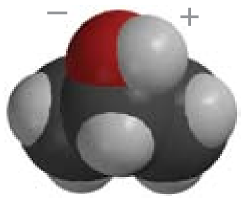
- The shape and size of sucrose molecules and sodium and chloride ions are different.
- The strength of the charges of the sodium and chloride ions is different than the strength of the charges on the polar areas of the sucrose molecule.
- The strength of the associations between the ions in sodium chloride is different than the strength of the associations between the molecules in sucrose.
- The way the sucrose molecules and the sodium and chloride ions pack together to create their crystal structures is different.
- The way water molecules can access and surround sucrose and sodium chloride is different.

For all these reasons, the solubility of sugar and salt are different and the effect of heat on their solubilities is different.

Activity 4.4—Dissolving different liquids in water

Isopropyl alcohol in water

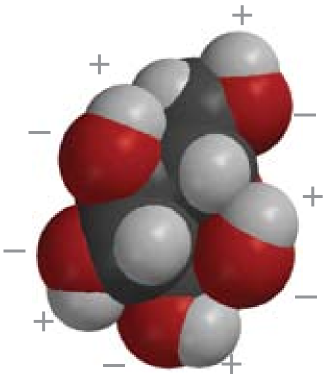
Isopropyl alcohol dissolves in water. Alcohol has an oxygen atom bonded to a hydrogen atom. This makes that part of the alcohol molecule polar and a source of attraction for water molecules. The other part of isopropyl alcohol is a short chain of carbon–hydrogen (C–H) bonds, which are not very attracted to water. But the mutual attractions between the water molecules and the alcohol molecules is enough to overcome the attractions the alcohol molecules have for each other so the isopropyl alcohol does dissolve. But, as a general rule, as the C–H group gets bigger in other alcohols, these alcohols are less soluble in water.



Isopropyl alcohol

Corn syrup in water

Corn syrup is made mostly from glucose and fructose molecules. These are the same two molecules that are covalently bonded to form sucrose. But in corn syrup, the glucose and fructose molecules are not covalently bonded together. They each have several polar areas based on O–H bonds. The glucose and fructose molecules associate with each other based on mutual attractions from these polar O–H bonds. These polar areas also attract polar water molecules. The mutual attraction between water molecules and the molecules of glucose and fructose overcomes the attraction the glucose and fructose molecules have for each other causing them to dissolve.



Glucose

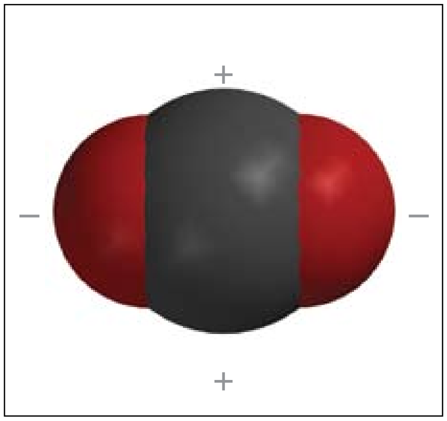
Vegetable oil in water

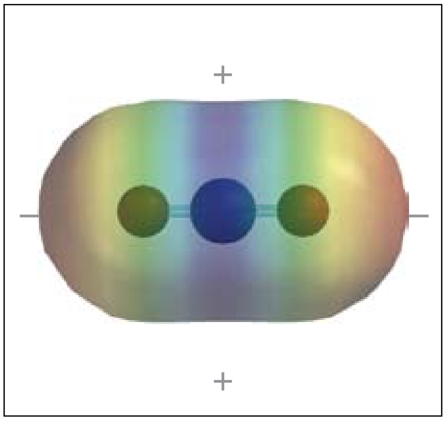
Vegetable oil is composed of molecules that are practically all long chains of carbon–hydrogen atoms bonded together. These C–H bonds create only a very small amount of positive and negative charge. There is very little mutual attraction between molecules of oil and water molecules so the oil does not dissolve.

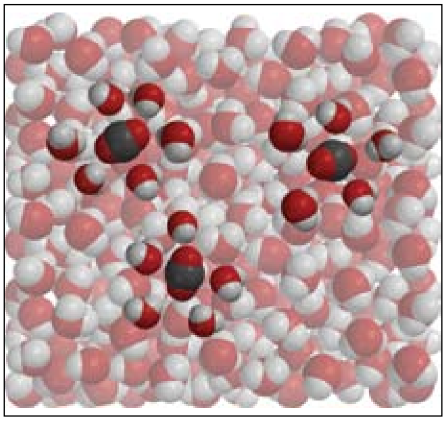
Carbon–hydrogen chain

Demonstration 4b—Gases can dissolve in liquids

The fact that gases can dissolve in liquids may be harder to imagine and accept than the dissolving of solids and liquids. But a gas is made up of molecules just like the molecules of solids and liquids. And just as the polar characteristics of water help explain the solubility of solids like sugar, and liquids like alcohol, it also helps explain the solubility of gases. The gas carbon dioxide (CO_2) is made from one carbon atom with an oxygen atom bonded on either side. Oxygen has a stronger attraction for electrons than carbon. So the electrons shared between the carbon and the oxygen atoms spend more time near the oxygen atoms. This makes the area near the oxygen atoms slightly negative and the area near the carbon atom slightly positive. The amount of negative charge near the oxygen and positive charge near the carbon in CO_2 is not as great as the amount of negative and positive charge near the oxygen and hydrogen in H_2O, but it is still there. These polar areas associate with the oppositely charged polar areas of water, causing the carbon dioxide to dissolve.







Activity 4.5—Temperature affects the solubility of gases

The characteristic properties of a substance, whether it is a solid, liquid, or gas influence the extent to which the substance will dissolve. The molecules of a gas, just like the molecules of a solid or liquid, dissolve in water because of mutual attractions between the molecules of the gas and the water molecules.

Usually, increasing the temperature of water causes more of a solid like salt or sugar to dissolve. But this situation is reversed for gases. As the temperature of a solvent, like water, is increased, *less* gas will dissolve or stay in the solution. When the temperature is lower, *more* gas will dissolve and more will stay in the solution.

Why does increasing the temperature decrease the solubility of carbon dioxide?

As heat is added to the carbonated water, the motion of the molecules increases. This increased motion can overcome the mutual attractions between the water molecules and the carbon dioxide molecules. These fast-moving carbon dioxide molecules gain enough energy to come out of solution.

As carbonated water is cooled, the motion of molecules slows. This decrease in motion allows the water and carbon dioxide molecules to retain their association with one another based on their mutual attraction. So the carbon dioxide molecules come out of solution more slowly.

Activity 4.6—A dissolving challenge

When salt, an M&M, or a pipe cleaner is placed in carbonated water, carbon dioxide gas comes out of the solution, forming little bubbles on the object. These bubbles rise to the surface and pop, sending the carbon dioxide gas out of the water and into the air. Even if you look in a cup of carbonated water with nothing in it, you will see bubbles forming on the inside surface of the cup. There are two main reasons why carbon dioxide gas comes out of solution in this way.

One reason is that there is much more carbon dioxide gas in carbonated water than can stay dissolved at room temperature and at normal pressures. Carbonated water manufacturers inject carbon dioxide at high pressure into very cold water. So at room temperature and normal pressure, carbon dioxide is very ready to come out of water.

The other reason carbon dioxide gas is so prone to come out of water has to do with the fact that carbon dioxide and other gases have a tendency to stick to any available surface, particularly rough or uneven surfaces. Even though a surface may look smooth to us, it is somewhat uneven on the molecular level. The irregular surface of a pipe cleaner or the bumps on individual grains of salt or sugar are ideal surfaces for carbon dioxide to adhere and collect.

With these two factors at work, the carbon dioxide dissolved in the carbonated water quickly joins other carbon dioxide molecules until enough collect to form a visible bubble. Being less dense than water, these bubbles rise to the surface of the water and pop, sending carbon dioxide gas out of the water.

Adding sugar to carbonated water gives dissolved carbon dioxide many surfaces to adhere and collect on. But dissolving the sugar in lemon juice to make a syrup reduces the surfaces available for the gas molecules, resulting in less bubbling and less carbon dioxide leaving the soda.

Activity 4.1
Defining dissolving

How can you tell when a substance is dissolved?

In this introductory activity, students see that sugar and food coloring dissolve in water but neither dissolves in oil. Based on their observations, students can conclude that both solids and liquids can dissolve but, they don't necessarily dissolve in all liquids. Through this activity and the rest of *Investigation 4*, students will refine their definition of *dissolve* and extend it to include solids, liquids, and gases.

Materials needed for each group

Water
Vegetable oil
Sugar
Food coloring
2 Small cups
4 Clear plastic cups
1 Tablespoon
1 Teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- You may distribute tap water in a source cup or bottle with a squirt-top for each group.
- Each group will need its own small bottle of food coloring. Any color will do.
- Students may use 2 clear plastic cups instead of 4 in this activity. After comparing how well sugar and food coloring dissolve in water, students can empty, rinse, and dry the cups. Students can then use the same cups to compare how well sugar and food coloring dissolve in oil.

Preparing materials

- Use a permanent marker to label 2 small cups **sugar** and **vegetable oil**.
- Place 2 teaspoons of sugar in its labeled cup.
- Place 2 tablespoons of vegetable oil in its labeled cup.

Activity sheet

Copy *Activity sheet 4.1—Defining dissolving*, pp. 183–186, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218-219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 4.1
Defining dissolving

Question to investigate

How can you tell when a substance is dissolved?

Take a closer look

1. Have students read the introductory story on *Activity sheet 4.1* and see that both sugar and food coloring dissolve in water.

Distribute *Activity sheet 4.1—Defining dissolving.* As students read about the student who adds drink mix to different liquids, distribute the sugar, food coloring, and water. Then have students add sugar and food coloring to water as described in the procedure below.

Procedure

Sugar

1. Place about 1 tablespoon of room-temperature water in each of 2 clear plastic cups.
2. Add 1 teaspoon of sugar to one cup and swirl for about 10 seconds. Observe.
3. Swirl for another 10 seconds and observe. Swirl for a final 10 seconds and observe.

Food Coloring

1. Gently place 1 drop of food coloring in the other cup of water. Observe.
2. Gently swirl for a few seconds. Swirl again for a few more seconds.

Expected results: **After swirling, very little to no sugar is visible in the water. The food coloring combines quickly and colors the water evenly.**

As students do the *Take a closer look* activity and answer the questions, circulate to make sure students are considering aspects of dissolving.

- The sugar is present even though you can't see it.
- The sugar and food coloring are evenly distributed throughout the water.

When students have completed the activity, ask them to share their ideas about dissolving. Point out that sugar, which is a solid, and food coloring, which is a liquid, both mixed evenly throughout the liquid. So, both solids and liquids can dissolve.

Try this!
2. Have students add sugar and food coloring to oil and record their observations.

Distribute vegetable oil to each student group.

Procedure

Sugar

1. Place 1 tablespoon of vegetable oil in each of 2 clear plastic cups.
2. Add 1 teaspoon of sugar to one cup and swirl for about 10 seconds. Observe.
3. Swirl for another 10 seconds and observe. Swirl for a final 10 seconds and observe.

Food Coloring

1. Gently place 1 drop of food coloring in the other cup of oil. Observe.
2. Gently swirl for a few seconds. Swirl again for a few seconds.

Expected results: **After swirling, most or all of the sugar is visible in the oil. Initially, the drop of food coloring sinks to the bottom of the cup. After swirling, small drops of color are visible in the oil.**

As students do the *Try this!* activity and answer the questions, circulate to make sure they recognize that neither sugar nor food coloring dissolves in oil. Ask students: If certain substances dissolve in a particular liquid, will they necessarily dissolve in another liquid?

What's next?
3. Discuss students' ideas about dissolving.

As a whole class, write a list of characteristics about dissolving and post it in the classroom. Based on this activity, some characteristics you might include are:

- Evenly mixed
- So well-mixed you can't see pieces, or drops
- May "disappear" but the substance is still there
- Solids and liquids can dissolve
- Even though a solid or liquid may dissolve in one liquid, it may not necessarily dissolve in another

You and your students should revisit this list and add to it as students explore different aspects of dissolving in each of the other activities in this investigation.

Student activity sheet
Activity 4.1

Name: ______________________________

Defining Dissolving

We keep lots of different drinks in our refrigerator. There's milk, juice, soda, and water. My parents even have carbonated water, which I never drink. The other day I was thirsty and took a look in the fridge. For some reason, nothing really interested me. I decided to mix some drink mix in water to make something different. The mix dissolved really quickly and made this purplish drink. It was pretty good. I thought that the mix might improve the carbonated water so I tried dissolving some in there. There was a lot of bubbling, and it didn't taste too bad. The mix dissolved well in water and in carbonated water so I was curious about whether it would dissolve in something else. I wasn't going to drink it, but I tried dissolving some of the mix in a little vegetable oil. I got a pretty interesting result. I wondered why things dissolve the way they do. I also wondered if I could use dissolving to make my own flavored soda.

How can you tell when a substance has dissolved?

Take a closer look

Two of the main ingredients in most drink mixes are sugar and coloring. You can do an activity to find out how well these ingredients dissolve in water.

Does sugar dissolve in water?

Sugar

1. Place about 1 tablespoon of room-temperature water in each of 2 clear plastic cups.
2. Add 1 teaspoon of sugar to one cup and swirl for about 10 seconds. Observe.
3. Swirl for another 10 seconds and observe. Swirl for a final 10 seconds and observe.

1. What did you observe when you swirled the sugar and water together?

____

2. What do you think happened to the sugar crystals?

____

____

Name: ______________________________

Defining Dissolving (*continued*)

Does food coloring dissolve in water?

Food coloring

1. Gently place 1 drop of food coloring in the other cup of water. Observe.
2. Gently swirl for a few seconds. Swirl again for a few more seconds.

3. What do you observe?

____

____

____

4. Do you think there is more food coloring in one part of the water than in another? ______
What makes you think that?

____

____

____

5. Do you think there is more sugar in one part of the water than in another?

____

____

____

6. Based on your observations so far, how do you know when a substance has *dissolved*?

____

____

____

Student activity sheet
Activity 4.1

Name: ______________________________

Defining Dissolving (*continued*)

Do sugar and food coloring dissolve in oil?

Sugar

1. Place 1 tablespoon of vegetable oil in each of 2 clear plastic cups.
2. Add 1 teaspoon of sugar to one cup and swirl for about 10 seconds. Observe.
3. Swirl for another 10 seconds and observe. Swirl for a final 10 seconds and observe.

7. What do you observe?

____

____

____

8. Would you say that the sugar dissolved in the oil? ________________________________

Why?

____

____

____

Food coloring

1. Gently place 1 drop of food coloring in the other cup of oil. Observe.
2. Gently swirl for a few seconds. Swirl again for a few seconds.

9. What do you observe?

____

____

____

10. Would you say that the food coloring dissolved in the oil?________________________

Why?

____

____

____

Student activity sheet
Activity 4.1

Name: ______________________________

Defining Dissolving (*continued*)

11. Even though a substance dissolves in one liquid, will it necessarily dissolve in another?

    ____

    Based on your observations in this activity, explain your answer.

    ____

    ____

    ____

    ____

12. How can you tell when a substance has dissolved?

    ____

    ____

    ____

    ____

What's next?

You saw that sugar and food coloring dissolve in water but don't dissolve in oil. So we can safely say that just because one substance dissolves in one liquid, it won't necessarily dissolve in another. When a substance dissolves, it is broken all the way down to its molecules or ions. These are so small and so well-mixed that you can't see them and they don't settle to the bottom. In the activity, you also saw that solids, like sugar, and liquids, like food coloring, can dissolve. In the coming activities, you'll learn more about dissolving solids and liquids and see that gases can dissolve, too.

Activity 4.2
Dissolving a substance in different liquids

Does colored sugar dissolve equally well in water, vegetable oil, and alcohol?

In the introductory story on *Activity sheet 4.1*, the student added drink mix to different liquids. Many drink mixes are sugar, coloring, and flavoring. In this activity, students make colored sugar and add it to water, alcohol, and oil to discover some interesting differences in dissolving.

Materials needed for each group

Water
Vegetable oil
Isopropyl rubbing alcohol, 70%
Sugar
Food coloring
Zip-closing plastic bag, sandwich size
3 Clear plastic cups
3 Popsicle sticks or stirrers
1 Teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**

Preparing materials

- Place 1 tablespoon of sugar in a sandwich-sized zip-closing plastic bag.
- You may choose to add 1 drop of food coloring to the sugar in the bag, or distribute bottles of food coloring so that each group can add the food coloring to the sugar on their own.
- Use a permanent marker to label 3 clear plastic cups **water**, **alcohol**, and **vegetable oil**.
- Place 1 tablespoon of each liquid in its labeled cup.

Activity sheet

Copy *Activity sheet 4.2—Dissolving a substance in different liquids*, pp. 190–191, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 4.2
Dissolving a substance in different liquids

Question to investigate

Does colored sugar dissolve equally well in water, vegetable oil, and alcohol?

1. Introduce the activity.

Tell students that water, alcohol, and oil are all commonly used to dissolve different substances. Depending on what the substance is, it may dissolve better in one of these liquids than another. For example, vanilla can be dissolved in a type of alcohol to make vanilla extract, but it does not dissolve well in water. Some vitamins, like Vitamin C, dissolve best in water, while others, like Vitamin E, dissolve best in oil. One of the properties of a substance is how well it dissolves in a particular liquid.

Distribute *Activity sheet 4.2—Dissolving a substance in different liquids.* Tell students they will make colored sugar and see how well it dissolves in water, rubbing alcohol, and vegetable oil.

2. Show students how to make colored sugar.

Demonstrate how to make colored sugar before having your students do it.

Procedure

1. Add 1 drop of food coloring to 1 tablespoon of sugar in a sandwich-sized zip-closing plastic bag.
2. Leaving air in the bag, seal the bag securely.
3. Shake the bag vigorously until the sugar is thoroughly colored.

3. Discuss with students how to design an experiment to compare how well colored sugar dissolves in water, alcohol, and vegetable oil.

Ask students how they would design an experiment to see how well colored sugar dissolves in water, alcohol, and oil. Students should suggest using the same amount of the same colored sugar in the same amount of each liquid and that the liquids should all be at the same temperature. They should also suggest stirring each in the same way and for the same amount of time.

4. Have students mix colored sugar in water, alcohol, and oil and record their observations.

Procedure

1. Add 1 teaspoon of colored sugar to 1 tablespoon of water, alcohol, and vegetable oil.
2. Stir each with a clean popsicle stick.
3. Record your observations on *Activity sheet 4.2.*

5. Discuss student observations.

Ask students questions like the following:

- What do you observe in each cup?
- Does the color seem to dissolve more in one liquid than in another?
- Does the sugar seem to dissolve more in one liquid than in another?

Expected results:

***Water*—The color and the sugar dissolve completely in the water.**

***Alcohol*—The color dissolves, but the sugar does not dissolve.**

***Oil*—The color does not dissolve, and neither does the sugar.**

Tell students that the amount of a substance that can dissolve in a liquid is called its *solubility.* Point out the similarity in the words *dissolve* and *solubility.*

6. Have students add to the class list about dissolving.

Ask students: What did you find out about dissolving from this activity? Students should realize that just because something dissolves in one liquid, doesn't necessarily mean that it will dissolve in another. They may also conclude that if a material is made of more than one substance, like colored sugar, one substance might dissolve while the other does not.

Student activity sheet
Activity 4.2

Name: ______________________

Dissolving a substance in different liquids

Does colored sugar dissolve equally well in water, vegetable oil, and alcohol?

Make colored sugar

Procedure

1. Your teacher will give you a plastic bag with 1 tablespoon of sugar in it. Add 1 drop of food coloring to the sugar.
2. Leaving air in the bag, seal the bag securely.
3. Shake the bag vigorously until the sugar is thoroughly colored.

Conduct the experiment

Procedure

1. Add 1 teaspoon of colored sugar to 1 tablespoon of water, alcohol, and vegetable oil.
2. Stir each with a clean popsicle stick.
3. Record your observations below.

What do you observe?

Describe what happens to both the color and the sugar when you stir colored sugar in each liquid.

Water	Alcohol	Oil

Name: ______________________________

Dissolving a substance in different liquids (*continued*)

1. In the experiment, you compared how well colored sugar dissolves in water, alcohol, and oil. What did you do to make sure it was a fair comparison?

2. If a substance dissolves in one liquid, will it necessarily dissolve equally well in another?

   Explain your answer using evidence from your experiment.

3. Let's say your teacher gave you a sample of water and a sample of isopropyl rubbing alcohol but did not tell you which one was which. Assuming you had no colored sugar; do you think dissolving salt or some other solute might help you identify the liquids? Why or why not?

Activity 4.3
Temperature affects dissolving

Does cocoa mix dissolve better in hot water or cold water?

Most solids dissolve better in a liquid when the liquid is heated. Students will begin this activity by comparing how well cocoa mix dissolves in cold and hot water. They will see that cocoa mix dissolves much better in hot water. In the follow-up *Demonstration 4a*, students will see that heating a liquid affects the solubility of different solids to different extents.

Materials needed for each group

Hot water
Cold water
Powdered cocoa mix
2 Clear plastic cups
2 Popsicle sticks or stirrers
Small-volume measures like ¼ cup and 1 teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Since student groups will plan their own experiment to answer the question, the materials and amounts may vary.

Preparing materials

- Either give each group one packet of cocoa mix or place about 2 teaspoons of cocoa mix in a small labeled cup for each group.

Activity sheet

Copy *Activity sheet 4.3—Temperature affects dissolving*, p. 195, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 4.3
Temperature affects dissolving

Question to investigate

Does cocoa mix dissolve better in hot water or cold water?

1. Have students discuss their experiences dissolving substances in hot and cold water.

Ask students how they would make hot chocolate from a powdered cocoa mix. Then ask students if they could make "cold chocolate" by stirring the mix into cold water or milk. Tell students that in the following activity, they will compare how well cocoa mix dissolves in both cold and hot water.

Distribute *Activity sheet 4.3—Temperature affects dissolving.*

2. In groups, have students design an experiment to compare how well hot cocoa mix dissolves in cold and hot water.

As you listen to each group's discussion make sure they address the following variables:

- Number of cups needed
- Amount of water in each cup
- Amount of cocoa in each cup
- Method and amount of time stirring

Students should realize that they will need to keep these variables the same. The only thing that should be different in each cup is the temperature of the water. Either have each group conduct its own experiment according to the groups' plans, or have a class discussion to decide on a procedure that everyone will use.

3. Have students conduct an experiment to see how well cocoa mix dissolves in cold and hot water.

The following procedure is one method students can use. Many different ratios of cocoa mix and water will work. The amounts suggested in this procedure do not follow the preparation directions on the package, but use convenient teaspoon and tablespoon measurements.

Procedure

1. Place ¼ cup of cold and hot water in each of 2 cups.
2. At the same time, add 1 teaspoon of cocoa mix to each cup.
3. Stir each for 10 seconds and observe.
4. Stir for another 10 seconds and observe again.

4. Discuss students' procedures and their results.

Ask students how they conducted their experiments and what they did to ensure that their test was fair.

Expected results: **The cocoa mix in the hot water will appear to mix in with the water, coloring it dark brown. The cocoa mix in the cold water will remain mostly dry on the surface of the water. With time and enough stirring, the cocoa mix in the cold water will also mix into the water and color it.**

Note: Cocoa mix is used in this activity because making hot chocolate from a mix is a common experience and shows how heating a liquid can affect the way a solid dissolves and mixes into it. The term "dissolving" is not used in its most technical sense in this activity because not all of the components in cocoa mix actually dissolve. Cocoa mix is made up of different ingredients, such as sugar, corn syrup, powdered milk, and cocoa. Some of these substances, like sugar and corn syrup, actually do dissolve in water. The cocoa and the milk probably don't dissolve because they have a fat component that is insoluble. These are likely mixed into the water as a *suspension* as opposed to being part of a solution. For the purpose of this activity, and considering the experience your students have with science, you can use the term "dissolve" to describe the process of the cocoa mixing into the water. For more information about the definition of dissolving, check the *Science background information*, pp. 174–179.

Ask students questions like the following:

- Does cocoa mix dissolve faster in hot or cold water?
- Could you make "cold chocolate" by stirring cocoa mix into cold water?
- What might you do instead if you wanted "cold chocolate"?

5. Have students add to the class list about dissolving.

Ask students: What did you find out about dissolving from this activity? Students should realize that the temperature of a liquid affects dissolving, and that substances seem to dissolve better when a liquid is warmer.

Student activity sheet
Activity 4.3

Name: ______________________________

Temperature affects dissolving

Does cocoa mix dissolve better in hot water or cold water?

Plan your experiment

1. In this experiment, you are going to compare how well cocoa mix dissolves in cold and hot water. Discuss how you will set up your experiment with your group and write your group's plan in the space below.

____

____

____

____

____

____

Conduct your experiment

What do you observe?

2. Describe what happens when you place cocoa mix in cold and hot water.

Cold water	Hot water

3. Based on what you saw in your experiment, does increasing the temperature of a liquid affect how much cocoa will dissolve in it?

____

Demonstration 4a
Temperature affects the solubility of salt and sugar

Do salt and sugar dissolve better in hot water than in cold water?

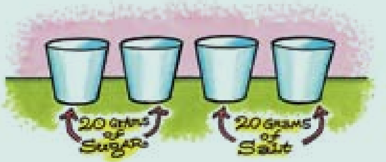
This demonstration builds on the previous activity where students saw that cocoa mix dissolves better in hot water than in cold. In this demonstration, students will observe sugar and salt being dissolved in cold and hot water. Sugar dissolves significantly better in hot water than in cold, but this is not true for salt. Only slightly more salt will dissolve in hot water than in cold. After comparing the results from the activity and demonstration, students should conclude that heating a liquid affects the solubility of different solids to different extents.

Note: This demonstration takes only a few minutes to do but takes about 20–30 minutes for clear results to develop. You can do the demonstration after *Activity 4.3* and wait to see the results the next day. Then students can use the results to complete the activity sheet. This demonstration is also presented differently than other demonstrations in *Inquiry in Action*. Students are asked to help develop the design of the experiment that will serve as the demonstration.

Materials needed for the demonstration

Hot water
Cold water
Sugar
Salt

4 Graduated cylinders
4 Straws
4 Small cups



Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**

Preparing materials

- Use a permanent marker to label 2 small cups **sugar** and 2 more small cups **salt**.
- Use a sensitive scale to weigh 20 grams of sugar for each cup labeled sugar.
- Use a sensitive scale to weigh 20 grams of salt for each cup labeled salt.

Activity sheet

Copy *Demonstration sheet 4a—Temperature affects the solublity of salt and sugar*, pp. 200–201, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Demonstration 4a
Temperature affects the solubility of salt and sugar

Question to investigate

Do salt and sugar dissolve better in hot water than in cold water?

1. Ask students to help design an experiment to test whether temperature affects the solubility of sugar and salt.

Remind students that they have seen that the temperature of water affected the solubility of powdered cocoa mix. Ask students how they could test whether the temperature of water affects the solubility of salt and sugar. Ask students questions such as:

If you were testing sugar first, for example,

- How many samples of sugar should you use?
- Should you use the same amount of sugar in each sample?
- Should the same amount of water be used to dissolve both samples?
- Should the water be the same or different temperatures?

Once students decide how to test the sugar you could ask if the same should be done for the salt.

The procedure below uses specific amounts of water, sugar and salt because these have been tested and show clear results.

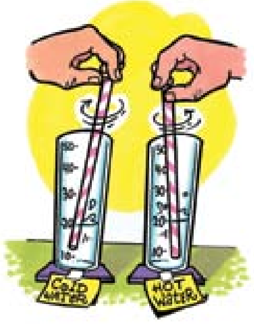
2. Do a demonstration to compare how well sugar dissolves in cold and hot water and how well salt dissolves in cold and hot water.

Note: It may take 20–30 minutes for the sugar and salt to settle so that the results become clear.

Procedure

Sugar in cold and hot water

1. Pour 10 ml of hot water into one graduated cylinder while a student volunteer pours 10 ml of cold water into another.
2. With the help of a student volunteer, pour 20 grams of sugar into each graduated cylinder at the same time.
3. With the help of a student volunteer, stir the contents of each graduated cylinder with a straw for about 1 minute. You and the student should try to stir in the same way and for the same length of time.
4. Allow the contents to settle as you do the same solubility test for salt.



Salt in cold and hot water

5. Repeat Steps 1–3 with salt.

3. Discuss the results of the demonstration and consider whether there is enough evidence to answer the question to investigate.

Ask students what they observed in each pair of graduated cylinders.

Expected results:

***Sugar*: There is a small amount of sugar left at the bottom of the graduated cylinder with the hot water. There is significantly more sugar in the bottom of the cylinder with the cold water.**
***Salt*: There is about the same amount of salt remaining at the bottom of both the hot and cold water cylinders.**

Ask students:

- Does temperature affect the solubility of sugar?
- How do you know?
- Does temperature affect the solubility of salt?
- How do you know?
- Which is affected more by increasing the temperature of water: the solubility of sugar or the solubility of salt?

Since there is a significant difference in the amount of sugar that dissolves in hot water than in cold, students can conclude that temperature greatly affects the solubility of sugar. And since there is only a very slight difference in the amount of salt that dissolves in hot water than in cold, students can conclude that temperature affects the solubility of sugar more than it affects the solubility of salt.

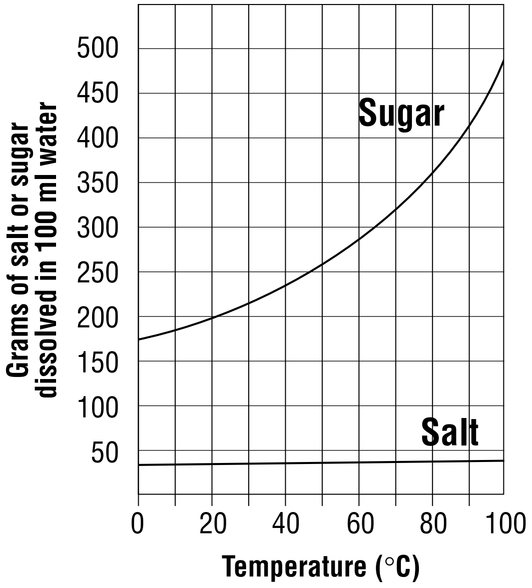
4. Have students use their observations to make statements about the effect of temperature on the solubility of salt and sugar.

Distribute *Demonstration sheet 4a—Temperature affects the solubility of salt and sugar.* Have students answer the questions on the first page of *Demonstration sheet 4a*, based on their observations during the demonstration.

5. Have students interpret the graph comparing the solubility of salt and sugar.

Point out the graph on the second page of *Demonstration sheet 4a*. Ask students if these curves make sense with what they observed in the demonstration.

- The graph shows that much more sugar can dissolve in very hot water than in cold. Students should agree that there was a significant difference in the amount of sugar that dissolved in hot and cold water.
- The graph also shows that only a little bit more salt can dissolve in very hot water than in cold. Students should agree that in the demonstration there was not much difference in the amount of salt that dissolved in hot and cold water.



Solubility of salt and sugar

Review with students how to interpret the graph.

- Each point on the curve for sugar shows the maximum amount of sugar that can dissolve in that temperature of water.
- Each point on the curve for salt shows the maximum amount of salt that can dissolve in that temperature of water.
- To find out how much sugar, or salt, dissolves at a certain temperature, look along the *x*-axis to find the temperature you are considering. Then follow that line straight up to the curve for sugar, or salt.
- Use a ruler or a straight edge to help you look straight across to the *y*-axis to find out the maximum grams of sugar, or salt, that can dissolve in 100 ml of water at that temperature.
- If it's difficult to tell the exact amount that can dissolve at that temperature, make a reasonable guess and write that number in the chart beside the graph.

Note: Be sure to accept a range of reasonable responses in the chart that students complete.

6. Have students add to the class list about dissolving.

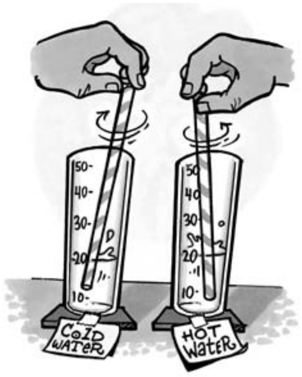
Ask students: What did you find out about dissolving from this demonstration? Students should realize that even though heating a liquid improves dissolving, it doesn't improve it by the same amount for all substances.

Student activity sheet
Demonstration 4a

Name: ______________________

Temperature affects the solubility of salt and sugar

Do salt and sugar dissolve better in hot water than in cold water?



1. Does **sugar** dissolve better in hot water than in cold water? ______________________

   Explain your answer, based on your observations from the demonstration.

2. Does **salt** dissolve better in hot water than in cold water? ______________________

   Explain your answer, based on your observations from the demonstration.

3. Which is affected most by increasing the temperature of the water—the solubility of salt or the solubility of sugar? ______________________

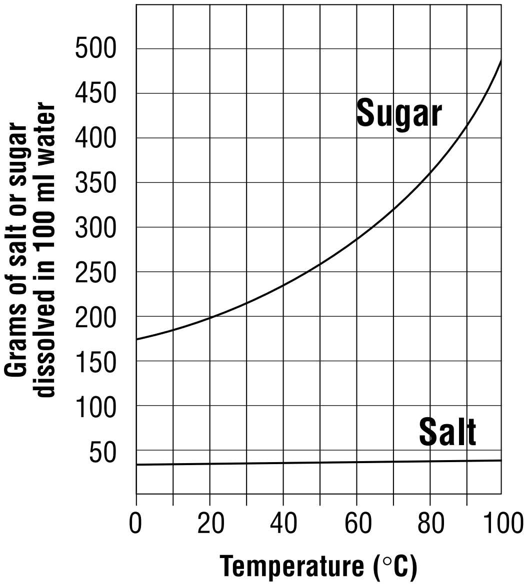
   Explain your answer.

Name:______________________________

Temperature affects the solubility of salt and sugar (*continued*)

The curves on the graph below show the amount of salt and sugar that can be dissolved in water at different temperatures. Use a ruler or straight edge to help you read the graph and fill out the chart beside it.

Solubility of salt and sugar



How much salt and sugar will dissolve in water at different temperatures?	Sugar (g)	Salt (g)
Freezing water 0 °C		
Room-temp water 20 °C		
Warm water 50 °C		
Very hot water 80 °C		
Boiling water 100 °C		

4. Which is affected most by increasing the temperature of the water—the solubility of salt or the solubility of sugar? ____

   Use the graph and chart to explain your answer.

   ____

   ____

   ____

Activity 4.4
Dissolving different liquids in water

Do all liquids dissolve in water?

In *Activity 4.3* and *Demonstration 4a,* students explore different *solids* dissolving in water. In this activity, students add different liquids to water and apply their working definition of “dissolving” to their observations. After observing isopropyl rubbing alcohol, vegetable oil, and corn syrup in water, students can conclude that while some liquids may dissolve in water, different liquids dissolve in water to different extents.

Materials needed for each group

Water
Vegetable oil
Isopropyl rubbing alcohol, 70%
Corn syrup
3 Clear plastic cups
3 Small cups
3 Popsicle sticks or stirrers

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using isopropyl alcohol, read and follow all warnings on the label.**

Preparing materials

- Use a permanent marker to label 3 small cups **alcohol**, **oil**, and **corn syrup**.
- Place 1 tablespoon of each liquid in its labeled cup.

Activity sheet

Copy *Activity sheet 4.4—Dissolving different liquids in water*, p. 204, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 4.4
Dissolving different liquids in water

Question to investigate

Do all liquids dissolve in water?

1. Introduce the idea that liquids can dissolve in water.

Remind students that they have seen that solids can dissolve in liquids. Ask students: Do you think that liquids can dissolve in other liquids?

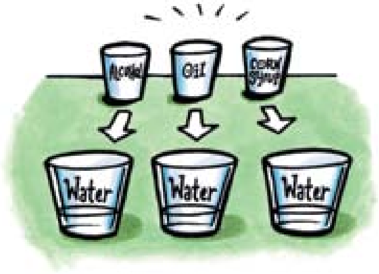
As a class, have students describe what they would do to compare how isopropyl alcohol, vegetable oil, and corn syrup dissolve in water. Students should agree that they will need three cups filled with the same amount of water. They should also realize that it's important that the same temperature water is used in each cup.

2. Have students conduct an activity to see how well isopropyl alcohol, vegetable oil, and corn syrup dissolve in water.

Distribute *Activity sheet 4.4—Dissolving different liquids in water.* Students will follow the procedure on the activity sheet, record their observations, and consider whether each of the liquids dissolves in water.

Procedure

1. Half-fill three clear plastic cups with room-temperature water.
2. While looking at the water from the side, slowly pour the alcohol into the first cup of water.
3. Observe first to see if the alcohol dissolves in the water.
4. Stir to see if the alcohol dissolves.
5. Record your observations on *Activity sheet 4.4*.
6. Repeat Steps 2–5 for vegetable oil and corn syrup.



3. Discuss student observations.

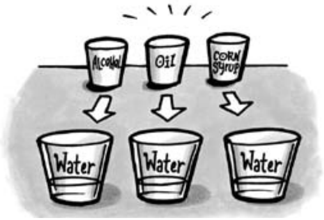
Expected results: **The alcohol is visible as it mixes into the water but quickly dissolves and turns clear. Stirring is not needed. The oil will drop into the water and then rise to the surface forming a layer. When stirred, the oil breaks apart a bit and then forms a layer on the surface of the water again. The oil does not dissolve. The corn syrup will sink to the bottom and stay there. After stirring, it dissolves and the solution turns clear.**

4. Have students add to the class list about dissolving.

Ask students: What did you find out about dissolving from this activity? Students should realize that not all liquids dissolve in water, and those that do, dissolve in water differently.

Student activity sheet
Activity 4.4

Name: ______________________________



Dissolving different liquids in water

Do all liquids dissolve in water?

You know that some solids, like sugar, can dissolve in water. In this experiment, you will find out if *liquids* can dissolve in water.

Conduct the experiment

Procedure

1. Half-fill three clear plastic cups with room-temperature water.
2. While looking at the water from the side, slowly pour the alcohol into the first cup of water.
3. Observe first to see if the alcohol dissolves in the water.
4. Stir to see if the alcohol dissolves.
5. Record your observations in the chart below.
6. Repeat Steps 2–5 for vegetable oil and corn syrup.

What do you observe?

1. Describe what happens when you mix the following liquids with water.

Isopropyl alcohol	**Vegetable oil**	**Corn syrup**
Does isopropyl alcohol dissolve in water? ___________	Does vegetable oil dissolve in water? ___________	Does corn syrup dissolve in water? ___________
How do you know?	How do you know?	How do you know?

2. Do all liquids dissolve equally well in water? ______________________________
Use evidence from your experiment to justify your answer.

____

____

____

____

Demonstration 4b
Gases can dissolve in liquids

Can a gas dissolve in a liquid?

Students have discovered that solids and liquids can dissolve in water. In this demonstration they will see that gases, in this case carbon dioxide, can also dissolve in water. In previous activities, students added solids and liquids to water to see if and how well they dissolve. This demonstration begins with gas already dissolved in water. Students will observe the gas as it becomes “undissolved” or comes out of solution.

Materials needed for the demonstration

Unopened bottle of club soda, 1- or 2-liter

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- The carbonated water used in this demonstration will also be used in *Activity 4.5*. If you have 5 or fewer student groups, use a 1-liter bottle in the demonstration. If you have 6 or more groups, use a 2-liter bottle.

Preparing materials

- Remove the label from the bottle of carbonated water. **Do not open the bottle.** You will open the bottle later as part of the demonstration.

Activity sheet

Copy *Demonstration sheet 4b—Gases can dissolve in liquids*, p. 207, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Demonstration 4b
Gases can dissolve in liquids

Question to investigate

Can a gas dissolve in a liquid?

1. Show students the bubbles that appear when a new bottle of soda is opened.

Remove the label from a bottle of carbonated water. Ask students how a bottle of carbonated water is different from a regular bottle of water. Students will probably say that carbonated water has bubbles. Then ask students if they see any bubbles in the carbonated water. They shouldn't see any yet.

Procedure

1. Very slowly unscrew the bottle cap.
2. Wait a few seconds to allow students to observe the bubbles.
3. Tighten the cap on the bottle.

2. Discuss student observations.

Ask students what they observed as you opened and then closed the bottle of soda.

Expected results: **When you loosen the cap, many bubbles will appear throughout the soda and rise up through the water to the surface, where they pop. When you tighten the cap, fewer bubbles will form.**

Tell students that the bubbles in the water are filled with the gas carbon dioxide. This gas is the reason why this water is called "*carbon*ated water".

3. Have students record their observations and further consider the concept of dissolving.

Distribute *Demonstration sheet 4b—Gases can dissolve in liquids.* The idea that carbon dioxide gas is dissolved in water and comes out of solution in the form of bubbles will be expanded upon in *Activities 4.5* and *4.6*.

4. Have students add to the class list about dissolving.

Ask students: What did you find out about dissolving from this demonstration? Students should realize that gases can be dissolved in a liquid. They may also add that dissolved gas can come out of a liquid. Remind students that they saw gas bubbles come out of solution, rise to the surface, and pop. Tightening the cap slowed the rate of gas bubbles coming out of solution. Tell students that in the next activity they will explore another way to help slow the rate of gas leaving soda.

Student activity sheet
Demonstration 4b

Gases can dissolve in liquids

Can a gas dissolve in a liquid?

Carbonated water is made by dissolving carbon dioxide gas in water.

1. What did you see when your teacher slowly opened a bottle of carbonated water?

2. What gas are the bubbles made of? ________________________

3. Where was this gas before the bottle was opened?

4. Based on this demonstration, what should you add to your class list about dissolving?

Activity 4.5

Temperature affects the solubility of gases

Does temperature have an effect on how quickly dissolved gas escapes from a soda?

In *Demonstration 4b*, students see bubbles of carbon dioxide gas escape from an open bottle of carbonated water. Students conclude that the gas must have been dissolved in the water. In *Activity 4.3* and *Demonstration 4a*, students realize that temperature affects the solubility of solids differently. Could temperature affect the solubility of gases, too? In this activity, students heat and cool carbonated water to find out whether temperature has an effect on how fast the dissolved gas leaves carbonated water.

Materials needed for each group

Club soda
Hot water
Cold water
4 Clear plastic cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Use the bottle of club soda opened during *Demonstration 4b*.
- Materials may vary depending on how students decide to heat and cool the carbonated water.

Preparing materials

- Fill one of the students' clear plastic cups about ⅔ of the way with carbonated water for each group. Students will split the carbonated water evenly into two cups during the activity.

Activity sheet

Copy *Activity sheet 4.5—Temperature affects the solubility of gases*, p. 211, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 4.5
Temperature affects the solubility of gases

Question to investigate

Does temperature have an effect on how quickly dissolved gas escapes from a soda?

1. Introduce the idea that temperature might affect the solubility of a gas.

Remind students that when they dissolved solids in water, they discovered that temperature has an effect on the solubility of the solid. Since temperature had an effect on solids dissolving in water, maybe temperature has an effect on gases dissolving in water, too. Ask students a question like the following:

- Do you think gas bubbles stay in carbonated water better if the carbonated water is heated or if it is cooled?

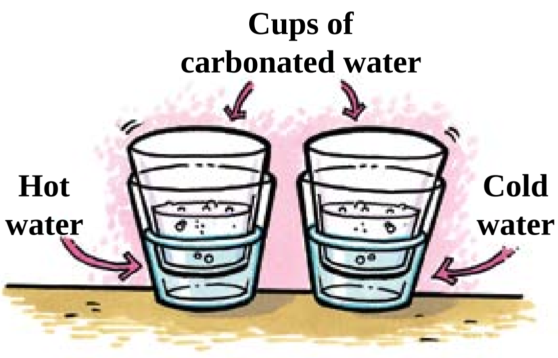
2. As a class, design an experiment to test whether temperature affects how quickly gas escapes from soda.

Distribute *Activity sheet 4.5—Temperature affects the solubility of gases*. Be sure to review the first paragraph of the activity sheet with students before they begin to plan their experiments. Students should realize that they can compare whether carbon dioxide gas is coming out or staying in solution by comparing the quantity of bubbles they see rise to the surface and pop. More bubbles rising and popping means more gas is coming out of solution.

Ask students how they might set up an experiment to see if the carbon dioxide gas in carbonated water stays dissolved or comes out of solution more if heated or cooled. Students should realize that they will need two cups of carbonated water. They will then need to heat one and cool the other. One simple way to heat and cool the cups is to use a hot or cold water bath like the one described below.

Procedure

1. Open a new bottle of club soda.
2. Fill two clear plastic cups about ⅓ of the way with the soda.
3. Fill one empty cup about ⅓ of the way with ice cold water and another empty cup about ⅓ of the way with hot tap water.
4. Place one of the soda cups in the cold water and place the other soda cup in the hot water as shown.
5. Watch the surface of the soda in both cups.



3. Discuss student observations.

***Expected results*: More bubbles will form and rise to the surface in the soda placed in hot water.**

Ask students questions like the following:

- Can you tell if there is a difference in the amount of gas that seems to be escaping from each sample of soda?
- What do you see that makes you think that?
- Based on what you observed in this experiment, why do you think people store soda pop in the refrigerator?

4. Have students add to the class list about dissolving.

Ask students: What did you find out about dissolving from this activity? Students should realize that dissolved gas comes out of solution faster from warm water than cold. The reverse is also true: Dissolved gas tends to stay dissolved better in cold water.

Tell students that soda isn't the only common example of liquid with dissolved gas in it. The water in which fish or other aquatic creatures live contains dissolved oxygen gas. These creatures use their gills to get the oxygen from the water in order to stay alive.

Student activity sheet
Activity 4.5

Temperature affects the solubility of gases

Does temperature have an effect on how quickly dissolved gas escapes from a soda?

When gas bubbles rise to the surface of a liquid and pop, the gas goes into the air above the liquid. So, watching bubbles rise to the surface and pop can give you a sense of how much gas is becoming “un-dissolved” or is leaving the solution. In this activity, you will compare the amount of gas that leaves warm and cold carbonated water by observing the number of bubbles that rise from each.

Plan your experiment

1. Use drawings and captions to describe your experimental design.

Conduct your experiment

What do you observe?

2. Go back to the drawing you made when planning your experiment. Add to your drawing and use captions to describe your observations.

3. Does gas escape faster from warm or cold carbonated water? ___________________
How do you know?

____

____

4. Why do you think people store soda pop in the refrigerator?

____

____

Activity 4.6
A dissolving challenge

How can you make a lemon soda that keeps as much carbonation as possible?

In *Demonstration 4b* and *Activity 4.5*, students see that dissolved gas comes out of carbonated water when a bottle is opened and when the temperature is increased. In this activity, students add objects and substances to carbonated water to discover that added objects also increase the rate dissolved gas comes out of solution. Students are then challenged to make a lemon soda that retains as much carbonation as possible by using carbonated water, sugar, and lemon juice. Students identify the difficulty in making a fizzy lemon soda, develop a better method, and then test it.

Materials needed for each group

1 Small bottle of club soda
Lemon juice
Sugar
Pipe cleaner
M&M's
Popsicle stick or stirrer
1 Teaspoon
4 Clear plastic cups
2 Small cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Materials may vary depending on how students decide to test their lemon sodas for carbonation. The procedure described in the activity uses M&M's for the test.

Preparing materials

- Either give each group a small unopened bottle of club soda or pour about 1 cup of carbonated water into a small bottle and secure tightly with a lid.
- Label 2 small cups **sugar** and **lemon juice** for each group.
- Place about 2 tablespoons of sugar in its labeled cup.
- Add about 2 tablespoons of lemon juice to its labeled cup.

Activity sheet

Copy *Activity sheet 4.6—A dissolving challenge*, pp. 216–217, and distribute one per student when specified in the activity. Give each student a piece white construction paper to create a mini-report about the process of making a fizzy lemon soda. Instructions are included on the second page of the activity sheet.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 218–219. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 4.6
A dissolving challenge

Question to investigate

How can you make a lemon soda that keeps as much carbonation as possible?

1. Have students add objects to carbonated water.

Distribute *Activity sheet 4.6—A dissolving challenge*. Have students follow the procedure and record their observations.

Procedure

1. Pour ¼ cup of club soda into a clear plastic cup.
2. Sprinkle a pinch of sugar onto the surface of the soda and observe.
3. Place an M&M in the soda. Watch it closely.
4. Place a pipe cleaner in the soda and observe.

2. Discuss student observations.

Expected results: **Bubbles form on the sugar, M&M, and pipe cleaner, and rise to the surface.**

Ask students questions like the following:

- Does the carbonated water in your cup have as much gas as it did before you added all of the objects?
- Where did the carbon dioxide gas that was dissolved in the water go?

Students should realize that their club soda lost carbonation with the addition of each object. Explain that the gas that was dissolved in the water attached to and accumulated on the objects. When enough gas accumulated, a bubble formed and rose to the surface.

Demonstration
3. As a demonstration, make a lemon soda by adding lemon juice and sugar to carbonated water.

Procedure

1. Pour ¼ cup of club soda into a clear plastic cup.
2. Add 1 teaspoon of lemon juice and stir with the spoon until the lemon juice is dissolved.
3. Add 1 teaspoon of sugar and stir with a spoon until the sugar is completely dissolved.

4. Discuss student observations.

Have students record their observations on *Activity sheet 4.6*. Then as a whole class, discuss student observations of the demonstration.

Expected results: **When lemon juice is added to club soda, few additional bubbles form. When sugar is added, much more bubbling occurs. Stirring until the sugar dissolves causes even more bubbles to form.**

5. Identify the problem of excessive bubbling when sugar was added.

Students should realize that adding sugar to carbonated water and stirring until it dissolves causes a great deal of carbon dioxide gas to escape. Remind students that the bubbles they saw when sugar was added were filled with carbon dioxide gas that was once dissolved in the water. When the bubbles formed, they rose to the surface of the carbonated water and popped, sending the carbon dioxide gas out of the soda and into the air. This means that the lemon soda you made has lost a lot of its carbonation, making it flat.

Then ask students questions like the following:

- What are “flat” sodas like?
- Which ingredient, lemon juice or sugar, causes most of the bubbling?

6. Have students write about the problem of making a lemon soda the way it was made in the demonstration.

Pass out one piece of white construction paper for each student. Direct students to fold the construction paper in half like a greeting card and label each page with the titles listed on the activity sheet. Students should then design a front cover and write about the problem with the way the lemon soda was made in the demonstration.

7. Challenge students to develop a method of making a lemon soda so that little gas is lost in the process.

Tell students that there must be a way to solve the problem of sugar making carbon dioxide gas leave carbonated water. After all, there are many sweet carbonated beverages on the market. Don’t tell students yet, but one solution is to dissolve the sugar in the lemon juice first. Then pour this syrup into the carbonated water. This method is described in the following procedure. If students need a hint, remind them that when the lemon juice was added, there wasn’t much bubbling. They will need to think of a way to add only liquids to the carbonated water.

Procedure

1. In a separate cup, combine 1 teaspoon of sugar and 1 teaspoon of lemon juice. Stir until the sugar is dissolved.
2. Fill your clear plastic cup about ¼ of the way with club soda.
3. Pour the sugar and lemon juice solution into the club soda and stir to mix.

Expected results: **There is much less bubbling using this method than there was when the sugar was added separately from the lemon juice in the demonstration.**

8. Have students write how they made a lemon soda that kept its carbonation better than the one made in the demonstration.

Have students add to their mini-report by describing their group's method for making a fizzy lemon soda on the page titled "A Better Way".

9. Have students develop a test to compare a lemon soda made with their method to a lemon soda made like the one in the demonstration.

Ask students what they think would happen if you would have placed salt, an M&M, or a pipe cleaner, in the lemon soda that you made in the demonstration. Would many bubbles form? Would more bubbles form in the lemon soda that students made?

Challenge students to develop a test to compare the amount of carbonation left in a soda made with their method to the amount left in a soda made like the one in the demonstration. However they choose to test the sodas, students should be sure to make both sodas at the same time and test them in the same way.

Procedure

1. Make a lemon soda using your method while your partners make a lemon soda using the method shown in the demonstration.
2. Place an M&M in each soda at the same time.
3. Observe from the side to compare the amount of bubbling in each soda.

***Expected results*: More bubbles rise from the M&M placed in the lemon soda made with the students' method.**

10. Have students describe their test and results on the last page of their mini-reports.

Students should write about the test they conducted on the page titled "Testing for Carbonation".

Tell students that syrups are often used to flavor sodas. If they look at the ingredient list on a can of soda pop, they will see that corn syrup is used as a sweetener. Ask students to explain one reason why corn syrup is a better sweetener to use than granulated sugar.

Student activity sheet
Activity 4.6

A dissolving challenge

What kinds of things make carbonated water lose its carbonation?

In the demonstration, your teacher opened a bottle of carbonated water, causing bubbles of carbon dioxide gas to come out of solution. In the last activity you saw that increasing the temperature of carbonated water causes more carbon dioxide gas to come out of solution. In this activity, you will see another way to cause the gas to leave the carbonated water.

Conduct the experiment

Procedure

1. Pour ¼ cup of club soda into a clear plastic cup.
2. Sprinkle a pinch of sugar onto the surface of the soda and observe.
3. Place an M&M in the soda. Watch it closely.
4. Place a pipe cleaner in the soda and observe.

Record your observations

Object	What did you observe?
Sugar	
M&M	
Pipe cleaner	

Watch your teacher make a lemon soda

1. Which ingredient, lemon juice or sugar, causes most of the bubbling? ______________

____

2. Which causes more gas bubbles to escape from carbonated water: solids or liquids?

____

3. Think about the amount of bubbling you saw when you placed sugar, an M&M, and a pipe cleaner in carbonated water. Would you expect as much bubbling if you placed these objects in the lemon soda your teacher made? ______________

Why or why not? ____

A dissolving challenge (*continued*)

How can you make a lemon soda that keeps as much carbonation as possible?

Make a better lemon soda

As you saw when your teacher made a lemon soda, adding lemon juice and sugar separately and stirring causes a great deal of gas to escape, which leaves you with a "flat" soda. Using the same ingredients your teacher used, find a way to make a lemon soda that keeps as much carbonation as possible.

Lemon soda ingredients

¼ cup club soda
1 teaspoon lemon juice
1 teaspoon sugar

Prove that your lemon soda is better

You saw that placing an object in carbonated water can give you an idea of how much carbonation is left. Develop a test to compare the amount of carbonation left in your lemon soda with the amount left in a soda made like the one in the demonstration.

Write a mini-report about making a fizzy lemon soda

Fold a piece of white construction paper in half, like a greeting card. Then label each page with the following titles.

Page	Title
Outside front cover	How to Make a Fizzy Lemon Soda
Inside left page	The Problem
Inside right page	A Better Way
Outside back cover	Testing for Carbonation

How to Make a Fizzy Lemon Soda

Draw a picture of a fizzy lemon soda as a cover picture for your mini-report.

The Problem

List the problems you observed with the lemon soda your teacher made.

A Better Way

Describe your group's most successful method for making a lemon soda that lost little carbonation as it was being made.

Testing for Carbonation

Describe your test to show that your group's method for making lemon soda is really better than the method your teacher used.

Investigation 4—Dissolving solids, liquids, and gases

Assessment rubric

Can solids, liquids, and gases all dissolve?

Activity 4.1—Defining dissolving
How can you tell when a substance is dissolved?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations
☐ ☐ ☐ Develops a working definition for *dissolve* based on observations

Circle one: Good Satisfactory Needs Improvement

Activity 4.2—Dissolving a substance in different liquids
Does colored sugar dissolve equally well in water, vegetable oil, and alcohol?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations
☐ ☐ ☐ Identifies variables that were controlled in the experiment
☐ ☐ ☐ Makes generalizations about solids dissolving in liquids based on evidence

Circle one: Good Satisfactory Needs Improvement

Activity 4.3—Temperature affects dissolving
Does cocoa mix dissolve better in hot water or cold water?

G S N
☐ ☐ ☐ Plans experiment with group
☐ ☐ ☐ Identifies variables and controls them
☐ ☐ ☐ Conducts experiment
☐ ☐ ☐ Records observations
☐ ☐ ☐ Makes generalizations about the effect of heat on dissolving based on evidence

Circle one: Good Satisfactory Needs Improvement

Demonstration 4a—Temperature affects the solubility of salt and sugar
Do salt and sugar dissolve better in hot water than in cold water?

G S N
☐ ☐ ☐ Uses evidence from the demonstration to make statements about the solubility of salt and sugar in cold and hot water
☐ ☐ ☐ Identifies whether the solubility of salt or sugar is most affected by increasing the temperature
☐ ☐ ☐ Uses the solubility curves on a graph to determine how much salt and sugar can dissolve at various temperatures
☐ ☐ ☐ Uses the solubility curves on a graph to compare the effect of temperature on the solubility of salt and sugar

Circle one: Good Satisfactory Needs Improvement

Investigation 4—Dissolving solids, liquids, and gases

Assessment rubric (*continued*)

Activity 4.4—Liquids mix differently in water

Do all liquids dissolve in water?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records and interprets observations
☐ ☐ ☐ Explains reasoning

Circle one: Good Satisfactory Needs Improvement

Demonstration 4b—Gases can dissolve in liquids

Can a gas dissolve in a liquid?

G S N
☐ ☐ ☐ Records observations
☐ ☐ ☐ Recognizes that a gas can dissolve in water

Circle one: Good Satisfactory Needs Improvement

Activity 4.5—Temperature affects the solubility of gases

Does temperature have an effect on how quickly dissolved gas escapes from a soda?

G S N
☐ ☐ ☐ Plans experiment to investigate the question
☐ ☐ ☐ Uses drawings and captions to record observations
☐ ☐ ☐ Uses evidence to determine whether gas escapes faster from warm or cold carbonated water
☐ ☐ ☐ Applies understanding to explain why opened soda pop is often stored in the refrigerator

Circle one: Good Satisfactory Needs Improvement

Activity 4.6—A dissolving challenge

How can you make a lemon soda that keeps as much carbonation as possible?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records observations
☐ ☐ ☐ Makes a prediction based on previous observations
☐ ☐ ☐ Produces a mini-report documenting the challenge of making a fizzy lemon soda

Circle one: Good Satisfactory Needs Improvement

To earn a “B”, a student must receive a “Good” in each category.
To earn an “A”, a student must also exhibit some of the following qualities throughout this investigation.

- ☐ Makes excellent contributions to the class chart about dissolving
- ☐ Writes outstanding explanations
- ☐ Possesses a well-developed understanding of variables and how to control them
- ☐ Participates well in class discussions
- ☐ Participates well in group work
- ☐ Uses scientific thinking
- ☐ Consistently exhibits exceptional thought and effort in tasks
- ☐ Other____

Teacher instructions

Review and apply

The following section, titled *Review and apply*, contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 4*, they will reflect on their learning, apply what they learned about experimental design to a new activity, and read about the making of soda pop. An optional reading explains, on the molecular level, dissolving solids, liquids, and gases and the effect of temperature on dissolving. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned in the dissolving investigation.

Distribute *Review and apply: Let's review*, pp. 222–224, and give students an opportunity to consider the statements about solids and liquids dissolving in water. Students should describe tests that could support their view.

The rest of this *Review and apply worksheet* involves graphing the solubility of potassium chloride. Let students know that they should use the data in the chart to plot points on the graph at the bottom half of the page. They should then connect the dots to create either a curve like the solubility of sugar or more of a line, like the solubility of salt. Explain to students that they will use the graph to answer questions about the solubility of sucrose (sugar), sodium chloride (table salt), and potassium chloride (salt substitute).

Science in action!

2. Have each student design and conduct an experiment to find out whether the size of a material affects the rate at which it dissolves.

Distribute *Review and apply: Science in action!*, pp. 225–226 along with two sugar cubes. Ask students to think about how they could use these two sugar cubes to investigate the question. You may need to help students realize that crushing one of the sugar cubes will give them the same amount of sugar, but in a smaller size. Then ask students why it is important to use the same amount of sugar in each test.

Provide cups, water, etc., so that students can conduct the experiment. This activity and the corresponding activity sheet can serve as a summative assessment, evaluating students' skills in designing an experiment, identifying and controlling variables, recording observations, and using evidence to answer a question.

3. When students have completed their experiments and worksheets, compare experimental designs and results.

Ask students the question they investigated: Does the size of the material being dissolved affect the rate at which it dissolves? How? Students should agree that the crushed sugar cube dissolved faster than the whole one did. Explain that water could more easily surround more sugar with the crushed cube than with the whole cube. Water could only surround the outside of the whole cube. Since more water could surround the sugar from the crushed cube, it dissolved faster. Ask students if their observations from their experiments support this idea that smaller pieces can dissolve faster than larger ones.

Think about it

4. Have students read about the making of soda pop and then answer questions.

Distribute *Review and apply: Think about it*, pp. 227–230. Tell students that the article they will read gives a brief history of soda pop and describes how it is manufactured today.

For additional information about Joseph Priestley's important discoveries, go to **www.inquiryinaction.org**

What's going on here? (*optional*)

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about dissolving on the molecular level and answer questions about the reading.

Distribute *Review and apply: What's going on here?*, pp. 231–235. This reading describes the structure of the water molecule and explains how this structure helps it to dissolve solids, liquids, and gases. It also addresses the effect temperature has on the solubility of different substances. Discuss the process of dissolving with students based on the reading.

This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level.

Material to support this reading can be found at
www.inquiryinaction.org

Name: ______________________________

Let's review

At the beginning of this investigation a student noticed that drink mix dissolved well in water but dissolved differently when mixed with other liquids. You did a similar activity with colored sugar and then extended the activity to investigate many other aspects of dissolving.

1. If someone said to you, "Since a solid dissolves in water, it will dissolve just as well in other liquids."

   Would you agree or disagree? ____

   Describe a test you could do that would show whether or not you are right. Be sure to explain how you would control the variables so that your test is fair.

   ____

   ____

   ____

   ____

   ____

   ____

2. If someone said to you, "If one liquid dissolves in water, that means that other liquids will dissolve just as well in water too."

   Would you agree or disagree? ____

   Describe a test you could do that would show whether or not you are right. Be sure to explain how you would control the variables so that your test is fair.

   ____

   ____

   ____

   ____

   ____

Name: ____________________________

Let's review (*continued*)

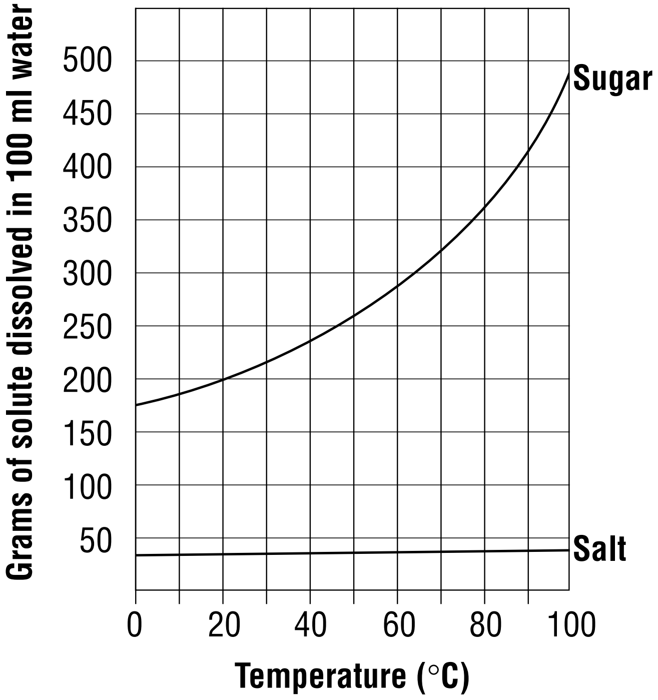
3. The chart below shows approximately how much *potassium chloride* can dissolve in 100 milliliters of water at different temperatures. Potassium chloride is used as a salt substitute for people who should not eat regular salt (sodium chloride).

Solubility of sodium chloride and potassium chloride

Temperature °C	0	20	40	60	80	100
Sodium chloride	35.5	36	36.5	37.5	38	39
Potassium chloride	28	33	38	44	50	55

The graph below shows how much salt (sodium chloride) and sugar (sucrose) can dissolve in 100 milliliters of water at different temperatures. Use the information about the solubility of potassium chloride in the chart above to mark new points on the graph. Then draw a smooth line that comes as close as possible to all the points. This new line will show the solubility of potassium chloride at different temperatures.

Solubility of sodium chloride, sucrose, and potassium chloride



Let’s review (*continued*)

4. According to the graph, which substance’s solubility is most affected by increasing the temperature of the water? ____

   Use evidence from the graph to explain your answer.

   ____

   ____

   ____

   ____

5. At what temperature would you say the solubility of sodium chloride and potassium chloride are about the same?

   Use evidence from the graph to explain your answer.

   ____

   ____

   ____

   ____

6. Look at the lines showing the solubility of sodium chloride and potassium chloride. Which is more soluble at low, medium, and high temperatures?

   ____

   ____

   ____

   ____

Name: ____________________________

Science in action!

Does the size of the material being dissolved affect the rate it dissolves?

In this investigation, you did several activities and learned about some different things that affect dissolving. One factor you did not investigate is whether the size of the material being dissolved affects the rate of dissolving. For example, it could be interesting to find out if a sugar cube or the same amount of small granules of sugar dissolves in water faster.

Plan your experiment

1. Describe a test you could conduct to find out which dissolves faster: a sugar cube or the same amount of sugar granules. Be sure to explain how you will control variables such as the amount of sugar, amount and temperature of the water, etc.

Conduct your experiment

Be sure to record your observations on the next page.

Name: ______________________________

Science in action! (*continued*)

Record your observations

What did you observe during your dissolving test?

Sugar cube	Sugar granules

2. What is your conclusion: Does the size of the material being dissolved affect the rate at which it dissolves? ____________________

3. Based on what you know about dissolving, try to explain why the sugar granules dissolved faster than the sugar cube.

Name: ____________________________

Think about it

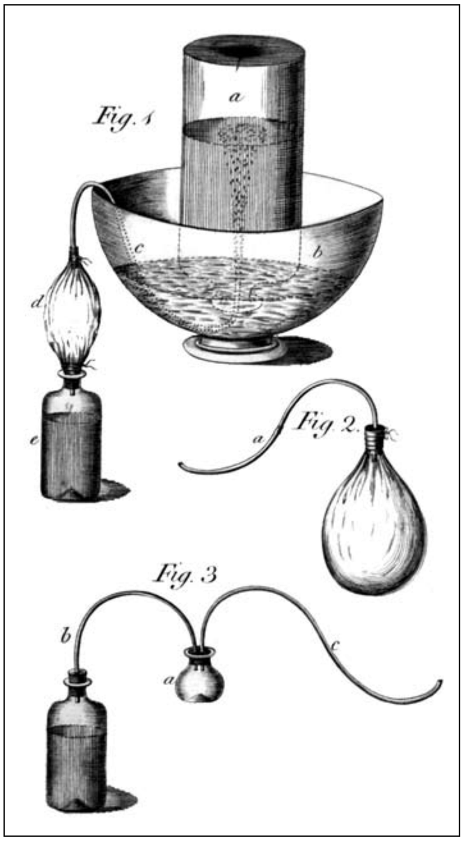
Vocabulary
- pharmacist
- carbonated
- concentrated
- fermenting
- apparatus

You made a lemon soda by dissolving a solid (sugar) in a liquid (lemon juice) to make a syrup. You then dissolved the syrup in another liquid (club soda). The club soda already had a gas dissolved in it. So the soda you made was a combination of dissolved solid, liquid, and gas. The type of soda you made is not that different from the sodas of the past.

History of soda pop

People have been making different types of soda pop for many years. The idea for making soda pop probably came from people drinking carbonated water from natural springs. The carbonation in the water was thought to improve health so lots of people wanted this special water. Scientists and pharmacists wanted to find a way to artificially add carbon dioxide to regular water so people wouldn't have to depend on natural springs as the only supply for carbonated water. Finding a way to add carbon dioxide to water was a challenging problem.

A scientist from England named Joseph Priestley is believed to be among the first people to figure out a way to artificially add carbonation to water. He knew that fermenting grain to make beer produced a lot of carbon dioxide gas. So Priestley figured out a way to hang a container of water over a beer-making tub so that the carbon dioxide could mix and dissolve into the water.



Courtesy of Douglas A. Lockard, Roy G. Neville Historical Chemical Library

Equipment Priestley used to add carbon dioxide to water.

A few years later, in 1772, Priestley used another method in which he dripped sulfuric acid onto marble to produce carbon dioxide gas and then mixed the gas into water. This method worked well but was not convenient for making carbonated water in small stores and pharmacies where it was needed. So inventors began working on different types of systems based on the acid-and-marble method to add carbonation to water. In the early 1830s an apparatus was finally invented that could produce carbonated water conveniently and in large quantities. These machines were installed and used in drug stores where carbonated water was produced, flavored, and sold by the glass.

Think about it (*continued*)

Soda pop today

The way that soda pop is made on a large scale in factories today is different but does have some similarities to the old methods. The four main ingredients in the soda pop you buy in the store are still water, sweetener, flavoring, and carbon dioxide gas.

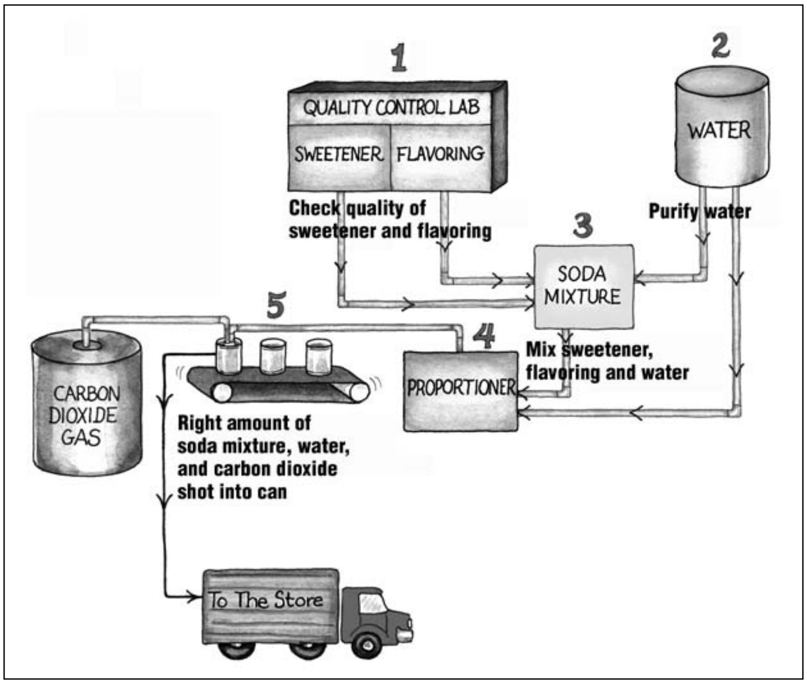
The water used to make soda pop is regular local water. The soda pop company may filter or treat the water in some way to be sure it is clean and ready for use.

The sweetener used is usually corn syrup. This is a very sweet liquid made mostly from the starches in corn. This syrup arrives at the soda pop factory in big tanker trucks. The syrup is checked for quality and then pumped into tanks for later use.

The flavoring is delivered as a concentrate. Since this is the part that gives the soda pop most of its flavor, the ingredients of the flavor concentrate are kept as secret as possible so other companies can't use them.

The carbon dioxide gas is stored in tanks and is injected into the soda as it is canned or bottled.

Putting it all together



Corn syrup and flavoring (1) and water (2) are added to giant stainless steel mixing tanks (3). These tanks have big rotating blades that thoroughly mix the sweetener, flavoring, and water together to make a concentrated syrup.

This water-sweetener-flavoring mixture is then transferred to another special tank called the proportioner (4). Here, more water is added so that all the ingredients have the correct concentrations.

At this point, the soda solution is ready except for the fizz. The soda solution is then added to bottles or cans (5), and carbon dioxide gas is injected under pressure at the same time. The bottles or cans are immediately sealed.

Name: ____________________________

Think about it (*continued*)

1. According to the reading, inventors most likely designed another way to make carbonated water because:
   a. It was dangerous to drip sulfuric acid over marble.
   b. It tasted better when marble was no longer used.
   c. A faster and more convenient way to make carbonated water was needed.
   d. Fermenting grain produces a bad smell.

2. The idea of modern soda pop came from people in history drinking carbonated water. In the reading, what is the best description of the word *carbonated*?
   a. water that has flavoring added
   b. the syrup used to make soda pop
   c. any liquid that is sold by the glass
   d. water that contains dissolved carbon dioxide gas

3. Which is the best summary of the section entitled “Soda pop today”?
   a. The disagreement over which type of soda is best continues today.
   b. Soda pop is made from four ingredients: water, sweetener, flavoring, and carbon dioxide gas.
   c. Joseph Priestley discovered the method in which soda pop is made today.
   d. Soda pop is actually made from a solid, liquid, and gas.

4. The purpose for the entire reading is to:
   a. tell how Joseph Priestley was an amazing inventor.
   b. explain that soda pop contains carbon dioxide and water.
   c. give some examples of how soda pop used to be made with machines in drug stores.
   d. inform the reader about the history of soda pop and how it compares to soda pop today.

5. The sweetener used in modern soda pop is made from:
   a. Sugar cane
   b. Starches from corn
   c. Glucose
   d. Fruit juice concentrate

6. Look back at the picture showing the steps for making modern soda pop. The last step in the process is to:
   a. add sugar and stir.
   b. add the carbon dioxide and soda solution and seal the container.
   c. heat the soda solution to release carbon dioxide gas.
   d. add the sweetener and flavoring and shake.

Name: ______________________________

Think about it (*continued*)

7. What was one of the most challenging problems in making the first artificially carbonated water?

8. Why did scientists and pharmacists want to find a way to artificially add carbon dioxide gas to water?

9. Joseph Priestley tried two methods for dissolving carbon dioxide into water. What were they?

10. Describe one way old-style and modern soda pop are similar and one way they are different?

Review and apply worksheet

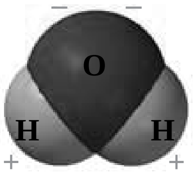
Name: ____________________________

What’s going on here?

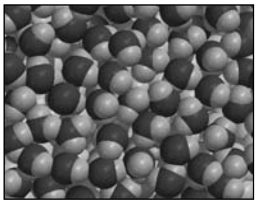
In this investigation you saw that solids, liquids, and gases can all dissolve. You also saw that just because a substance dissolves in one liquid, it won’t necessarily dissolve in another. Also, increasing the temperature of water affects the amount of a substance that dissolves. You also saw that dissolved gas tends to come out of a solution faster when the solution is warmed.

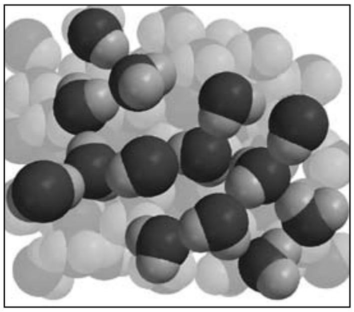
Water molecules

Because of the characteristics of the oxygen and hydrogen atom and how they are bonded together, there is a negatively charged area near the oxygen and a positively charged area near the hydrogens.



Water

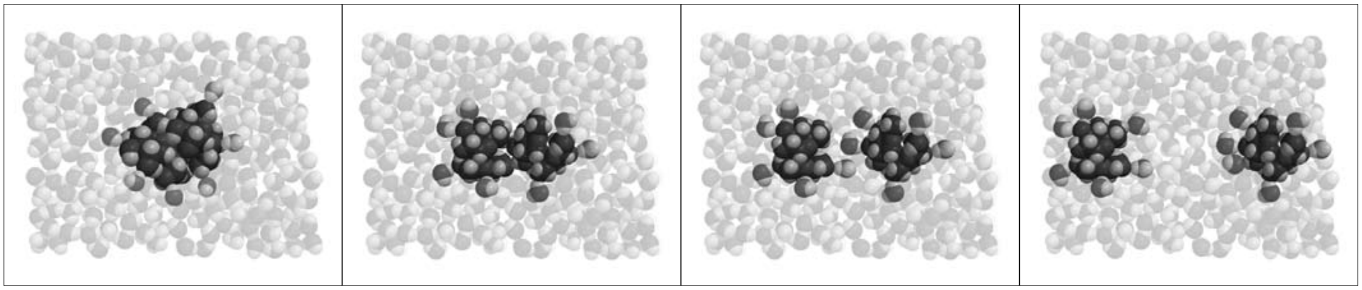




The smaller illustration at the right shows that the molecules in liquid water associate very closely with one another. The larger illustration shows how the positive part of one water molecule is attracted to the negative part of another. And the negative part of one water molecule is attracted to the positive part of another. Water molecules are also attracted to the oppositely charged areas of other molecules. This is why water is such a good dissolver.

Dissolving colored sugar in different liquids

When you put colored sugar in water, the positive and negative areas of the water molecules were attracted to the oppositely charged areas of the color and the sucrose molecules. In fact, there was so much mutual attraction between the water and the color that the color came off the sugar and dissolved into the water. There was also enough mutual attraction between the water and sucrose molecules to overcome the attraction that the sucrose molecules had for each other. In the series of pictures below, water molecules separate two sucrose molecules from each other causing them to dissolve.



What's going on here? (*continued*)

But sugar did not dissolve in alcohol and oil as well as it did in water. This is because the molecules of alcohol and oil are different from water molecules. They are made of different atoms, their shape is different, and the strength and number of positive and negative areas are different. The mutual attraction between these molecules and the sugar molecules was not strong enough to overcome the attraction of sugar molecules for each other and therefore, the sugar did not dissolve.

Dissolving different liquids in water

You normally think of dissolving as a solid dissolving in a liquid like water, but liquids can dissolve in liquids too.

A solid will dissolve in water if there is enough mutual attraction between the molecules of the solid and the water molecules. When these attractions overcome the attractions the molecules of the solid have for each other, the solid dissolves.

The same is true for liquids. Liquid molecules are also attracted to each other. A liquid will dissolve in water when there is enough mutual attraction between the molecules of the liquid and the water molecules. When these attractions overcome the attractions the molecules of the liquid have for each other, the liquid dissolves.

For example, isopropyl alcohol and corn syrup will dissolve in water because there is enough attraction between their molecules and the water molecules. Vegetable oil will not dissolve because there is very little mutual attraction between the molecules of oil and the water molecules.

What's going on here? (*continued*)

Gas dissolved in water

A gas can dissolve in a liquid. Just like the attraction between water molecules and the molecules of a solid or liquid, there can be attraction between water molecules and the molecules of a gas. The molecules of carbon dioxide in carbonated water are mixed in and spread throughout the water so they are actually dissolved in the water.

Adding heat makes molecules vibrate and move faster. This movement helps overcome the attractions holding one molecule to another in a solid like sugar or salt. But adding heat has the opposite effect on gases, like carbon dioxide, dissolved in water. Adding heat makes molecules vibrate and move faster. This movement helps overcome the attractions between the carbon dioxide molecules and the water molecules. These faster-moving gas molecules can break away from the liquid and go into the air.

Cooling carbonated water slows the motion of the molecules. This slower movement allows the carbon dioxide molecules and the water molecules to stay together better. So the carbon dioxide stays dissolved longer.

Dissolving solids, liquids, and gases to make a soda

The carbonated water you used to make lemon soda had quite a bit of carbon dioxide gas dissolved in it. Gas that is dissolved in water tends to cling to any surface. When enough gas builds up, a little bubble forms, rises to the surface, and pops, sending the gas out of the water.

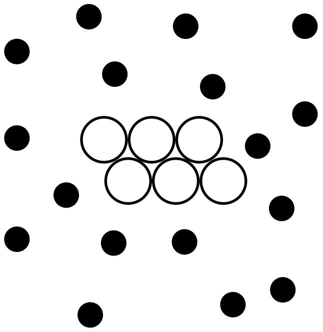
When sugar is added to carbonated water, there are many surfaces for the gas to attach to and make bubbles. Dissolving sugar in lemon juice eliminates the surfaces, so fewer bubbles form. This keeps more carbon dioxide gas in your soda.

Review and apply worksheet

Name: ______________________________

What’s going on here? (*continued*)

1. Imagine that the six circles represent molecules of a solid. The black dots represent water molecules. Draw pictures and write captions to explain how a solid dissolves in water.

	Drawings	Captions
Before		The molecules of the solid are attracted to each other. There is also mutual attraction between the molecules of this solid and the water molecules.
During		
After		

Name: ____________________________

What’s going on here? (*continued*)

2. Why does sugar dissolve better in hot water than in cold water?

____

____

____

____

3. Most solids dissolve better in hot water than in cold, but the opposite is true for gases. Why does carbon dioxide gas leave water faster when carbonated water is warmed?

____

____

____

Cool factoid

Almost all soda pop that does not contain artificial sweeteners is sweetened with high-fructose corn syrup (HFCS). In the *Think about it* section, you read that HFCS is made from corn starch. To make HFCS, chemicals called *enzymes* are used to break the starch down into the sugars glucose and fructose. Of the three different enzymes that are used, two come from bacteria and the other comes from a fungus.

Investigation 5

Chemical change

Do powders that look the same have the same chemical reactions?

Summary

In this investigation, students gain experience with the evidence of chemical change—production of a gas, change in temperature, color change, and formation of a precipitate. Students begin by observing that similar-looking powders can be differentiated by the way they react chemically with certain test liquids. Students then use their chemical tests and observations to identify an unknown powder and, in a follow-up activity, to identify the active ingredients in baking powder. Students continue to explore chemical change by using a thermometer to observe that temperature either increases or decreases during chemical reactions. Then they control these reactions by adjusting the amount of reactants. In another set of activities, students use the color changes of red cabbage indicator to classify substances as acids or bases, neutralize solutions, and compare the relative acidity of two different solutions. Students conclude the investigation by comparing a precipitate to one of the reactants that formed it. Students see that a new substance was created during the chemical reaction.

Investigation 5: Chemical Change

Key concepts for students

- Substances react chemically in characteristic ways.
- Evidence that a chemical reaction has occurred includes: production of a gas, change in temperature, color change, and formation of a precipitate.
- A chemical reaction can be controlled by adjusting the amount of reactants.
- A chemical reaction can result in an increase in temperature (exothermic) or a decrease in temperature (endothermic).
- The color change of an acid–base indicator can help classify a solution as an acid or a base, identify when a solution has been neutralized, and compare the amount of acid or base in a solution.
- In a chemical reaction, the bonds holding one atom to another are broken, atoms rearrange, and then combine in new ways to create one or more different substances.
- In a chemical reaction, the atoms that make up the reactants are never destroyed or disappear. They rearrange and bond in new ways to form the products.

Learning objectives

Students will be able to:

- Design a testing procedure to compare the chemical reactions of different substances.
- Use the characteristic chemical reactions to identify an unknown substance.
- Recognize that production of a gas, change in temperature, color change, and formation of a precipitate are evidence of chemical change.
- Use a thermometer and graduated cylinder accurately.
- Control chemical reactions by adjusting the amount of the reactants.
- Use the color changes of an acid-base indicator to classify and compare different substances.
- Determine whether a new substance is created during a chemical reaction.

Investigation questions

Do powders that look the same have the same chemical reactions?

- How can you use the characteristic ways substances react to tell similar-looking substances apart?
- How can you identify an unknown powder?
- What are the active ingredients in baking powder?
- Aside from bubbling, what else happens during a reaction between baking soda and vinegar?
- How can you control the amount of gas produced in a baking soda-and-vinegar reaction?
- Can the temperature increase during a chemical reaction?
- How can you tell if a substance is an acid, a base, or neutral?
- How can you return the color of a red cabbage indicator solution back to blue?
- How can neutralizing acids help you compare the amount of acid in different solutions?
- What happens when soap is added to hard water?

Assessment

The assessment rubric *Chemical change,* pp. 305–307, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section on pp. 308–322.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties, including…the ability to react with other substances.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Scientists use different kinds of investigations depending on the questions they are trying to answer.
Types of investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties.
Substances react chemically in characteristic ways.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials charts for student activities

5.1 Powder particulars
5.2 Using chemical change to identify an unknown
5.3 Exploring baking powder
5.4 Change in temperature—Endothermic reaction
5.5 Production of a gas—Controlling a chemical reaction
5.6 Change in temperature—Exothermic reaction
5.7 Color changes with acids and bases
5.8 Neutralizing acids and bases
5.9 Comparing the amount of acid in different solutions
5.10 Formation of a precipitate

The materials needed for *Activities 5.1–5.6* are in the chart below. The materials needed for *Activities 5.7–5.10* are in the chart on the next page.

	Activity					
Each group will need	5.1	5.2	5.3	5.4	5.5	5.6
Baking soda in cup	●	●	●	●	●	
Baking powder in cup	●	●				
Cream of tartar in cup		●	●			
Powdered laundry detergent in cup		●				
Cornstarch in cup		●	●			
Unknown in cup (baking powder)		●				
Water in squirt bottle					●	●
Water in cup		●	●			
Vinegar in cup	2	●		●	●	
Dilute iodine solution in cup		●				
Red cabbage indicator in cup		●				
Liquid dish detergent solution in cup					●	
Baking soda solution in cup						●
Calcium chloride in cup						●
⅛ Teaspoon					●	●
¼ Teaspoon		●			●	●
½ Teaspoon				●	●	●
Popsicle sticks		5	3			
Droppers		4	1		1	
Blank strip of paper		●				
Graduated cylinder, 50 ml					●	●
Waste container					2	●
Clear plastic cups				1		
Paper towels					●	●
Thermometer				●		●

Each group will need

	Activity			
	5.7	5.8	5.9	5.10
Cream of tartar in cup	●	●		
Water in squirt bottle	●			
Vinegar in cup	●			
Red cabbage indicator in cup		●		
Red cabbage leaves	2	2	2	
Powdered laundry detergent in cup	●	●		
Laundry detergent solution		●		
Epsom salt			●	●
Piece of Ivory® soap			●	●
1 teaspoon			●	●
1 tablespoon	●	●		
Measuring cup, 1 cup	●			
Popsicle sticks			2	2
Toothpicks	●			
Straws			●	●
Droppers	1	2	1	1
White piece of paper	●	●		
Clear plastic cups	4	3	6	6
Permanent marker or tape and pen	●	●		
Paper towels	●			
Coffee filter			●	●
Zip-closing plastic bag	●	●		

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Purchase one fresh head of cabbage for use in the demonstration in *Activity 5.1* and *Activities 5.2, 5.7, 5.8,* and *5.9*. Refrigerate the cabbage so that it will stay fresh for use in all of these activities. Do not purchase pre-shredded cabbage: It will not work.
- Use a quart-size zip-closing plastic bag to make red cabbage indicator. “Storage” bags work well.
- **Dilute the tincture of iodine according to the instructions, p. 260. Read and follow all warnings on the label.**
- Students will need to rinse out the graduated cylinders during *Activity 5.5*. Using a squirt bottle is one easy way to do this if you do not have sinks at tables. Some types of bottled water for drinking have convenient squirt tops that can be used to distribute water to student groups. If sinks are readily available, use only one container. If there is not a sink in the classroom, each group will need 2 waste containers.
- *Activity 5.6* requires a chemical that is not as common as most of the other substances used in *Inquiry in Action*. It is calcium chloride, which is sold in hardware stores as a moisture absorber under the name DampRid®. It is also available through the chemical supplier your school or district uses. You should purchase at least 500 grams. If the container is sealed tightly, calcium chloride will keep for many uses.
- AlkaSeltzer® will be needed for the *Review and apply: Science in action!* activity, pp. 313–315.

Materials chart for teacher demonstrations

5.1 Powder particulars
5.5 Production of a gas—Controlling a chemical reaction
5.9 Color changes with acids and bases

	Activities		
	5.1	5.5	5.9
Zip-closing plastic bag	●		●
Clear plastic cups	3		3
Red cabbage leaves	●		●
Cream of tartar	●		
Powdered laundry detergent	●		●
Laundry detergent solution			●
Popsicle stick	2		
Water	●		●
Graduated cylinder		●	
Baking soda		●	
Vinegar		●	
Liquid dish detergent solution		●	
Droppers		1	2
Tablespoon measure			●
Waste container		●	
Clear plastic cups			3
Permanent marker			●

Science background information for teachers

In *Investigations 1–4*, students explore physical properties and physical change. They see that different substances undergo physical change in characteristic ways. In this investigation, students will see that different substances also undergo *chemical change* in characteristic ways. Unlike a physical change where the identity of a substance does not change, in a chemical change, a new and different substance is formed.

For videos, animations, and other information related to this investigation, go to
www.inquiryinaction.org

Chemistry concepts

- Substances react chemically in characteristic ways.
- Production of a gas, change in temperature, color change, and formation of a precipitate are evidence that a chemical reaction has occurred.
- In a chemical reaction, bonds in the reacting molecules are broken, the atoms rearrange, and new bonds form to produce new product molecules.
- In a chemical reaction, the atoms that make up the reactants are never destroyed or disappear. They rearrange to form the products.
- It takes energy to break chemical bonds, and energy is released when bonds are formed.
- In an endothermic reaction, it takes more energy to break the bonds of the reactants than is released when the new bonds are formed.
- In an exothermic reaction, more energy is released when product molecules are formed than was used to break the bonds of the reactants.
- Red cabbage indicator changes color showing when a substance is acidic, basic, or neutral.
- Water reacts with itself to form H_3O^+ and OH^-. Pure water has an equal concentration of H_3O^+ and OH^-.
- An acid increases the concentration of H_3O^+, which decreases the concentration of OH^-.
- A base decreases the concentration of H_3O^+, which increases the concentration of OH^-.
- A solution containing an acid can react with a solution containing a base by combining H_3O^+ and OH^- to create water. This process is called *neutralization*.
- When two solutions react to form a solid, the solid is called a *precipitate*.

Chemical reactions

In a chemical reaction, atoms rearrange and bond together in different ways to create new substances. To understand chemical reactions, it's helpful to look at why atoms bond together in the first place.

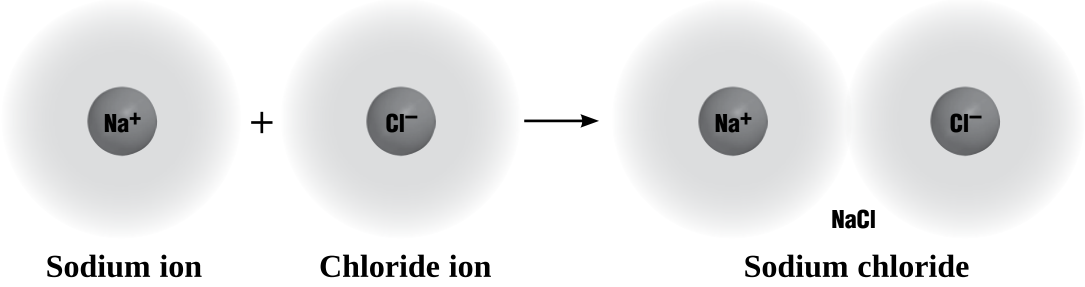
Atoms have positively charged protons in the nucleus and negatively charged electrons that move around the nucleus. All atoms, except hydrogen, also have neutrons in the nucleus. Neutrons have no electric charge. Because protons and electrons have opposite charges, they are attracted to each other. This is what holds an atom together. But the protons and electrons of an atom also have an attraction for the oppositely charged electrons and protons of other atoms. This is the basis for why atoms come together and form bonds.

Ionic bonding between atoms

When atoms are close enough together, there is an attraction between the protons and electrons in one atom for the oppositely charged electrons and protons in the other atom. If the attraction is stronger in one direction than the other, it's possible that one or more electrons may leave one atom and join the other atom, forming positive and negative ions (See p. 74).

The atom that lost an electron becomes a positively charged ion and the atom that gained an electron becomes a negatively charged ion. These ions then can attract each other and bond together based on the attraction of opposite charges. This is called an *ionic bond*. When this happens, a chemical reaction has taken place because the two ions bonded together are now an ionic compound, and a different substance from the individual atoms that formed it.

A common example of a reaction between two atoms involving ionic bonding is the reaction that produces sodium chloride (NaCl) from sodium (Na) and chlorine (Cl). At room temperature, sodium is a soft silvery-colored metal that reacts violently when placed in water. Chlorine is a greenish-colored gas that is very poisonous. But a reaction between them forms ions that bond to form a new and different substance—sodium chloride, which we eat as table salt.



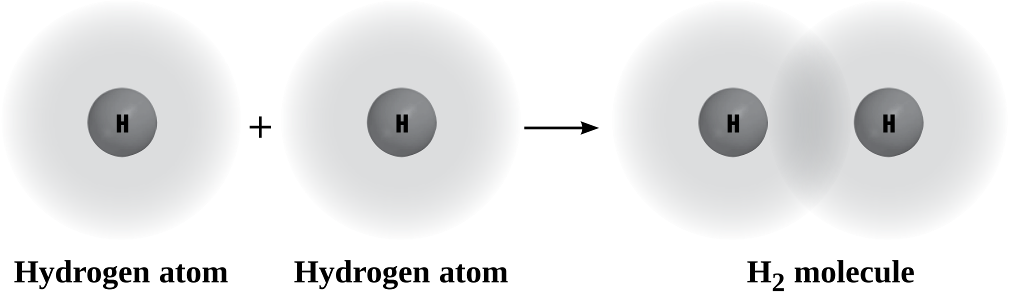
Covalent bonding between atoms

When two atoms are close enough together there is an attraction between the protons and electrons from one atom and the oppositely charged electrons and protons from the other atom.

If these mutual attractions are strong enough and similar in both directions, it's possible that one or more electrons from each atom will be pulled toward the nucleus of both atoms. This can cause electrons from each atom to move around the nuclei of both atoms. When this happens, the atoms form a covalent bond.

So if the attraction is sufficiently strong and balanced enough in both directions, a covalent bond can be formed. This is a chemical reaction because the two bonded atoms, now a molecule, is a different substance than the individual atoms that formed it.

A common example of a reaction between two atoms that results in a covalently bonded molecule is the reaction that forms hydrogen gas, H_2. When two hydrogen atoms get close enough together, there is mutual attraction by the proton and electron from each atom for the oppositely charged electron and proton from the other atom. Since the attraction is balanced in both directions, the electron from each hydrogen atom can end up going around the nucleus of both atoms instead of just the one it started with. When this happens, a new substance, hydrogen gas (H_2), is formed.



In the picture, the gray area around each hydrogen atom indicates where its electron is most likely to be found. In the hydrogen molecule, the darker area between the two nuclei shows where the two shared electrons are most likely to be.

Comparing ionic and covalent bonds

In ionic bonding, the attraction between the protons of one atom and the electrons from the other tends to pull electrons completely toward one of the atoms and away from the other. In ionic bonding, there is complete transfer of one or more electrons from one atom to another. In covalent bonding, the attractions are more balanced between the atoms so electrons tend to be pulled more equally toward both atoms. Instead of complete transfer, the electrons move around the nucleus of both atoms.

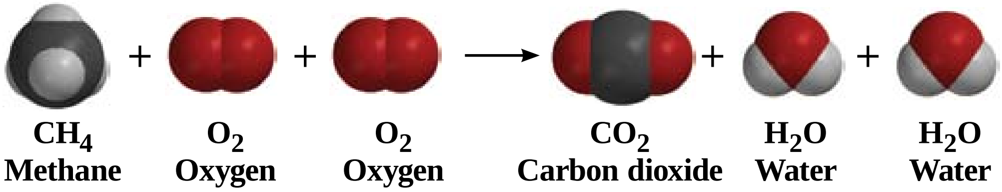
The explanation above describes how ionic or covalent bonds form a new substance in a simple reaction between two atoms. A similar process is involved when ionic or covalent bonds form a new substance in a chemical reaction between two *molecules.*

Ionic and covalent bonding between molecules

If two molecules get close enough together, the protons and electrons from the atoms in one molecule may experience attractions for the oppositely charged electrons and protons from the atoms in another molecule. If these mutual attractions are strong enough and the atoms can transfer (ionic) or share (covalent) one or more electrons, the atoms in the reacting molecules may break the bonds holding them together, rearrange themselves, and bond together in new ways to form new substances. These new substances are called the *products* of the reaction.

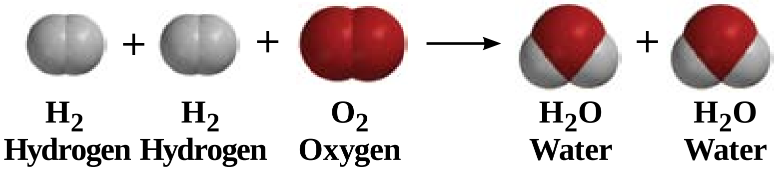
Examples of chemical reactions

A common example of a reaction between two molecules is the reaction that happens when you light a gas stove in your house. The methane gas in the stove has a chemical formula of CH_4. It reacts with oxygen (O_2) from the air to produce carbon dioxide gas (CO_2), water (H_2O), and a great deal of heat. Notice how all of the atoms on the left side of the arrow also appear on the right side of the arrow. They are just rearranged to form different molecules.

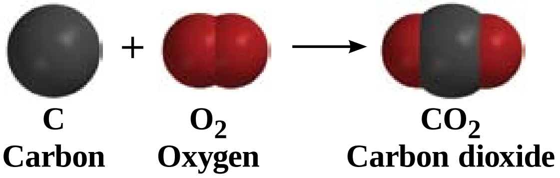


The carbon that was in the methane becomes part of the carbon dioxide. The hydrogen from the methane becomes part of the water. And the oxygen from the air ends up in both the carbon dioxide and the water.

In the following reaction, hydrogen combines with oxygen to form water.



Here carbon and oxygen combine to create carbon dioxide gas.



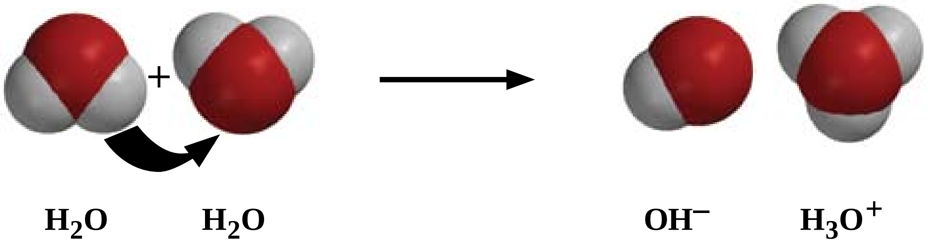
In all of these reactions the atoms in the reactants break the bonds that hold one atom to another, rearrange themselves, and bond together in new ways to form the products.

Water reacts with water

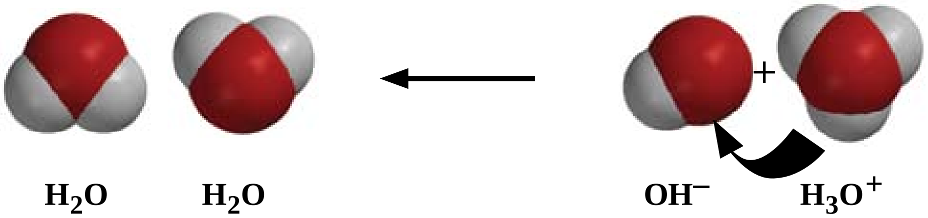
Water is an important component of many chemical reactions. We think of water as H_2O, but in fact, water molecules are constantly reacting with each other. When two water molecules react, a proton from a hydrogen atom in one of the water molecules gets transferred to the other water molecule. This proton leaves its electron behind in the water molecule it came from.

When a proton is transferred from one water molecule to another, it's as if the molecule gaining the proton is actually gaining another hydrogen atom (but without the electron). So in the reaction between the two water molecules, the one that gained the extra proton changes from H_2O to become the ion H_3O^+, called the *hydronium ion*.

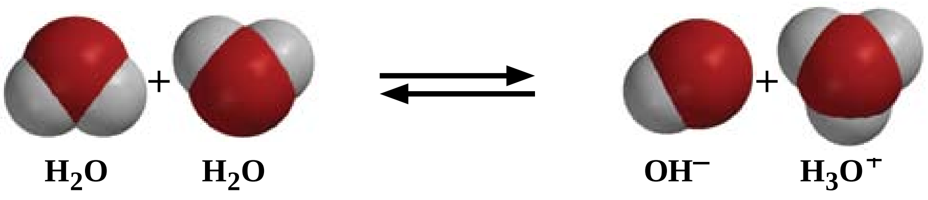
The reverse is true for the water molecule that lost the proton. It's as if the water molecule lost a hydrogen atom (but held on to the electron). So the water molecule that lost the proton changes from H_2O to become the ion OH^-, called the *hydroxide ion*.



But the H_3O^+ ions and the OH^- ions also react with one another. In this reaction, the extra proton on the H_3O^+ can be transferred back to the OH^- to form two water molecules again.



So, in pure water, these reactions balance one another and result in a small but equal concentration of H_3O^+ and OH^-. The arrows pointing in both directions indicate that, at equilibrium, this process happens back and forth at the same rate.



The role of water in acids and bases

The concentration of H_3O^+ in water determines how *acidic* or *basic* a solution is. If a solution has a higher concentration of H_3O^+ than pure water, it is considered an acid. If the solution has a lower concentration of H_3O^+ than pure water, it is considered a base. The pH scale is a measure of the concentration of H_3O^+ in water.

An acid reacts with water so that a proton from the acid is transferred to a water molecule forming more H_3O^+. Since the solution has a higher concentration of H_3O^+, it is acidic.

A base is a little trickier because adding a base *reduces* the concentration of H_3O^+ ion. Bases can reduce the concentration of H_3O^+ in different ways. Some bases like sodium hydroxide (NaOH) already have an OH^- ion in the compound. When these substances dissolve in water, OH^- ions are produced. Some of these ions then react with H_3O^+ ions to produce water. This reduces the concentration of H_3O^+ so the resulting solution is basic.

Another way a base can reduce the concentration of H_3O^+ is to accept a proton from the H_3O^+ to form H_2O, water. Or the base could accept a proton from a water molecule to create an OH^- ion. Some of these OH^- ions then react with H_3O^+ to produce water. This process reduces the concentration of H_3O^+ resulting in a basic solution.

Strength and concentration in acids and bases

The effect that an acid or base has in a chemical reaction is determined by its *strength* and *concentration*. It is easy to confuse these two terms.

Strength

There are different kinds of acids. There are strong acids, weak acids, and acids in-between. Some acids are so strong that they can make a hole in a piece of metal. Other acids, like citric acid or ascorbic acid (Vitamin C), are weaker and are even safe to eat.

The factor that determines the strength of an acid is its ability to donate a proton, increasing the amount of H_3O^+ in water. A strong acid produces a lot of H_3O^+ in water, while the same amount of a weak acid produces a smaller amount of H_3O^+.

Concentration

Concentration is different from strength. Concentration has to do with the *amount* of acid added to a certain amount of water.

It is the combination of the concentration and the strength of an acid that determines the amount of H_3O^+ in the solution. And the amount of H_3O^+ is a measure of the acidity of the solution.

How strength and concentration work together

Here's an example of how strength and concentration work together: Let's say you dissolve equal amounts of a strong acid and a weak acid in the same amount of water in separate containers. Since you used the same amount of each acid in the same amount of water, the solutions have the same *concentrations*. But because one acid is *stronger* than the other, the solution made from the stronger acid will be more acidic than the solution made with the weaker acid. This is true even though both solutions have the same concentration.

You could also dissolve a strong acid in a very large volume of water and dissolve the same amount of a weak acid in a small amount of water. In this case, the solution containing the strong acid may have such a low concentration that it is less acidic than the solution of the weaker acid that is more concentrated.

Strength and concentration work the same way for bases. When conducting chemical reactions with acids and bases, the strength of the acid or base as well as the concentration determine how acidic the acid solution is or how basic the base solution is.

Activity 5.1—Powder particulars

Similar looking substances can be distinguished by the way they react chemically. When baking soda and baking powder react with vinegar, bubbles of carbon dioxide gas are produced. Although both powders bubble with vinegar, there is an observable difference: The reaction with baking powder is less vigorous and lasts longer. In both reactions, baking soda reacts with an acid to produce carbon dioxide gas. Because baking powder is a combination of baking soda, a powdered acid, and cornstarch, there is less baking soda available to react with the vinegar than in the reaction with straight baking soda.

Red cabbage indicator can be used to distinguish between acids and bases. When an acid, like cream of tartar, is added to this indicator, it turns pink. When a base, like powdered laundry detergent, is added to this indicator, it turns green. Refer to the section titled “The chemical reactions,” on p. 249, for more information about the chemical reactions between *Vinegar/baking soda* and *Red cabbage indicator/different substances.*

Activity 5.2—Using chemical change to identify an unknown

The particular white powders were chosen for this activity because they are common, inexpensive, safe, and have some interesting reactions with some common test liquids. Below is a list and a short description of the powders and the test liquids used in the activity.

The powders

Baking soda—Sodium bicarbonate, used in baking to generate bubbles in recipes that contain acidic ingredients; it is a weak base.

Baking powder—A combination of baking soda, calcium acid phosphate (a weak acid), and cornstarch; used in baking to generate bubbles. Will cause bubbling in water.

Cornstarch—A starch that can be used as a thickening agent. It is neither an acid nor a base.

Cream of tartar—An acid that is used to prevent crystallization of sugar in candy-making and to stabilize meringue and frosting.

Powdered laundry detergent—Combination of substances used for cleaning clothes; contains strong surfactants, enzymes, and water softening agents, plus many other substances. These substances are generally very basic.

The test liquids

Iodine solution—Tincture of iodine (iodine and potassium iodide, dissolved in alcohol, and diluted with water). One of the iodide ions reacts with starch to make a dark blue/black color.

Red cabbage solution—Pigment from red cabbage dissolved in water. It acts as an acid/base or pH indicator. Indicates through a color change whether a substance is an acid or a base. It is bluish-purple when neutral, tends toward pink with acids and greenish-blue with bases.

Vinegar—Acetic acid; will react with carbonates, like chalk or marble, and bicarbonates, like baking soda, to form carbon dioxide gas.

Water —H_2O; small numbers of water molecules react to form H_3O^+ ions and OH^- ions. These ions play an important role in reactions involving acids and bases. The reaction of water molecules to form ions is described in more detail under the heading *Water reacts with water*, on p. 246

The chemical reactions

Vinegar/baking soda

Vinegar is acetic acid, $HC_2H_3O_2$, diluted with water. Baking soda is sodium bicarbonate, $NaHCO_3$. When acetic acid is mixed with water to make vinegar, the additional protons from the acetic acid increase the concentration of H_3O^+ ion in the water. When sodium bicarbonate is placed in water, it dissociates into Na^+ and the bicarbonate ion HCO_3^-. The reaction between H_3O^+ and the HCO_3^- produces the bubbling that is carbon dioxide (CO_2) gas. The chemical equation for this reaction is on p. 250.

Vinegar/baking powder

Vinegar will also cause baking powder to bubble. Baking powder is made with baking soda (sodium bicarbonate) and a dry acid called calcium acid phosphate. This acid adds H_3O^+ ions to those already in the vinegar. As explained above, the H_3O^+ ions react with the bicarbonate ion HCO_3^- to produce carbon dioxide gas. Baking powder may seem to bubble less compared with baking soda. This may be because the concentration of bicarbonate ion is not as high in the baking powder as it is in the baking soda.

Water/baking powder

When water is added to baking powder, bubbling results. As discussed above, baking powder is made with baking soda (sodium bicarbonate) and the dry acid calcium acid phosphate. When water is added to the baking powder, the acid will cause the concentration of H_3O^+ in the water to increase. This ion will react with the bicarbonate ion HCO_3^- from the baking soda to produce carbon dioxide gas.

Red cabbage indicator/baking soda, baking powder, cream of tartar, detergent

Red cabbage and many other fruits and vegetables contain pigment molecules that change color when an acid or a base is added to them. These pigment molecules are large and complex. When an acid is added to the indicator solution, the concentration of H_3O^+ ion in the water increases. A proton from H_3O^+ is transferred to the indicator, resulting in a change in color from blue to pink. When a base is added, the proton is transferred from the pigment to the base. This causes a color change from pink back toward blue.

Iodine/starch

The dilute tincture of iodine solution contains iodine, potassium iodide, water, and alcohol. This solution is a good indicator for starch. Starch is a long and complex molecule that can form a helical shape when it interacts with iodide ions from the tincture of iodine solution. This shape change results in a color change.

Activity 5.3—Exploring baking powder

The chemical reaction involved in this activity is explained in the section titled *Water/baking powder*, p. 249.

Activity 5.4—Change in temperature: Endothermic reaction

Vinegar is acetic acid, $HC_2H_3O_2$, diluted with water. Baking soda is sodium bicarbonate, $NaHCO_3$. Breaking the bonds of the acetic acid and sodium bicarbonate requires energy. Not as much energy is released when the new bonds in the products are formed. This causes the temperature to decrease.

$$\underset{\substack{\textbf{Acetic}\\\textbf{acid}}}{H_3CCOOH} + \underset{\substack{\textbf{Sodium}\\\textbf{bicarbonate}}}{NaHCO_3} \longrightarrow \underset{\substack{\textbf{Acetate}\\\textbf{ion}}}{H_3CCOO^-} + \underset{\substack{\textbf{Sodium}\\\textbf{ion}}}{Na^+} + \underset{\substack{\textbf{Carbon}\\\textbf{dioxide}}}{CO_2} + \underset{\textbf{Water}}{H_2O}$$

This is one of the basic principles of chemistry: **It takes energy to break chemical bonds, and energy is released when bonds form.** If the amount of energy required for breaking bonds is greater than the energy released when new bonds are formed, the reaction is *endothermic*. Endothermic reactions feel cold to the touch and cause the temperature to drop. If the amount of energy required to break the bonds is less than the amount released when new bonds are formed, the reaction is *exothermic* and will feel warm and will cause the temperature to rise.

Activity 5.5—Production of a gas: Controlling a chemical reaction

The chemical reaction involved in this activity is explained in the section titled *Vinegar/baking soda*, p. 249.

Activity 5.6—Change in temperature: Exothermic reaction

Breaking the bonds in calcium chloride and baking soda requires energy. More energy is released when the new bonds in the products are formed. This causes the temperature to increase.

One interesting aspect of this reaction is that it not only produces a temperature change and a gas but also the precipitate calcium carbonate.

$$\underset{\substack{\textbf{Calcium}\\\textbf{chloride}}}{CaCl_2} + \underset{\substack{\textbf{Sodium}\\\textbf{bicarbonate}}}{2\ NaHCO_3} \longrightarrow \underset{\substack{\textbf{Calcium}\\\textbf{carbonate}}}{CaCO_3} + \underset{\substack{\textbf{Sodium}\\\textbf{chloride}}}{2\ NaCl} + \underset{\textbf{Water}}{H_2O} + \underset{\substack{\textbf{Carbon}\\\textbf{dioxide}}}{CO_2}$$

Activity 5.7—Color changes in acids and bases

The chemical change resulting in the color change of red cabbage indicator is based on the concentration of H_3O^+ in the indicator solution. When an acid is added to the indicator, the H_3O^+ concentration increases. A proton from H_3O^+ is transferred to the indicator, resulting in a change in color from blue to pink. When a base is added, the proton is transferred from the pigment to the base. This causes a color change from pink back toward blue.

Activity 5.8—Neutralizing acids and bases

If a solution is too acidic for a certain purpose, a basic solution can be added to it to bring it closer to neutral. This process is called *neutralizing* an acid. The same thing can be done with bases. If a solution is too basic, an acid solution can be added to neutralize it.

Adding drops of a base to an acidic solution increases the amount of OH^- in the solution. These OH^- ions react with the H_3O^+ in the acidic solution to form water, making the solution less acidic. When the amount of base added equals the amount of acid initially in the solution, the solution has been neutralized.

The reverse is true when drops of an acid are added to a basic solution. Adding drops of an acid to a basic solution increases the amount of H_3O^+ in the solution. These H_3O^+ ions react with the OH^- in the basic solution to form water, making the solution less basic. When the amount of acid added equals the amount of base initially in the solution, the solution has been neutralized.

Activity 5.9—Comparing the amount of acid in different solutions

When a base is used to neutralize two acid solutions, the number of drops of base needed to neutralize each solution will indicate which solution contains more acid molecules. The solution containing more acid will require more drops of base to neutralize the solution.

Activity 5.10—Formation of a precipitate

Epsom salt is magnesium sulfate ($MgSO_4$). When it is dissolved in water, it dissociates into Mg^{2+} ions and SO_4^{2-} ions. Soap molecules have an end that is negatively charged. The magnesium ion binds to the end of two soap molecules and creates a molecule that is no longer soluble in water. This precipitate is commonly called *soap scum*.

Is it a chemical change or a physical change?

Some changes can easily be classified as either a chemical change or a physical change. For example, burning paper is a chemical change while tearing paper is a physical change. But some changes are not so easy to classify.

The classic observable clues that a chemical change has occurred are the production of a gas, a color change, a change in temperature, and the formation of a precipitate. These clues do not necessarily mean that a chemical change has occurred: These clues can sometimes be the result of a physical change. The following are examples of physical changes that may seem to have clues of chemical change.

Production of a gas

For instance, pouring a soda or carbonated beverage into a glass, causes bubbles of carbon dioxide gas to form and rise to the surface. Or if an object is placed in soda, carbon dioxide gas will attach to the object and bubbles will rise to the surface. It may look like gas is being produced and one could easily believe that a chemical change is occurring. But this is really a physical phenomenon of dissolved gas coming out of solution and rising as a bubble. No new substance is created, so a chemical reaction has not occurred.

Color change

Adding food coloring to water causes a color change. The pigment molecules dissolve into the water, which is a physical change. Since new substances are not produced, no chemical reaction takes place.

Change in temperature

If heat is added or removed from a substance, its temperature changes. But this change results from the physical increase or decrease in molecular motion and not from the breaking and making of chemical bonds as in a chemical reaction.

Precipitate

Sometimes combining two liquids, such as lemon juice and milk, can produce a curd-like solid. The acid in the lemon juice acts to alter the shape of the protein in the milk, giving it a curd-like appearance and texture. It could be argued that this change is mostly physical since it mainly involves the shape change of the protein and is not a chemical change as no new substances are formed.

The production of a gas, a color change, a change in temperature, or the formation of a solid from two liquids indicates that a chemical reaction may have occurred. To find out conclusively requires further investigation.

Activity 5.1
Powder particulars

How can you use the characteristic ways substances react to tell similar-looking substances apart?

In the introductory activity and demonstration, students will be introduced to the concept that different substances react chemically in characteristic ways. First they will compare the way baking soda and baking powder react with vinegar. Then they will see dramatic color changes when red cabbage indicator is added to cream of tartar and laundry detergent. Seeing some of the ways similar-looking powders react with different test liquids will lay the foundation for *Activity 5.2*.

Materials needed for each group

Baking soda
Baking powder
Vinegar
4 Small cups

Materials needed for the demonstration

Red cabbage leaves
Cream of tartar
Powdered laundry detergent
Water
Zip-closing plastic bag (quart-size, storage-grade)
3 Clear plastic cups
⅛ Teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Purchase one fresh head of red cabbage; pre-shredded red cabbage will not work. This red cabbage will be used to make indicator solution for *Activities 5.1*, *5.2*, *5.7*, *5.8*, and *5.9*. Refrigerate the cabbage so that it will stay fresh.

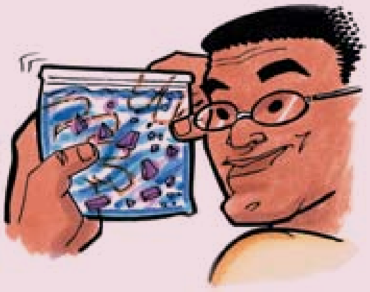
Preparing materials for the activity

- Label 2 small cups **vinegar**, 1 small cup **baking soda** and 1 other small cup **baking powder** for each group.
- Pour 1 teaspoon of vinegar into each of its labeled cups.
- Place ½ teaspoon of baking soda and ½ teaspoon of baking powder in their labeled cups.

Activity 5.1
Powder particulars

Preparing materials for the demonstration

- Tear 2 red cabbage leaves into small pieces and place them in a storage-grade zip-closing plastic bag.
- Add about 1 cup of room-temperature water. Get as much air out of the bag as possible and seal the bag securely.
- While holding the bag, repeatedly squeeze the water and cabbage leaves until the water turns a medium to dark blue.
- Open a corner of the bag and carefully pour the red cabbage indicator into an empty clear plastic cup, leaving the cabbage pieces behind in the bag.
- Place about ⅛ teaspoon of cream of tartar in one empty clear plastic cup and about ⅛ teaspoon of laundry detergent in another. Do not reveal the identity of these powders to your students until the end of the activity.



Activity sheet

Copy *Activity sheet 5.1—Powder particulars*, pp. 258–259, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.1
Powder particulars

Question to investigate

How can you use the characteristic ways substances react to tell similar-looking substances apart?

Take a closer look

1. Have students read the introductory story on *Activity sheet 5.1* and compare the way baking soda and baking powder react with vinegar.

Distribute *Activity sheet 5.1—Powder particulars.* As students read the introductory story, distribute the baking soda, baking powder, and cups of vinegar. Then, have students follow the procedure to see if they can figure out which clues the student in the story used to correctly identify baking powder and baking soda.

Can you use vinegar to tell baking soda and baking powder apart?

Procedure

1. Look closely at the samples of baking soda and baking powder that your teacher gave you. How are these powders similar and different?
2. With the help of your lab partner, pour all of the vinegar from each cup directly onto the baking soda and baking powder at the same time.
3. Observe until you think both reactions are over.
4. Record your observations on the activity sheet.

Expected results: **Both powders bubble when vinegar is added. Baking soda bubbles more vigorously at first, but baking powder bubbles for a longer period of time.**

2. Discuss students' observations.

Ask students questions such as the following:

- Could you tell baking soda and baking powder apart just by looking at them?
- What differences did you observe when baking soda and baking powder were reacting with vinegar?
- Do you think you could you tell baking soda and baking powder apart by comparing the way each reacts with vinegar?

Students may notice slight differences in the appearance of baking soda and baking powder. Baking powder may seem whiter, while baking powder may seem slightly yellow. Students should agree that adding vinegar reveals a more obvious difference between the two powders.

Tell students that the bubbles they observed in each cup were made of carbon dioxide gas. This new substance was created during the reactions. When two or more substances combine and make new a substance, it is called a *chemical reaction*. The difference in the way each powder reacted with vinegar shows that there is a chemical difference between the two powders. Bubbling, or *production of a gas*, is evidence that a chemical reaction has occurred.

Watch this!

3. Do a demonstration with red cabbage indicator to show students that the similar-looking powders are different.

Before beginning this demonstration you will need to have prepared red cabbage indicator along with two clear plastic cups containing cream of tartar and powdered laundry detergent. Instructions are on p. 254. Do not reveal the identity of these powders yet.

Hold up both cups of powders and tell students that the powders in the cups may look alike, but this does not necessarily mean that they are the same. Explain that you will use red cabbage indicator to see if the powders are the same or different.

Procedure

1. While students are watching, pour about ⅓ of the cabbage juice indicator into the cup with the cream of tartar and swirl.
2. Pour about ⅓ of the indicator into the cup with the laundry detergent and swirl. Leave about ⅓ of the indicator in the cup as a control.
3. Have students write how they know that these similar-looking powders are different on the activity sheet.

***Expected results*: The cream of tartar turns the blue cabbage juice pink and the laundry detergent turns it green.**

4. Discuss the results of the demonstration.

Ask students:

- How do you know that the two white powders in the bottom of each cup at the start of the demonstration were different?

Reveal the identities of the two powders to students. Explain to students that the blue liquid you used in the demonstration comes from a red cabbage. Red cabbage has a special chemical in it which gives the leaves a purple color. This chemical changes color when it reacts with certain types of substances. A change in color, like the production of a gas, is evidence that a chemical reaction has occurred. Tell students that they will experiment with the amazing color-changing property of red cabbage juice in future activities in this investigation (*Activities 5.2*, *5.7*, *5.8*, and *5.9*).

What's next?

5. Review the definition of a chemical reaction and introduce the signs that a chemical reaction has occurred.

Tell students that test liquids like vinegar and red cabbage indicator can be used to tell similar-looking powders apart. The differences they saw in each reaction were evidence that the powders were made of different chemicals.

Explain that in the following activity, students will compare the way baking soda, baking powder, and other similar-looking powders react with vinegar, red cabbage indicator, water, and iodine solution. Since each powder has a characteristic set of reactions with the test liquids, the reactions can be used to correctly identify an *unknown* powder.

Student activity sheet
Activity 5.1

Name: ______________________________

Powder particulars

Sometimes on a rainy weekend, my parents let us mess around in the kitchen with some of the stuff they bake with. We like to mix vinegar and baking soda because the reaction causes a lot of bubbling. I was curious whether vinegar would work with baking powder the way it does with baking soda. After all, both powders are used in baking and look pretty similar. So I put a little baking powder in one cup and a little baking soda in another. Then I added some vinegar to each one. Both bubbled, but not in exactly the same way. So I asked my mom to give me a challenge. She put a little bit of each powder in two separate cups, but didn't tell me which was which. Then I did my "vinegar test" to see if I could figure out which one was baking powder and which was baking soda.

How can you use the characteristic ways substances react to tell similar-looking substances apart?

Take a closer look

Test baking soda and baking powder with vinegar to see if you can figure out what clues the student in the story may have used to identify each powder.

Can you use vinegar to tell baking soda and baking powder apart?

Procedure

1. Look closely at the samples of baking soda and baking powder that your teacher gave you. How are these powders similar and different?
2. With the help of your lab partner, pour all of the vinegar from each cup directly onto the baking soda and baking powder at the same time.
3. Observe until you think both reactions are over.
4. Record your observations in the boxes below.

Baking soda	Baking powder

Student activity sheet
Activity 5.1

Name: ______________________________

Powder particulars (*continued*)

Watch this!

Can red cabbage indicator help you tell if two similar-looking powders are the same or different?

You used vinegar and saw that two similar-looking powders reacted somewhat differently. Then your teacher used red cabbage indicator to test two other similar-looking powders.

1. How do you know that the powders your teacher tested with the red cabbage indicator are not the same?

____

____

____

What's next?

You saw that a test liquid like vinegar or red cabbage indicator can be used to tell similar-looking powders apart. The differences you observed when each test liquid was added to each powder were evidence that these powders are chemically different. Scientists can use the changes that occur when certain substances react together to help them identify unknown substances. In the next activity you will test different powders with four different test liquids. Once you have conducted the tests in an organized way and recorded your results, you will then be able to test and identify an unknown powder.

Activity 5.2

Using chemical change to identify an unknown

How can you identify an unknown powder?

In this activity, students will develop a method to test five similar-looking powders with four test liquids. They will use the characteristic set of reactions for each powder to identify an unknown powder, which is one of the five powders they have tested.

Note: This activity will probably take more than one class period. On the first day, students can plan how to test baking soda, test it, record observations, discuss results, and consider how to test the other powders. On the second day, students can test the remaining powders, record observations, plan how to test the unknown, and then test and identify the unknown powder.

Materials needed for each group

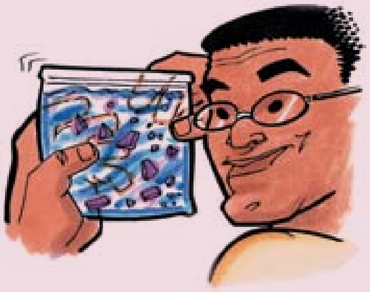
Baking soda
Baking powder
Cream of tartar
Detergent
Cornstarch
Water
Vinegar
Iodine solution
Red cabbage indicator
5 Popsicle sticks
4 Droppers
10 Small cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **When using iodine, read and follow all warnings on the label.**
- Use fresh red cabbage leaves; pre-shredded red cabbage will not work.

Preparing materials

- Label 6 small cups **baking soda**, **baking powder**, **cream of tartar**, **detergent**, **cornstarch**, and **unknown** for each group.
- Place about ½ teaspoon of each powder into its labeled cup. Baking powder works well as the unknown.
- Prepare the iodine solution for the class by adding 1 teaspoon of tincture of iodine to ¼ cup water.
- Prepare the red cabbage indicator according to the directions on p. 254.
- Label 4 small cups **water**, **vinegar**, **iodine**, and **red cabbage indicator** for each group.
- Place about 2 teaspoons of each solution into its labeled cup.



Testing sheet

Make one copy of *Testing sheet 5.2—Using chemical change to identify an unknown*, pp. 266–267, for each group. You may choose to copy the testing strips onto colored paper to give some contrast to the white powders. Be sure the paper you select is light enough that the labels can be easily read. Once laminated, these testing strips can be reused.

- Use a paper cutter to cut one blank piece of paper into strips so that each group can write the names of the test liquids on the strip.
- Cut 6 different testing strips for each group.
- Laminate the labeled strips and trim the edges.
- Sort out the testing strips for baking soda and the blank strips of paper. These will be distributed at the start of the activity.
- Compile sets of testing strips including baking powder, cream of tartar, detergent, cornstarch, and the unknown. These will be distributed after students have tested baking soda and decided how they will organize and test the remaining powders.

Activity sheet

Copy *Activity sheet 5.2—Using chemical change to identify an unknown*, p. 268, and distribute one per student when specified in the activity. This activity sheet is a chart for students to record their observations. First students will transfer their recorded observations from the four tests on baking soda onto the chart. Then they will record their observations for each of the other powders immediately after conducting each test. Once complete, students will use this chart to help them identify the unknown powder. They will refer to it again in *Activity 5.3*.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.2
Using chemical change to identify an unknown

Question to investigate

How can you identify an unknown powder?

1. Discuss with students how they might test the baking soda with four different test liquids.

Tell students that in this activity they will test five different powders with water, vinegar, iodine solution, and red cabbage indicator. Explain that the set of reactions the liquids have with each powder will be different. Let students know that at the end of the activity, they will be given an unknown powder that is the same as one of the known powders they have been testing. Their job is to identify this unknown powder.

2. Discuss with students how they might test baking soda with four different test liquids.

Ask students questions like the following to help them plan how they will organize and conduct their tests with baking soda.

- **Do we need more than one pile of baking soda?**
  Students should test each liquid on a separate pile of baking soda.
- **How many piles of baking soda should we make?**
  Since there are four liquids, students should make four piles of baking soda.
- **Do the piles have to be about the same size?**
  The size of the piles is not particularly important as long as enough powder is used to see a reaction, if there is one. However, it may be easier for students to compare the results of the unknown to the results from each of the powders if the piles are of similar size.
- **Should the number of drops placed on each pile be the same?**
  The precise number of drops is not particularly important, although enough liquid should be added to see the reaction if there is one. However, it will be easier for students to compare the results of the unknown to the results from each of the powders if they use the same number of drops on each pile.
- **How will you remember which pile was tested with which liquid?**
  Students should write the names of the test liquids in four separate areas on a strip of paper. The name of each test liquid should be next to each pile of baking soda.
- **How will we remember our observations for each reaction?**
  Students should agree to record their results. They can design a chart or table to organize their observations for baking soda.

3. Test baking soda with water, vinegar, iodine, and red cabbage indicator.

Distribute the testing strip for baking soda, one blank strip of paper, the cup with baking soda, the four droppers, and the four test liquids to each group. Have your students follow their class plan for setting up, labeling, and testing the baking soda. The procedure provided below is one example of a possible plan.

Procedure

1. Use a popsicle stick to place 4 equal piles of baking soda on the labeled laminated strip.
2. Place a blank strip of paper next to the laminated strip, and write the name of each test liquid next to each pile.
3. Test each pile of baking soda with 5 drops of each liquid and record your observations.

4. Have students share their results and how they recorded their observations.

As you discuss each group's observations, also discuss how students recorded their observations. Students should explain how they described their observations, whether with words, drawings, or both. They should also explain whether they used a chart or other method to organize their observations.

Expected results: **Refer to the results for baking soda in the chart on p. 264.**

5. Discuss a possible testing strategy that would make it easy to compare the reaction each powder has with each test liquid.

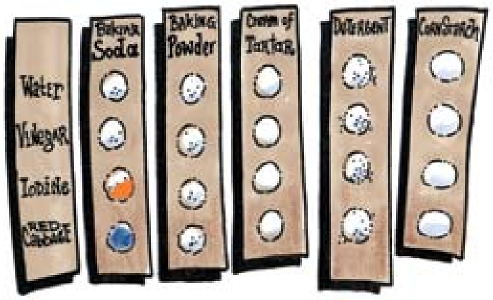
Let students know that they will be testing four other powders with the same test liquids and will need to compare the set of reactions for each powder. Ask students what they could do so that it would be easy to see and compare the way each powder reacts with a certain test liquid. Students should realize that powders in the same position on separate labeled strips should be tested with the same liquid. Ask students how they should record their observations for all the reactions in an organized way.

Distribute *Activity sheet 5.2—Using chemical change to identify an unknown*, p. 268. Students should transfer their results for baking soda and place the names of the test liquids in the proper order.

6. Conduct the tests on the remaining powders and record the results.

Distribute the testing strips and the labeled cups of baking powder, cream of tartar, detergent, and cornstarch.

Procedure



1. Set up the baking powder, cream of tartar, laundry detergent, and cornstarch on laminated strips of paper the way you did with the baking soda.
2. Test each of the powders with the test liquids the way you tested baking soda.
3. Record your observations for each reaction in its corresponding area on your observation chart.

Expected results:	**Baking soda**	**Baking powder**	**Cream of tartar**	**Detergent**	**Cornstarch**
Water	No change	Bubbling foamy	No change	No change	No change
Vinegar	Lots of bubbling, ends quickly	Bubbling foamy	No change	A little sudsy-looking	No change
Iodine	Stays orange	Black/purple in color foamy	Stays orange	Yellowish	Turns black
Cabbage	Stays blue	Pinkish-purple, then fades to blue, bubbles	Turns pink	Turns green	Stays blue

7. Test the unknown powder and try to identify it.

Explain that you will give each group a powder that is the same as one of the powders students have tested, but you won't tell them which one it is. Students will need to find a way to identify the unknown powder. Ask students:

- Is it possible to correctly identify the unknown powder?
- How could you test the unknown powder so that you could identify it?
- How will you use the results from all of your tests to help identify the unknown?

Students should realize that they will need to test the unknown powder the same way they tested all of the other known powders and compare the results. If the unknown powder reacts with each test liquid the same way one of the known powders does, then these two powders must be the same.

Distribute the unknown powder (baking powder) to each group.

Procedure

1. Place four samples of your group's unknown powder on a separate strip of laminated paper.
2. Test the unknown with each test liquid in the same way you tested the other powders.
3. Compare the set of reactions for the unknown with the other test strips and with your written observations.

8. Have students report the identity of the unknown and discuss what evidence led them to their conclusion.

Ask each group to state what it thinks is the identity of the unknown. Then ask them which observations led them to their conclusion. Remind students that color changes and bubbling are evidence of chemical change. Explain that they were able to use their observations to identify the unknown because each powder had its own set of characteristic chemical reactions with each of the test liquids.

Expected results:

		Powder being tested					
		Baking soda	**Baking powder**	**Cream of tartar**	**Detergent**	**Cornstarch**	**Unknown**
Test liquid	**Water**	No change	Bubbling foamy	No change	No change	No change	Bubbling foamy
	Vinegar	Lots of bubbling, ends quickly	Bubbling foamy	No change	A little sudsy-looking	No change	Bubbling foamy
	Iodine	Stays orange	Black/purple in color foamy	Stays orange	Yellowish	Turns black	Black/purple in color foamy
	Cabbage	Stays blue	Pinkish-purple, then fades to blue, bubbles	Turns pink	Turns green	Stays blue	Purple, then fades to blue, bubbles

Testing sheet 5.2

Using chemical change to identify an unknown

Baking soda

Baking powder

Cream of tartar

Testing sheet 5.2

Using chemical change to identify an unknown

Unknown

Detergent

Cornstarch

Student activity sheet
Activity 5.2

Name: ______________________________

Using chemical change to identify an unknown

Test liquid					
				Baking soda	**Powder being tested**
				Baking powder	
				Cream of tartar	
				Detergent	
				Cornstarch	
				Unknown	

What is the identity of the unknown? ______________________________

Activity 5.3
Exploring baking powder

What are the active ingredients in baking powder?

In *Activity 5.2* baking powder was the only substance that reacted with water to produce a gas. Baking powder is not just a single substance. It is a combination of substances that, when mixed with water, react to release carbon dioxide gas. Baking powder can be made from baking soda, cream of tartar, and corn starch. In *Activity 5.2,* students tested these substances and others and kept a record of their observations. In this activity, students will use these recorded results to identify the substances in baking powder. They will then test combinations of these substances to find out which are the active ingredients in baking powder.

Materials needed for each group

Baking soda
Cream of tartar
Cornstarch
Water

3 Popsicle sticks
1 Dropper
3 Small cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**

Preparing materials

- Label 3 small cups **baking soda**, **cream of tartar**, and **cornstarch**.
- Place ½ teaspoon of each powder into its labeled cup.

Testing sheet

Make 3 or 4 copies of *Testing sheet 5.3—Exploring baking powder*, p. 272. (This page contains two testing sheets and each group will need only one.) You may choose to copy the testing sheets onto colored paper to give some contrast to the white powders. Be sure the paper you select is light enough that the labels can be easily read. Cut along the dotted lines and laminate each testing sheet. Once laminated, these testing sheets can be reused. Distribute the testing sheets when specified in the activity.

Activity sheet

Copy *Activity sheet 5.3—Exploring baking powder*, p. 273, and distribute one per student when specified in the activity. Students will need to refer back to their recorded observations on *Activity sheet 5.2—Using chemical change to identify an unknown*, p. 268.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.3
Exploring baking powder

Question to investigate

What are the active ingredients in baking powder?

1. Have students identify the substances in baking powder.

Distribute *Activity sheet 5.3—Exploring baking powder.* Remind students that baking powder was a unique powder in *Activity 5.2* because it was the only one that bubbled when water was added to it. Tell students that baking powder is a combination of three substances and that some of the powders used in *Activity 5.2* can be combined to make baking powder.

Ask students to look back at their recorded observations on *Activity sheet 5.2—Using chemical change to identify an unknown*, to see whether they can identify substances that reacted similarly to baking powder. They should see how baking powder reacted with each test liquid, write that reaction down on *Activity sheet 5.3*, and then write the name of the powder that reacted similarly with that liquid.

Students should notice similarities like the following:

Test liquid	**What did you observe when you added this test liquid to baking powder?**	**Which substance reacted in a similar way?**
Water	Bubbled	None
Vinegar	Bubbled	Baking soda
Iodine	Turned black	Cornstarch
Cabbage	Pinkish-purple, then changed to blue; bubbled	Cream of tartar (Pinkish, but didn't turn to blue)

Baking soda, cornstarch, and cream of tartar each reacted in a similar way to baking powder when tested with the test liquids. Since students know that baking powder is made from a combination of different substances, they could agree that these substances might be baking soda, cornstarch, and cream of tartar.

2. Help students identify all the possible combinations of two powders that could be the active ingredients in baking powder.

Tell students that two of the three powders they identified are the active ingredients in baking powder. When these two powders are combined and water is added, they will bubble. To find which combination of powders are the active ingredients in baking powder, students will need to test the different combinations with water.

Ask students to figure out all the different combinations of two powders using baking soda, cornstarch and cream of tartar. Have students list these combinations on *Activity sheet 5.3*. The different possible combinations are:

Baking soda + Cornstarch
Baking soda + Cream of tartar
Cornstarch + Cream of tartar

Distribute laminated *Testing sheet 5.3—Exploring baking powder.* Students should recognize that the combinations of powders on the testing sheet are the same as the ones they figured out.

3. Have students test their combinations with water and identify the active ingredients in baking powder.

Ask students to suggest how they could test each set of powders. As a whole class, agree on a procedure. The following procedure is an example.

Procedure

1. Use a separate popsicle stick to place a small amount of each powder in its labeled area onto laminated *Testing sheet 5.3—Exploring baking powder.*
2. Use a popsicle stick to combine the powders in each area together to make three separate combinations of powder.
3. Use a dropper to add about 5–10 drops of water to each pile.

***Expected results*: Only the combination of baking soda and cream of tartar bubbles when water is added.**

4. Discuss student observations.

Ask students which combinations of powders bubbled when water was added. Then ask them to identify the active ingredients in baking powder.

Students should conclude that baking soda and cream of tartar are the active ingredients in baking powder. Cornstarch is also an ingredient in baking powder, but it is not involved in the reaction. Its purpose is to absorb moisture from the air so that the baking soda and cream of tartar don't react while in an open can. Tell students that cream of tartar is an acid. Remind students that vinegar is an acid too. This is why both cream of tartar and vinegar react with baking soda to produce a gas.

Students will explore cream of tartar and vinegar further in *Activity 5.7—Color changes with acids and bases*, pp. 285–288.

Testing sheet 5.3

Exploring baking powder

Baking soda + Cornstarch	Baking soda + Cream of tartar	Cornstarch + Cream of tartar

Testing sheet 5.3

Exploring baking powder

Baking soda + Cornstarch	Baking soda + Cream of tartar	Cornstarch + Cream of tartar

Student activity sheet
Activity 5.3

Name: ______________________________

Exploring baking powder

What are the active ingredients in baking powder?

Look back at the observations you recorded on *Activity sheet 5.2* to find the powders that react in a similar way to baking powder.

Test liquid	What did you observe when you added this test liquid to **baking powder**?	Which **other powder** reacted like baking powder when this test liquid was added to it?
Water		
Vinegar		
Iodine		
Red cabbage indicator		

1. List all the possible combinations of two powders using baking soda, cream of tartar, and cornstarch.

____

____

____

Test each of these combinations with water

2. Which combination of powders bubble with water the way that baking powder does?

____

____

____

3. What are the two active ingredients in baking powder?

______________________________ ______________________________

Activity 5.4
Change in temperature—Endothermic reaction

Aside from bubbling, what else happens during a reaction between baking soda and vinegar?

In each of the previous activities, students observed bubbling and learned that this was evidence that a chemical change occurred. In this activity, students will observe another aspect of the reaction between baking soda and vinegar. Along with bubbling, students will see that the temperature decreases. A change in temperature is another clue that a chemical reaction has occurred. A reaction that results in a decrease in temperature is called an *endothermic* reaction.

Materials needed for each group

Baking soda
Vinegar
Thermometer
½ Teaspoon
1 Clear plastic cup
2 Small cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- The bulb of the thermometer needs to be completely submerged in the vinegar in order to get an accurate reading. Due to the small amount of vinegar suggested in the procedure, you may need to have students tilt their cups of vinegar so that the bulb of the thermometer is completely submerged. If your thermometers have a plastic backing, you may be able to "lower the bulb" by clipping the plastic backing so that it is even with the bottom of the bulb.

Preparing materials

- Label 2 small cups **vinegar** and **baking soda**.
- Place about 1 tablespoon of vinegar and about 1 teaspoon of baking soda in their labeled cups. **Note:** If you plan to do *Activity 5.5* immediately after *Activity 5.4,* increase the amounts to 4 tablespoons (¼ cup) vinegar and 1 tablespoon baking soda. These source cups can then be used for both activities.

Activity sheet

Copy *Activity sheet 5.4—Change in temperature: Endothermic reaction*, p. 276, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 5.4
Change in temperature—Endothermic reaction

Question to investigate

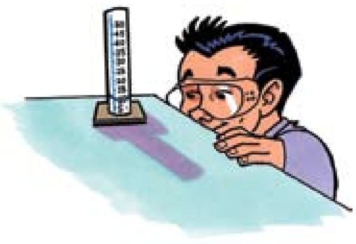
Aside from bubbling, what else happens during a reaction between baking soda and vinegar?

1. Have students measure the change in temperature in the reaction between baking soda and vinegar.

Decide in advance whether you will have students use the Fahrenheit or Celsius scale. Review with students how to read a thermometer. Explain that the bulb of the thermometer should be submerged during the reaction and when students are reading the thermometer.

Distribute *Activity sheet 5.4—Change in temperature—Endothermic reaction*.
Use the activity sheet to help explain how to use a graduated cylinder to measure liquids before students begin the activity.

Procedure



1. Use a graduated cylinder to measure 10 ml of vinegar and pour it into a clear plastic cup.

2. Place a thermometer in the vinegar. Read the thermometer and record the temperature on the activity sheet.
3. While the thermometer is in the cup, add ½ teaspoon of baking soda.
4. Watch the thermometer to observe any change in temperature. Record the lowest temperature reached.

Expected results: **If you begin with room-temperature vinegar, the temperature will drop about 12 °F or about 7 °C. There is also a gas produced.**

2. Have students share their observations.

Ask student groups whether the temperature increased, decreased, or stayed the same during this reaction. Then have them share the lowest temperature reached during the reaction. There will likely be some variation.

Explain to students that a change in temperature is a sign that a chemical reaction has occurred. Introduce the term *endothermic* to describe a reaction in which the temperature decreases.

Remind students that in chemical reactions, new substances are formed. Ask students if they observed anything that might be considered a new substance. Students should recognize the bubbles of carbon dioxide gas (introduced in *Activity 5.1*) as a new substance.

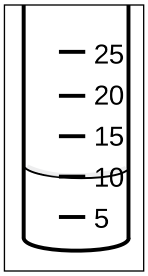
Student activity sheet Name: ______________________________

Activity 5.4

Change in temperature—Endothermic reaction

Aside from bubbling, what else happens during a reaction between baking soda and vinegar?

You have seen that mixing baking soda and vinegar produces a gas. This bubbling is a sign that something new was produced. In this activity, you will combine baking soda and vinegar again. But this time you will use a thermometer to see if the temperature changes during this reaction.



In the procedure below you will use a graduated cylinder to measure 10 ml of vinegar. When measuring, you need to make sure your eye is level with the 10 ml mark. Then carefully add a little bit of vinegar to the graduated cylinder. You may notice a little curve at the top of the vinegar. This is called the *meniscus*. Keep watching the level of the vinegar as you add more. Stop adding vinegar when the bottom of the *meniscus* touches the 10 ml line.

Procedure

1. Use a graduated cylinder to measure 10 ml of vinegar and pour it into a clear plastic cup.
2. Place a thermometer in the vinegar. Read the thermometer and record the temperature in the chart below.
3. While the thermometer is in the cup, add ½ teaspoon of baking soda.
4. Watch the thermometer to observe any change in temperature. Record the lowest temperature reached in the chart below.

	Temperature
Before adding baking soda	
After adding baking soda	
Change in temperature	
Did the temperature increase or decrease?	

When two or more substances are mixed together and the temperature changes, this is a clue that a chemical reaction has occurred. When the temperature decreases during a chemical reaction, it's called an *endothermic* reaction.

Activity 5.5

Production of a gas—Controlling a chemical reaction

How can you control the amount of gas produced in a baking soda and vinegar reaction?

In this investigation, students have seen a few reactions that produce a gas. In this activity, they will adjust the amount of baking soda and vinegar to control the *amount* of gas produced in the reaction. Since the bubbles of carbon dioxide gas normally disappear quickly, students will add a little detergent to make a longer-lasting foam. They will then evaluate the amount of gas produced based on the height the foam rises in a graduated cylinder.

Materials needed for each group

Baking soda
Vinegar
Water
Liquid dish detergent
Graduated cylinder, 50 ml
½, ¼, and ⅛ Teaspoons
1 Dropper
2 Small cups
2 Waste containers
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- You may reuse the source cups of vinegar and baking soda left over from *Activity 5.4*.
- Use a 50 ml graduated cylinder if possible. If you have a different size, you will need to adjust the amount of baking soda and vinegar used so that the resulting foam overflows in the demonstration portion of the activity, p. 278.
- Students will need to rinse out the graduated cylinders during the activity. Using a squirt bottle and waste container is one easy way to do this if you do not have sinks at tables.
- Only one waste container is needed per group if sinks are readily available.

Preparing materials

- If you are not using cups from *Activity 5.4*, label 2 small cups **vinegar** and **baking soda.**
- Place about 3 tablespoons of vinegar and about 1 tablespoon of baking soda in their labeled cups.
- Label one small cup **detergent** for each group.
- Make enough solution for the class by adding 1 teaspoon of liquid dish detergent to 2 tablespoons of water. Stir gently until well-mixed.
- Place 1 teaspoon of the detergent solution you made into each labeled cup.

Activity sheet

Copy *Activity sheet 5.5—Production of a gas: Controlling a chemical reaction*, p. 280, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.5
Production of a gas—Controlling a chemical reaction

Question to investigate

How can you control the amount of gas produced in a baking soda and vinegar reaction?

1. Introduce the activity.

Students know that baking soda and vinegar produce a gas. Explain that in chemical reactions, the change resulting from the reaction can be controlled by the amount of each substance used. Tell students that they will investigate how the amount of baking soda and vinegar used in a reaction influences the amount of gas produced.

Demonstration

2. As a demonstration, combine vinegar, detergent, and baking soda in a graduated cylinder so that the foam overflows.

Procedure

1. Use a graduated cylinder to measure 10 ml of vinegar. (Refer to *Activity sheet 5.4*, p. 276 if necessary.)
2. Pour the vinegar in a small cup and add 1 drop of detergent. Swirl gently to mix.
3. Add ½ teaspoon of baking soda to the empty graduated cylinder.
4. Stand the graduated cylinder in the center of a plastic waste container.
5. Pour the vinegar and detergent from the cup into the graduated cylinder. Have students observe the level of foam in the graduated cylinder.
6. Rinse the graduated cylinder over a sink, bucket, or separate waste container.

Expected results: **A white foam will rise up and overflow from the graduated cylinder.**

3. Discuss with students what they might change to create a foam that rises to the top of the graduated cylinder without overflowing.

Ask students what they could change to create a foam that does not overflow.

Students might mention variables such as:

- The amount of vinegar, detergent, or baking soda.
- The order in which the substances are added to the graduated cylinder.

Explain that the amount of detergent is not varied in this activity because it is used as an indicator to help *measure* the amount of gas produced in the baking soda and vinegar reaction.

4. Have a class discussion to help groups plan their testing strategies.

Remind students that 10 ml of vinegar and ½ teaspoon of baking soda caused a reaction that flowed over the top of the graduated cylinder. Students should consider these amounts as they plan how much of each reactant they will use as they start their trials.

- Every test should be conducted the same way. For example, in the demonstration baking soda was placed in the graduated cylinder before the vinegar and detergent were added. This method mixes the baking soda and vinegar better. All new trials should be conducted this same way.
- Discuss with students the importance of thoroughly rinsing the graduated cylinder between trials.
- Ask students how they will remember the amounts of vinegar and baking soda they used in each trial. Point out the necessity of making and recording accurate measurements since they may need to reproduce their results. It is easy to forget how much of each reactant was used for each test and how high the foam rose.

5. Have students conduct their trials.

Distribute *Activity sheet 5.5—Production of a gas.* Tell students that they should try to get the foam to go as high up in the graduated cylinder as possible without overflowing. It is fine for the foam to rise above the rim in a dome as long as it does not drip down the outside. You may choose to limit students to a maximum of three tries or let them experiment further if time and supplies allow.

Procedure

Students should follow the same procedure as in the demonstration but with different amounts of baking soda and vinegar. They should use 1 drop of detergent in each trial.

On the activity sheet, students will describe the level of foam either by the number of milliliters it reaches or using words such as *almost to the top, a little overflow*, etc.

***Expected results*:** **Using ⅛ teaspoon of baking soda, 5 ml of vinegar, and 1 drop of detergent will cause foam to rise to the top of the cylinder without overflowing. Results may vary.**

6. Have students report on their trials.

Have groups share their findings about the amounts of baking soda and vinegar that came closest to reaching the top of the cylinder. Did each group use similar amounts of baking soda and vinegar? Ask students if the amount of baking soda and vinegar used affects the amount of carbon dioxide gas produced. They should agree that it does.

Student activity sheet
Activity 5.5

Name: ______________________________

Production of a gas—Controlling a chemical reaction

How can you control the amount of gas produced in a baking soda and vinegar reaction?

The amount of baking soda and vinegar used in the demonstration caused the foam to overflow. You will need to adjust the amounts to create a column of foam that rises to the top of the graduated cylinder without overflowing.

Procedure

1. Record the amount of vinegar and baking soda you plan to use.
2. Use a graduated cylinder to measure the vinegar. Remember that the bottom of the meniscus should touch the line.
3. Pour the vinegar in a small cup and add 1 drop of detergent. Swirl gently to mix.
4. Add baking soda to the empty graduated cylinder.
5. Stand the graduated cylinder in the center of a plastic waste container.
6. Pour the vinegar and detergent from the cup into the graduated cylinder.
7. Describe the level the foam reached either by the number of milliliters it reaches or using words such as *almost to the top, barely overflowed*, etc.
8. Use a sink or a squirt bottle held over a waste container to rinse out the graduated cylinder.

1. Be sure to record the amounts you used and your results in the chart below.

Trials	Demonstration	1st trial	2nd trial	3rd trial
Vinegar	10 ml			
Baking soda	½ teaspoon			
Detergent	1 drop	1 drop	1 drop	1 drop
How close did the foam get to the top of the cylinder?	It overflowed a lot.			

2. What amount of vinegar and baking soda created a foam that rose to the top of the graduated cylinder without overflowing?

Vinegar ______________________________

Baking soda ______________________________

Detergent _____________1 drop_____________

Activity 5.6
Change in temperature—Exothermic reaction

Can the temperature increase during a chemical reaction?

In *Activity 5.4*, students saw that the temperature decreased during the chemical reaction between baking soda and vinegar. In this activity, students will add calcium chloride to a baking soda solution and observe an *increase* in temperature along with the production of a gas and a white precipitate. A change in temperature is a clue that a chemical reaction has occurred. A reaction that results in an increase in temperature is called an *exothermic* reaction.

Materials

Baking soda solution
Calcium chloride
Water
Thermometer
Graduated cylinder, 50 ml
½, ¼, and ⅛ Teaspoons
2 Small cups
Waste container
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Calcium chloride is sold in hardware stores as a moisture absorber under the name DampRid®. It is also available through the chemical supplier your school or district uses. If the container is sealed tightly, calcium chloride will keep for many uses.
- The bulb of the thermometer needs to be completely submerged in the baking soda solution. Due to the small amount of baking soda solution suggested in the initial procedure, you may need to have students tilt their cups of baking soda solution so that the bulb of the thermometer is completely submerged. If your thermometers have a plastic backing, you may be able to "lower the bulb" by clipping the plastic backing so that it is even with the bottom of the bulb.

Preparing materials

- Label 2 small cups **calcium chloride** and **baking soda solution**.
- Place about 1 rounded tablespoon of calcium chloride in its labeled cup for each group. If using DampRid® place about 2 tablespoons in the calcium chloride cup.
- Make the baking soda solution for the entire class by adding ¼ cup of baking soda to 2 cups of water. Stir until the baking soda is as dissolved as possible. It's ok if some is left undissolved.
- Pour about ¼ cup of baking soda solution in its labeled cup for each group.

Activity sheet

Copy *Activity sheet 5.6—Change in temperature: Exothermic reaction*, p. 284, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 5.6
Change in temperature—Exothermic reaction

Question to investigate

Can the temperature increase during a chemical reaction?

1. Have students observe and record the temperature change of calcium chloride reacting with a baking soda solution.

Distribute *Activity sheet 5.6—Production of a gas.*

Note: If using DampRid®, have students use 1 teaspoon of DampRid® instead of the ½ teaspoon of calcium chloride specified in the procedure.

Procedure

1. Use a graduated cylinder to measure 10 ml of baking soda solution and pour it into a clear plastic cup.
2. Place a thermometer in the baking soda solution. Read the thermometer and record the temperature on the activity sheet.

3. While the thermometer is in the cup, add ½ teaspoon of calcium chloride.
4. Watch the thermometer to observe any change in temperature. Record the highest temperature on the activity sheet.

Expected results: **The temperature of the solution increases from about 20 °C (about 70 °F) to about 45 °C (about 110 °F). Carbon dioxide gas is produced and a white cloudy precipitate, calcium carbonate, is formed.**

2. Discuss with students what they might change to make the reaction get even hotter.

Ask students what they might change to increase the temperature by another 5 °C or about 10 °F. Students may suggest increasing the amount of calcium chloride or baking soda solution or both. Discuss whether it makes sense to change the amount of both at the same time or if it would be better to change the amount of just the calcium chloride or baking soda solution first. Try to have students understand that dealing with one variable at a time is a good strategy at first. That way, students can see how much each variable affects the result.

3. Have students conduct their trials.

Remind students that the goal is to increase the temperature by 5 °C or about 10 °F, not as much as possible. You may choose to limit students to a maximum of three tries or let them experiment further if time and supplies allow.

Procedure

Students should follow the same procedure as before except adjust the amounts of calcium chloride or baking soda solution. As expected, increasing the amount of calcium chloride increases the temperature of the reaction. However, if students try increasing the amount of baking soda solution, they will find that the temperature does not increase as much. This is because any possible advantage gained by adding more baking soda is counterbalanced by the additional volume of solution that needs to be heated. It may not be intuitive; but *decreasing* the amount of baking soda solution is actually one way to increase the temperature of the reaction.

Expected results: **Adding ¾ teaspoon of calcium chloride instead of ½ teaspoon is one way to reach the target temperature. Using 5 mls of baking soda solution instead of 10 is another way to reach the target temperature.**

Once students have discovered the effect of changing the amount of each of the reactants, they may try increasing the amount of calcium chloride while also decreasing the amount of baking soda solution.

Student activity sheet
Activity 5.6

Name: ______________________________

Change in temperature—Exothermic reaction

Can the temperature increase during a chemical reaction?

Conduct the following procedure as written and record the change in temperature in the chart below. Then adjust either the amount of baking soda solution or calcium chloride to try to reach a target temperature.

Procedure

1. Use a graduated cylinder to measure 10 ml of baking soda solution and pour it into a clear plastic cup.
2. Place a thermometer in the baking soda solution. Read the thermometer and record the temperature in the chart next to the words “Initial temperature”.
3. While the thermometer is in the cup, add ½ teaspoon of calcium chloride.
4. Watch the thermometer to observe any change in temperature. Record the highest temperature in the chart.
5. After conducting the activity according to the procedure, add another 5 °C or about 10 °F to the highest temperature. This is your *target temperature*. Write this target temperature in your chart for each of the 3 trials.
6. Try changing the amount of baking soda solution or calcium chloride to reach your target temperature

Trials	Procedure written above	1st trial	2nd trial	3rd trial
Baking soda solution	10 ml			
Initial temperature				
Calcium chloride	½ teaspoon			
Highest temperature				
Target temperature				
Difference between the highest and target temperatures				
Is this too high, too low, or just right?				

When the temperature increases during a chemical reaction, it’s called an *exothermic* reaction.

Activity 5.7
Color changes with acids and bases

How can you tell if a substance is an acid, a base, or neutral?

In *Activities 5.1* and *5.2,* students saw that the color changes of red cabbage indicator can be used to help distinguish similar-looking powders. Students used this evidence to conclude that the powders were chemically different. In this activity, students will use the color changes of red cabbage indicator to classify substances as either acid or base. This knowledge will then be built upon in *Activity 5.8* as students neutralize acid and base solutions and in *Activity 5.9* as students compare the amount of acid in different solutions.

Materials needed for each group

Red cabbage leaves
Cream of tartar
Vinegar
Powdered laundry detergent
Water
Zip-closing plastic bag, storage-grade, quart-size
5 Clear plastic cups
3 Small cups
2 Flat toothpicks
1 Dropper
1 Tablespoon
Permanent marker
White piece of paper

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Use fresh red cabbage; pre-shredded red cabbage will not work. Students will also make red cabbage indicator solution in *Activities 5.8* and *5.9.* Refrigerate the cabbage so that it will stay fresh.
- If you choose to do *Activity 5.8—Neutralizing acids and bases* immediately following this activity, do not discard any of the liquids. These will be reused in *Activity 5.8.* If you plan to do *Activity 5.8* on another day, students should make fresh solutions.

Preparing materials

- Label 3 small cups **vinegar**, **detergent**, and **cream of tartar** for each group.
- Place about 1 teaspoon of vinegar in its labeled cup.
- Place about ¼ teaspoon of detergent and ¼ teaspoon of cream of tartar in their labeled cups.

Activity sheet

Copy *Activity sheet 5.7—Color changes with acids and bases,* p. 288, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.7
Color changes with acids and bases

Question to investigate

How can you tell if a substance is an acid, a base, or neutral?

1. Introduce this activity.

Remind students about the demonstration you conducted during *Activity 5.1*, p. 256, with red cabbage indicator solution and two similar-looking powders—cream of tartar and laundry detergent. Tell students that in this activity, they will make their own indicator solution and experiment with these powders. Tell students that red cabbage indicator changes color when certain chemicals are added to it. It turns pinkish when *acids* are mixed with it. It turns green when *bases* are mixed with it. And it remains blue when *neutral* substances are mixed with it. A neutral substance is neither an acid nor a base.

Distribute *Activity sheet 5.7—Color changes with acids and bases.*

2. Have students prepare for the activity.

Procedure

Make red cabbage indicator solution

1. Tear 2 red cabbage leaves into small pieces and place them in a storage grade zip-closing plastic bag.
2. Add about 1 cup of room temperature water. Get as much air out of the bag as possible and seal the bag securely.
3. While holding the bag, repeatedly squeeze the water and cabbage leaves until the water turns a medium to dark blue. This is your indicator solution.
4. Open a corner of the bag and carefully pour the red cabbage indicator into an empty clear plastic cup, leaving the cabbage pieces behind in the bag.

Prepare the cups

5. Label four empty clear plastic cups **indicator + detergent**, **indicator + cream of tartar**, **indicator + vinegar**, and **control**.
6. Carefully pour 2 tablespoons of indicator solution into each cup.
7. Place the four labeled cups on a white piece of paper.

3. Have students add acids and a base to the indicator.

Procedure

Cream of tartar

1. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup.
2. Gently swirl to mix. Observe any color change in the cup and record this in the chart on the activity sheet.

Laundry detergent

3. Use the flat end of a toothpick to scoop up a small amount of laundry detergent. Add the detergent to the *indicator + detergent* cup.
4. Gently swirl to mix. Observe any color change in the cup and record this in the chart.

Vinegar

5. Use a dropper to add 1 drop of vinegar to the *indicator + vinegar* cup.
6. Gently swirl to mix. Observe any color change in the cup and record this in the chart.

Expected results: **Cream of tartar and vinegar turn the indicator a pinkish color. Laundry detergent turns the indicator a greenish-blue color.**

4. Discuss student observations.

Remind students that red cabbage indicator turns pink when acids are added to it and greenish-blue when bases are added to it. Ask students which substances they tested are acids and which are bases. They should conclude that vinegar and cream of tartar are both acids and that laundry detergent is a base.

Remind students that in *Activity 5.3—Exploring baking powder,* the combination of baking soda and cream of tartar was the only pair that bubbled when water was added. That is because cream of tartar, like vinegar, is an acid and will react with baking soda to produce carbon dioxide gas.

Note: If you choose to do *Activity 5.8—Neutralizing acids and bases* immediately following this activity, do not discard any of the liquids. These will be reused in *Activity 5.8*. If you plan to do *Activity 5.8* on another day, students should make fresh solutions.

Student activity sheet
Activity 5.7

Name: ______________________________

Color changes with acids and bases

How can you tell if a substance is an acid, a base, or neutral?

Red cabbage indicator turns pink or purplish pink when acids are added to it, turns greenish-blue when bases are added, and remains blue when neutral substances are added. Do this experiment to find out if cream of tartar, laundry detergent, and vinegar are acids, bases, or neutral.

Set-up the experiment

Procedure

1. Follow your teacher's directions to make red cabbage indicator solution.
2. Label 4 empty clear plastic punch cups **indicator + cream of tartar**, **indicator + detergent**, **indicator + vinegar**, and **control.**
3. Carefully pour 2 tablespoons of indicator solution into each cup.
4. Place the four labeled cups on a white piece of paper.

Conduct the experiment

Procedure

Cream of tartar

1. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup.
2. Gently swirl to mix. Observe any color change in the cup and record this in the chart below.

Laundry detergent

3. Use the flat end of a toothpick to scoop up a small amount of laundry detergent. Add the detergent to the *indicator + detergent* cup.
4. Gently swirl to mix. Observe any color change in the cup and record this in the chart below.

Vinegar

5. Use a dropper to add 1 drop of vinegar to the *indicator + vinegar* cup.
6. Gently swirl to mix. Observe any color change in the cup and record this in the chart below.

Substance	**Color of indicator + substance**	**Is this substance an acid, base, or neutral?**
Cream of tartar		
Laundry detergent		
Vinegar		

Activity 5.8
Neutralizing acids and bases

How can you return the color of a red cabbage indicator solution back to blue?

In *Activity 5.7,* students saw that acids turn red cabbage indicator pink and bases turn it greenish-blue. In this activity, students will use their knowledge of color changes with red cabbage indicator to neutralize an acidic solution with a base and then neutralize a basic solution with an acid.

Materials needed for each group

Red cabbage leaves
Cream of tartar
Powdered laundry detergent
Water
Zip-closing plastic bag (quart-size, storage-grade)
4 Clear plastic cups
2 Small cups
4 Toothpicks
1 Tablespoon
Permanent marker
White piece of paper

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Use fresh red cabbage; pre-shredded red cabbage will not work.
- Students should make fresh cabbage indicator solution or, if conducting this activity immediately after *Activity 5.7,* use the left over indicator solution.

Preparing materials

- Either reuse the labeled cups and substances from *Activity 5.7* or label 2 small cups **detergent** and **cream of tartar**.
- Place about ¼ teaspoon of laundry detergent and ¼ teaspoon of cream of tartar in their labeled cups.

Activity sheet

Copy *Activity sheet 5.8—Neutralizing acids and bases*, p. 293, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.8
Neutralizing acids and bases

Question to investigate

How can you return the color of a red cabbage indicator solution back to blue?

1. Introduce the concept of *neutralization*.

Ask students if they can think of a way to return the pink indicator solution from *Activity 5.7* back to blue. Give students a hint by telling them that acids and bases are like chemical opposites. Tell students that adding just the right amount of laundry detergent to the indicator + cream of tartar can bring the indicator solution back to its neutral color—blue. This process is called *neutralizing* an acid.

Ask students what they might do to return the green indicator solution from *Activity 5.7* back to blue. Tell students that they will use the color changes of red cabbage indicator to help them neutralize both an acid and a base.

Distribute *Activity sheet 5.8—Neutralizing acids and bases.*

2. Have students prepare for the experiment.

If students conduct this activity immediately after *Activity 5.7*, they can reuse the solutions and skip the procedure on the activity sheet.

Procedure

1. Make indicator solution as described on p. 286. This indicator solution will be used in this activity and in *Activity 5.9*.
2. Label 3 empty clear plastic cups **indicator + detergent**, **indicator + cream of tartar**, and **control**.
3. Carefully pour 2 tablespoons of indicator solution into each cup and place the cups on a white piece of paper.
4. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup. Gently swirl to mix.
5. Use the flat end of a different toothpick to scoop up a small amount of laundry detergent. Add the detergent to the *indicator + detergent* cup. Gently swirl to mix.

***Expected results*: Cream of tartar turns the indicator a pinkish color. This means that vinegar and cream of tartar are both acids. Laundry detergent turns the indicator a greenish-blue color. This means that laundry detergent is a base.**

3. Discuss with students how they might neutralize each solution.

Ask questions such as the following to help students plan how they will neutralize each solution.

- What should you add to the pink *indicator* + *cream of tartar* solution to change the color back to blue like the control?
- What should you add to the green *indicator* + *laundry detergent* solution to change the color back to blue like the control?
- Should you add a little bit of laundry detergent or cream of tartar, or a lot at once?
- What will you do if the color does not quite change back to blue after mixing the powder into the indicator solution?
- How will you know when the solution has been neutralized?

Students should suggest adding a little bit of laundry detergent to the pink *indicator* + *cream of tartar* and adding a little bit of cream of tartar to the green *indicator* + *laundry detergent* solution. They should realize that they will need to add a little bit of powder at a time, mix the contents of the cup, compare the color to the color of the control, and repeat if necessary. This process is described in the procedure below.

4. Have students neutralize the *indicator* + *cream of tartar* solution and the *indicator* + *laundry detergent* solution.

Procedure

1. Use a clean toothpick to add a small amount of laundry deterent to the *indicator* + *cream of tartar* and swirl. Observe the color. If needed, continue this process until the solution returns to blue.
2. Use a different clean toothpick to add a small amount of cream of tartar to the *indicator* + *laundry detergent* and swirl. Observe the color. If needed, continue this process until the solution returns to blue.

Expected results: **The pink *indicator* + *cream of tartar* solution will return to blue after adding small amounts of laundry detergent. The greenish *indicator* + *laundry detergent* solution will return to blue after adding small amounts of cream of tartar. The color of the indicator may not return to the exact color of the control.**

5. Discuss student experiences.

Ask students questions like the following to find out what they could do if they accidentally added too much detergent to the *indicator* + *cream of tartar* or too much cream of tartar to the *indicator* + *detergent*:

- Were you able to return the pink and greenish-blue indicator solutions back to blue?
- What could you have done if the pink indicator turned greenish-blue instead of blue?
- What could you have done if the greenish-blue indicator turned pink or purplish-pink instead of blue?
- Do you think you could have neutralized the greenish-blue indicator + laundry detergent solution with vinegar?
- How would you neutralize an indicator + vinegar solution?
- Can a base neutralize an acid?
- Can an acid neutralize a base?

Students should realize that adding a small amount of cream of tartar to the greenish-blue indicator solution could bring it back to blue and adding a small amount of detergent to the pink solution could bring it back to blue. Also, vinegar is an acid like cream of tartar. It can be used to neutralize an *indicator + detergent* solution. A base, like detergent, can be used to neutralize the *indicator + vinegar* solution. Students should conclude that a base can neutralize an acid and an acid can neutralize a base.

6. Conclude the activity by giving students real-life examples of the process of neutralizing.

Suggest some examples where neutralizing acids and bases is useful.

- Sometimes soil needs to be made a little more acidic or basic so that certain plants will grow better.
- Excess stomach acid can be neutralized with an antacid, which is a base.
- The amount of acid or base in a swimming pool or aquarium is adjusted by adding either an acid or base to help neutralize the water.
- The amount of acid or base in drinking water is adjusted at water purification plants. The water is made acidic to clean it and then neutralized before sending it out to homes and businesses. If the water were too acidic, it could react with the pipes and cause leaks.

Student activity sheet
Activity 5.8

Name: ____________________________

Neutralizing acids and bases

How can you return the color of red cabbage indicator solution back to blue?

Procedure

1. Follow your teacher's directions to make red cabbage indicator solution.
2. Label 3 empty clear plastic cups **indicator + detergent**, **indicator + cream of tartar**, and **control**.
3. Carefully pour 2 tablespoons of indicator solution into each cup and place the cups on a white piece of paper.
4. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup. Gently swirl to mix.
5. Use the flat end of a toothpick to scoop up a small amount of laundry detergent. Add the detergent to the *indicator + detergent* cup. Gently swirl to mix.

1. It is possible to get the pink indicator solution and the green indicator solution to both return to blue. How do you think you could do this? ***Hint***: Acids and bases are like chemical opposites.

____

____

____

Try to make both solutions return to blue.	**Initial color**	**Describe what you did to get this solution to return to blue.**
Indicator + Cream of Tartar	Pink	
Indicator + Laundry Detergent	Greenish-blue	

2. What is the purpose of a control in this experiment?

____

____

____

Activity 5.9
Comparing the amount of acid in different solutions

How can neutralizing acids help you compare the amount of acid in different solutions?

In *Activity 5.8*, students used a base to neutralize an acidic solution and an acid to neutralize a basic solution. In this activity students will use a similar process to compare the *amount* of acid in two different indicator + acid solutions. The teacher demonstrates this process using laundry detergent solution to neutralize two solutions containing 1 and 3 drops of vinegar. Students will then use the same detergent solution to compare two solutions containing vinegar and cream of tartar. By comparing the number of drops used to return each solution back to its blue color, students can discover which solution initially contained more acid.

Materials needed for the demonstration

Red cabbage indicator
Vinegar
Laundry detergent solution
3 Clear plastic cups
2 Droppers
Permanent marker

Materials needed for each group

Red cabbage indicator
Cream of tartar
Vinegar
Laundry detergent solution
3 Clear plastic cups
3 Small cups
2 Droppers
1 Toothpick
1 Tablespoon
Permanent marker
White piece of paper

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Have students make fresh red cabbage indicator solution according to the instructions on p. 286.

Preparing materials for the demonstration

- Label 3 clean clear plastic cups **control**, **1 drop vinegar**, and **3 drops vinegar**.
- Pour 2 tablespoons of red cabbage indicator into each cup.

Preparing materials for each group

- Make detergent solution for the entire class and the demonstration by combining 1 tablespoon powdered laundry detergent and ¾ cups of water in a plastic cup. Stir and wait a minute or two to allow some of the detergent to settle.
- Label 3 small cups **vinegar**, **cream of tartar**, and **detergent**.
- Place about 1 teaspoon vinegar and 1 tablespoon detergent solution in their labeled cups.
- Place less than ⅛ teaspoon of cream of tartar in its labeled cup.

Activity sheet

Copy *Activity sheet 5.9—Comparing the amount of acid in different solutions*, p. 297, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.9
Comparing the amount of acid in different solutions

Question to investigate

How can neutralizing acids help you compare the amount of acid in different solutions?

Demonstration

1. Demonstrate how to use drops of a base to compare the amount of acid in two solutions.

You will need 3 clear plastic cups labeled **control**, **1 drop vinegar**, and **3 drops vinegar**. Each cup should contain 2 tablespoons of red cabbage indicator. Explain that you will use a technique similar to one scientists use to compare the amount of acid in different solutions. This technique is also very similar to the process students used to neutralize solutions in *Activity 5.8*.

Procedure

1. In front of students, use a dropper to add 1 drop of vinegar and 3 drops of vinegar to their labeled cups. Swirl each gently to mix. Ask students if they would be able to tell which cup contained more acid if the cups were not labeled.
2. Use a dropper to add 1 drop of detergent solution to the cup with 1 drop of vinegar and gently swirl. Compare the color of the indicator solution to the color of the control.
3. If the color is not yet blue like the control, continue adding a single drop of detergent solution, swirling, and comparing the color to the control. Stop adding drops when the color is similar to the color of the control. Record the number of drops on the board.
4. Repeat Steps 2–3 for the cup with 3 drops of vinegar.

Expected results: **More drops of detergent solution are needed to neutralize the solution with three drops of vinegar than the solution with one drop of vinegar**.

2. Discuss student observations.

Ask students:

- Which cup had more acid in it?
- What is the relationship between the amount of acid in the solution and the number of drops of base it takes to return the solution back to neutral?

Students should realize that the more acid in a solution, the more drops of a base, like the detergent solution, will be needed to neutralize the solution.

3. Have students compare the amount of acid in an *indicator + vinegar* solution to the amount or acid in an *indicator + cream of tartar* solution.

Distribute *Activity sheet 5.9—Comparing the amount of acid*, along with cups of vinegar, cream of tartar, detergent solution, indicator solution, and 3 clean clear plastic cups. Have students follow the procedure on the activity sheet.

Procedure

1. Label 3 clear plastic cups **indicator + vinegar**, **indicator + cream of tartar** and **control**.
2. Use a dropper to add 1 drop of vinegar to the *indicator + vinegar* cup. Gently swirl to mix.
3. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup. Gently swirl to mix.
4. Use a dropper to add 1 drop of detergent solution to the cup with the *indicator + vinegar* and gently swirl.
5. Check to see if the color of the indicator solution is similar to the color of the control. If so, stop and record the number of drops in the chart on the activity sheet.
6. If not, continue adding and counting drops of detergent solution, swirling, and comparing the color to the control. Stop adding drops when the color is similar to the color of the control. Record the number of drops in the chart.
7. Repeat Steps 4–6 for the cup with *indicator + cream of tartar.*

Expected results: **The number of drops of detergent solution needed to bring the color of the indicator solutions back to the color of the control will vary. In the cup with *indicator + 1 drop vinegar,* expect to use about 6 drops of detergent solution. When we conducted this experiment, it took about 12 drops of detergent solution to neutralize the *indicator + cream of tartar.* Since the amount of cream of tartar your students add to this cup depends on how much they pile on the flat end of a toothpick, expect the number of drops of laundry detergent students use to neutralize this solution to vary accordingly.**

4. Have groups discuss their results.

Ask students questions such as the following:

- Which solution contained more acid: the *indicator + vinegar* or the *indicator + cream of tartar*?
- What evidence led you to this conclusion?
- How might you compare the amount of base in two greenish-blue indicator solutions?

Students should realize that more drops of base are required to neutralize the solution that contains more acid. They should also infer that they would need to add drops of vinegar or some other acid to the two greenish-blue indicator solutions to neutralize each solution. The solution that requires more drops of acid to return it to blue must have contained more base than the other.

Student activity sheet
Activity 5.9

Name: ______________________________

Comparing the amount of acid in different solutions

How can neutralizing acids help you compare the amount of acid in different solutions?

Procedure

1. Label 3 clear plastic cups **indicator + vinegar**, **indicator + cream of tartar**, and **control**.
2. Use a dropper to add 1 drop of vinegar to the *indicator + vinegar* cup. Gently swirl to mix.
3. Use the flat end of a toothpick to scoop up a small amount of cream of tartar. Add the cream of tartar to the *indicator + cream of tartar* cup. Gently swirl to mix.
4. Use a dropper to add 1 drop of detergent solution to the cup with the *indicator + vinegar* and gently swirl.
5. Check to see if the color of the indicator solution is similar to the color of the control. If so, stop and record the number of drops in the chart below.
6. If not, continue adding and counting drops of detergent solution, swirling, and comparing the color to the control. Stop adding drops when the color is similar to the color of the control. Record the number of drops in the chart below.
7. Repeat Steps 4–6 for the cup with *indicator + cream of tartar.*

1. In the activity, you used a base to neutralize two acidic solutions. How did you know which one contained more acid?

____

	Indicator + Vinegar	**Indicator + Cream of tartar**
How many drops of laundry detergent solution did you use to get the solution to return to blue?		
Place a check in the box beneath the solution that contains more acid.		

2. If you had two red cabbage indicator solutions that were greenish-blue, you would know that each of these solutions had a base in it. How could you compare these two solutions to find out which contained more base?

____

____

____

Activity 5.10
Formation of a precipitate

What happens when soap is added to hard water?

Sometimes when two liquids combine, a solid forms and falls to the bottom of the liquid. This solid is a new substance, called a *precipitate*, and is evidence that a chemical reaction has occurred. Soap scum, a common example of a precipitate, forms when certain minerals in hard water react with soap molecules. In this activity, students will compare the bubbling of soap-scum-in-water to the bubbling of soap-in-water to show that the soap scum that formed is a different substance than soap.

Materials needed for each group

Water
Epsom salt
Piece of Ivory® soap
Piece of paper
Coffee filter
1 Dropper
2 Popsicle sticks
2 Straws
6 Clear plastic cups
1 Small cup
1 Tablespoon
1 Teaspoon

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- One bar of soap is enough for an entire class to do this activity.

Preparing materials

- Label 1 small cup **Epsom salt** for each group.
- Place 2 teaspoons of Epsom salt in its labeled cup.
- Cut one bar of Ivory® soap into eighths with a knife.

Activity sheet

Copy *Activity sheet 5.10—Formation of a precipitate*, pp. 302–304, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 305–307. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 5.10
Formation of a precipitate

Question to investigate

What happens when soap is added to hard water?

1. Have students make a soap solution and hard water.

Distribute *Activity sheet 5.10—Formation of a precipitate*. Tell students that they are going to make *hard water* and see how it reacts with soap. Explain that hard water is water that has minerals dissolved in it. In some areas, minerals like calcium, iron, or magnesium are naturally dissolved in the water. These minerals interfere with the cleaning ability of soap. Tell students that in this activity, they will add soap to hard water to create *soap scum*. Then they will compare the bubbling ability of soap and soap scum to find out whether or not soap scum is different from soap.

Procedure

1. Label 3 plastic cups **soap**, **water**, and **hard water**.
2. Place 3 tablespoons of water in the *soap* cup and 2 tablespoons of water into each of the *water* and *hard water* cups.
3. Hold a piece of Ivory soap on a piece of paper. Use a popsicle stick or plastic spoon to scrape soap flakes onto the paper.

4. Add about 1 tablespoon of soap flakes to the water in the *soap* cup, and stir about 1 minute until the water is white.
5. Make "hard water" by adding 2 teaspoons of Epsom salt to the water in the *hard water* cup, and mix until no more Epsom salt will dissolve.

2. Have students add soap solution to water and hard water.

The procedure below recommends using a dropper to transfer soapy water into a teaspoon in order to add this soap solution to the water and hard water. This method helps to avoid picking up large pieces of undissolved soap.

Procedure

1. Use a dropper to pick up soap solution from the *soap* cup. Carefully squirt several droppers-full of the soap solution into a teaspoon until it is full.
2. Pour this teaspoon of soap solution into the *water* cup. Use the dropper to collect another teaspoon of soap solution, and also add it to the *water* cup.
3. Using the same method described in Steps 1 and 2, add 2 teaspoons of soap solution to the *hard water* cup.
4. Look at the cups from the top and the side.

3. Discuss student observations.

Ask students if they notice any differences in the way soap combines with water compared with hard water.

Expected results: **The soap solution will mix with water and cause the water to look cloudy. When soap solution is added to hard water, a white curd-like substance will form. This is the precipitate, soap scum. Expect about ⅛ to ¼ teaspoon of precipitate.**

4. Ask students how they could design a test to compare soap and soap scum.

Ask students if they think the white substance in the hard water is soap or some other substance. Ask them for their ideas about tests they could conduct on this substance to find out whether or not it is still soap. Students might suggest comparing the ability of each to clean, the way they feel, whether they dissolve in water, or whether they can be used to make bubbles.

Since bubbling is easy to test, suggest that students compare the bubbling ability of this white substance to the bubbling ability of soap. Students may suggest adding soap to water and soap scum to water in separate containers and shaking them or blowing air into them to compare the amount of bubbling.

5. Have students compare the bubbling of a soap and soap scum solution.

The following is an example of one way to compare soap and soap scum based on how well they bubble when air is blown into them.

How do you know that soap scum is different from soap?

Procedure

Prepare the cups

1. Label one cup **soap** and the other **soap scum**.
2. Add 2 tablespoons of water to each of the labeled cups. These cups will be used after the soap scum is collected.

Collect the soap scum

3. Place a coffee filter on the top of a plastic cup as shown. Hold the filter in place as you pour the hard water and soap scum into the filter.
4. Allow some of the water to drain through. Then carefully remove the filter and gently squeeze the remaining water into the cup.
5. Carefully lay the coffee filter on a paper towel as shown. Use a popsicle stick to scrape the filter to collect the soap scum.

Compare the amount of bubbling in each cup

6. Look at the amount of soap scum you have. Then place a similar amount of soap flakes into the cup labeled *soap* and stir gently.
7. Add the soap scum to its labeled cup and stir gently.
8. Place a straw into both cups. Gently blow through each straw and compare the amount of bubbling.

Expected results: **The soap scum may look like soap, but it does not dissolve as well as soap. Also, soap scum in water does not bubble as much as soap in water when air is blown through it. Students may notice some bubbling in the soap scum and water. This may be due to some residual unreacted soap. However, the difference in the amount of bubbling in each cup should be enough to show that the soap scum is different than the original soap.**

6. Have students share their observations and conclusions.

Ask students questions such as the following:

- Based on your observations, do you think that soap scum is different from soap?
- Would you consider adding soap to hard water a chemical change? Why or why not?

Adding soap to hard water is a chemical change because a new substance, soap scum, is formed. You may want to mention to students that detergents were created because they do not react with hard water the way that soap does.

Student activity sheet
Activity 5.10

Name: ______________________________

Formation of a precipitate

What happens when soap is added to hard water?

In certain parts of the country, minerals like calcium, iron, or magnesium are naturally dissolved in the water. Water that has minerals dissolved in it is called *hard water.* These minerals can combine with soap to create *soap scum*. In this activity, you are going to make hard water and see how it reacts with soap.

Procedure

Prepare the cups

1. Label 3 plastic cups **soap**, **water**, and **hard water**.
2. Place 3 tablespoons of water in the *soap* cup and 2 tablespoons of water into each of the *water* and *hard water* cups
3. Hold a piece of Ivory soap on a piece of paper. Use a popsicle stick or plastic spoon to scrape soap flakes onto the paper.

4. Add 1 tablespoon of soap flakes to the water in the *soap* cup, and stir until the water is white.
5. Make “hard water” by adding 2 teaspoons of Epsom salt to the water in the *hard water* cup, and mix until no more Epsom salt will dissolve.

Add soap to water and to hard water

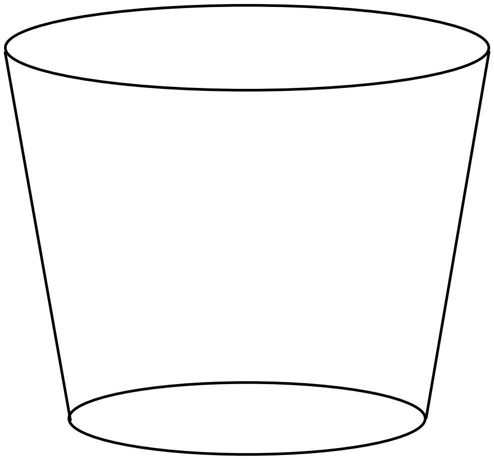
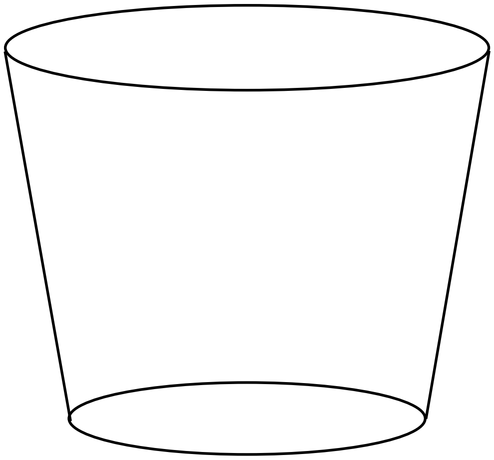
6. Use a dropper to pick up soap solution from the *soap* cup. Carefully squirt several droppers-full of the soap solution into a teaspoon until it is full.
7. Pour this teaspoon of soap solution into the *water* cup. Use the dropper to collect another teaspoon of soap solution, and also add it to the *water* cup.
8. Using the same method described in Steps 1 and 2, add 2 teaspoons of soap solution to the *hard water* cup.
9. Look at the cups from the top and the side. Record your observations at the top of the following page.

Student activity sheet
Activity 5.10

Name: ______________________________

Formation of a precipitate (*continued*)

Use words and drawings to describe what you see in each cup.

Soap in water	Soap in hard water
	

How do you know that soap scum is different from soap?

Procedure

Prepare the cups

1. Label one cup **soap** and the other **soap scum**.
2. Add 2 tablespoons of water to each of the labeled cups. These cups will be used after the soap scum is collected.

Collect the soap scum

3. Place a coffee filter on the top of a plastic cup as shown. Hold the filter in place as you pour the hard water and soap scum into the filter.
4. Allow some of the water to drain through. Then carefully remove the filter and gently squeeze the remaining water into the cup.
5. Carefully lay the coffee filter on a paper towel as shown. Use a popsicle stick to scrape the filter to collect the soap scum.

Compare the amount of bubbling in each cup

6. Look at the amount of soap scum you have. Then place a similar amount of soap flakes into the cup labeled *soap* and stir gently.
7. Add the soap scum to its labeled cup and stir gently.
8. Place a straw into both cups. Gently blow through each straw and compare the amount of bubbling.

Student activity sheet
Activity 5.9

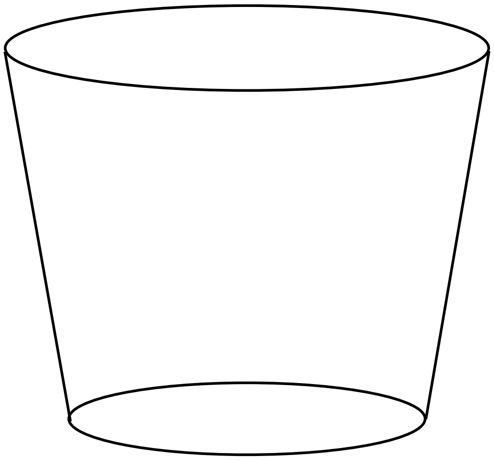
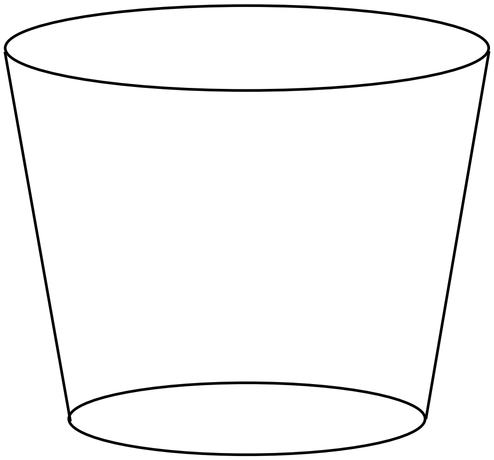
Name: ______________________________

Formation of a precipitate (*continued*)

1. Does soap scum dissolve in water as well as soap? ______________________________

2. Does soap scum bubble in water as well as soap? ______________________________

Draw the amount of bubbling you saw in each cup.

Soap in water	Soap scum in water
	

3. Do you think a chemical reaction occurs when soap is added to hard water? ________

   Think about the definition of "chemical reaction" and what you observed in your experiment to explain your answer.

   ____

   ____

   ____

   ____

   ____

Investigation 5—Chemical change

Assessment rubric

Do powders that look the same have the same chemical reactions?

Activity 5.1—Powder particulars

How can you use the characteristic ways substances react to tell similar-looking substances apart?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records observations
☐ ☐ ☐ Recognizes that substances react chemically in characteristic ways

Circle one: Good Satisfactory Needs Improvement

Activity 5.2—Using chemical change to identify an unknown

How can you identify an unknown powder?

G S N
☐ ☐ ☐ Develops a logical and organized way to test powders
☐ ☐ ☐ Records observations in chart form
☐ ☐ ☐ Identifies the unknown powder

Circle one: Good Satisfactory Needs Improvement

Activity 5.3—Exploring baking powder

What are the active ingredients in baking powder?

G S N
☐ ☐ ☐ Uses recorded observations to identify ingredients in baking powder
☐ ☐ ☐ Conducts experiment
☐ ☐ ☐ Identifies the two active ingredients in baking powder

Circle one: Good Satisfactory Needs Improvement

Activity 5.4—Change in temperature—Endothermic reaction

Aside from bubbling, what else happens during a reaction between baking soda and vinegar?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Correctly uses a graduated cylinder to measure 10 ml
☐ ☐ ☐ Records observations
☐ ☐ ☐ Recognizes that the term “endothermic reaction” refers to a chemical reaction that results in a decrease in temperature

Circle one: Good Satisfactory Needs Improvement

Investigation 5—Chemical change

Assessment rubric (*continued*)

Activity 5.5—Production of a gas—Controlling a chemical reaction
How can you control the amount of gas produced in a baking soda and vinegar reaction?

G S N
☐ ☐ ☐ Identifies variables that affect the amount of foam generated
☐ ☐ ☐ Correctly uses a graduated cylinder to measure 10 ml
☐ ☐ ☐ Reasonably adjusts amounts of baking soda and vinegar used
☐ ☐ ☐ Conducts at least three trials
☐ ☐ ☐ Records what was done and observed in each trial
☐ ☐ ☐ Succeeds in generating a foam that rises high without overflowing

Circle one: Good Satisfactory Needs Improvement

Activity 5.6—Change in temperature—Exothermic reaction
Can the temperature increase during a chemical reaction?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Correctly uses a graduated cylinder to measure 10 ml
☐ ☐ ☐ Correctly uses a thermometer to monitor the reaction
☐ ☐ ☐ Identifies variables that affect the temperature of the reaction
☐ ☐ ☐ Reasonably adjusts the amounts of baking soda solution and calcium chloride used
☐ ☐ ☐ Conducts at least three trials
☐ ☐ ☐ Records what was done and observed in each trial
☐ ☐ ☐ Recognizes that the term “exothermic reaction” refers to a chemical reaction that results in an increase in temperature

Circle one: Good Satisfactory Needs Improvement

Activity 5.7—Color changes with acids and bases
How can you tell if a substance is an acid, a base, or neutral?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records and interprets observations
☐ ☐ ☐ Uses the color changes of indicator solution to classify a substance as an acid, a base, or neutral.

Circle one: Good Satisfactory Needs Improvement

Investigation 5—Chemical change

Assessment rubric (*continued*)

Activity 5.8—Neutralizing acids and bases

How can you return the color of a red cabbage indicator solution back to blue?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Uses the color changes of an indicator solution to determine when a solution has been neutralized
☐ ☐ ☐ Describes how to return acid and base indicator solutions back to blue
☐ ☐ ☐ Uses and understands the purpose of a control

Circle one: Good Satisfactory Needs Improvement

Activity 5.9—Comparing the amount of acid in different solutions

How can neutralizing acids help you compare the amount of acid in different solutions?

G S N
☐ ☐ ☐ Uses the process of neutralizing to compare the amount of acid in two solutions
☐ ☐ ☐ Determines that the solution containing the most acid will require more drops of base to become neutralized
☐ ☐ ☐ Applies understanding to explain how the process of neutralizing could be used to compare the amount of base in two solutions

Circle one: Good Satisfactory Needs Improvement

Activity 5.10—Formation of a precipitate

What happens when soap is added to hard water?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations with words and/or drawings
☐ ☐ ☐ Determines that soap scum has different properties than soap
☐ ☐ ☐ Recognizes that new substances with different properties are formed during chemical reactions

Circle one: Good Satisfactory Needs Improvement

To earn a "B", a student must receive a "Good" in each category.
To earn an "A", a student must also exhibit some of the following qualities throughout this investigation.

- ☐ Writes outstanding explanations
- ☐ Possesses a well-developed understanding of variables and how to control them
- ☐ Participates well in class discussions
- ☐ Participates well in group work
- ☐ Uses scientific thinking
- ☐ Consistently exhibits exceptional thought and effort in tasks
- ☐ Other____

Teacher instructions

Review and apply

The following section contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 5,* they will reflect on their learning, apply what they learned about chemical change to a new activity, and read about two common chemical changes. An optional reading explains that in a chemical reaction the atoms of the reactants are rearranged to form the products. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned during the investigation on chemical change.

Distribute *Review and apply: Let's review*, pp. 311–312, and give students an opportunity to answer questions about the activities. Students will explain what they did to identify the unknown powder and find the "active" ingredients in baking powder. They will also describe experiments they could do to show that temperature can decrease during a chemical change, to compare the amount of acid in two solutions, and to find out whether hard water affects detergent the way it does soap.

Science in action!

2. Have students predict what happens when an Alka-Seltzer® tablet is placed in red cabbage indicator.

Note: This activity uses Alka-Seltzer, original formula. Because Alka-Seltzer contains aspirin, do this activity in class under your supervision.

Ask students what happens when an Alka-Seltzer tablet is placed in water. Some students may know that bubbles form as the tablet gets smaller. Ask students whether or not they think a chemical reaction is occurring. They should agree that a gas is being produced so this is most likely a chemical reaction. Tell students that Alka-Seltzer tablets contain citric acid, aspirin, and baking soda. Explain further that citric acid and aspirin are both acids and that baking soda is a base. This activity and the corresponding *Review and apply* worksheet can serve as a summative assessment evaluating students' skills making reasonable predictions, using a thermometer, recognizing evidence of chemical change, and developing explanations based on evidence.

Distribute *Review and apply: Science in action!*, pp. 313–315. Tell students that they will predict what will happen when an Alka-Seltzer tablet is placed in red cabbage indicator and write their thoughts on the *Review and apply* worksheet.

3. Have students observe an Alka-Seltzer tablet in red cabbage indicator.

Distribute 2 red cabbage leaves, a zip-closing plastic bag, a clear plastic cup, and water to each student group. Have students make red cabbage indicator and follow the procedure as described on the *Review and apply* worksheet. Once students have recorded an initial temperature, place an Alka-Seltzer tablet in each group's cup of red cabbage indicator. Students should leave the thermometer in their cup so that they can monitor any change in temperature during the reaction. Have students record their observations on the *Review and apply* worksheet and describe and interpret the color changes.

4. When students have completed their worksheets, discuss their observations.

Ask students questions such as the following:

- Did a chemical reaction take place?
- How do you know?
- Was this an endothermic or an exothermic reaction?
- Describe the color changes you observed.
- Use the words, “acid”, “base”, and “neutral” to explain the color changes…
  - when the Alka-Seltzer tablet was first placed in the indicator solution.
  - while the reaction was taking place.
  - after the reaction was complete.

Students should agree that a chemical reaction did take place. The bubbling, color changes, and temperature change are all evidence of chemical change. Students should recognize that the initial bright pink color of the indicator solution showed that the solution was acidic. This could be because the acids are stronger than the base, that there is more acid than base, or that the acids are more soluble than the base. As the ingredients continued to dissolve and the reaction took place, the solution became purplish-pink. This color change indicated that the solution was becoming less acidic and moving toward neutral. Once the reaction was complete and the contents of the cup were mixed, the solution turned blue. This final color change indicated that the solution was neutralized.

Think about it

5. Have students read about photosynthesis and cell respiration.

Tell students that the article they will read explains what happens during two very important chemical reactions. Without these chemical reactions, plants and animals could not exist! These reactions are *photosynthesis* and *cell respiration*.

Ask students what they know about photosynthesis. Explain that photosynthesis is a process that plants use to convert carbon dioxide, water, and energy from the sun into a sugar (glucose) and oxygen. Explain that cell respiration is a process that plants, animals, and people use to get energy as they convert glucose and oxygen into carbon dioxide and water.

Distribute *Review and apply: Think about it*, pp. 316–319. Ask students if they notice any similarities between the chemical equations for photosynthesis and cell respiration. Students should notice that the two are the reverse of one another.

Point out the chemical equations for photosynthesis and cell respiration. Explain that the molecules that are on the left side rearrange themselves to become new molecules on the right. For example, in photosynthesis, you can see that hydrogen atoms are part of water on the left side of the equation and are part of glucose on the right side. Have students do a check to see that hydrogen, oxygen, and carbon atoms are all represented on both sides of each equation. Point out that new atoms aren’t made during chemical reactions—they are rearranged to form different molecules.

Explain that the number “6” in front of H_2O, CO_2, and O_2, means that in photosynthesis, 6 water molecules react with 6 carbon dioxide molecules to produce 1 glucose molecule and 6 oxygen molecules. So if you add up all of the hydrogen atoms on the left side of the equation, this will equal the number of hydrogen atoms on the right side. The same is true for the carbon and oxygen atoms. You can also count the number of atoms on both sides of the equation for the reaction for cell respiration. Like photosynthesis, the number of atoms is the same on both sides.

Note: The chemical reactions for photosynthesis and cell respiration are actually multi-step reactions with many intermediate reactions. The equations shown on the worksheet are really the net result of many reactions.

Give students time to read the article and answer the questions.

For additional information about a product of photosynthesis—maple syrup, go to **www.inquiryinaction.org**

What's going on here? (*optional*)
Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about a few common chemical reactions. The reading explains that in a chemical reaction the atoms of the reactants are rearranged to form the products.

Distribute *Review and apply: What's going on here?*, pp. 320–322. Have students read and answer the comprehension questions.

This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level.

Material to support this reading can be found at **www.inquiryinaction.org**

Name: ____________________________

Let’s review

At the beginning of this investigation a student tried to tell the difference between baking soda and baking powder by testing them with vinegar. By observing the chemical reactions from the test, he could figure out which was which. You did a similar activity and then conducted tests on five similar-looking powders. You tested them with different liquids to discover the identity of an unknown. You also did other activities exploring the production of a gas, change in temperature, color change, and the formation of a precipitate. All these changes are evidence that a chemical change has occurred.

1. After you tested all the known powders with all the test liquids, describe what you did to identify the unknown powder.

2. Baking powder contains baking soda, cream of tartar, and cornstarch. When water is added, two of these three ingredients react to produce carbon dioxide gas. Describe what you did to figure out what the two “active” ingredients in baking powder are.

Let’s review (*continued*)

3. If a chemical change occurs, there is usually a change in temperature. Some people think that when the temperature changes during a chemical reaction, it always *increases.* Is this true? ____

   Describe an experiment you did that supports your answer.

   ____
   ____
   ____
   ____

4. Acids make red cabbage indicator turn from blue to pink. Bases make red cabbage indicator turn from blue to greenish-blue. If you had two pink solutions and wanted to figure out which one contained more acid, how could you use a base to find out?

   Describe what you would do below.

   ____
   ____
   ____
   ____
   ____
   ____

5. What would you do to find out if hard water affects detergent the same way it affects soap?

   ____
   ____
   ____
   ____
   ____
   ____
   ____

Name: ____________________________

Science in action!

What evidence of chemical change do you observe when an Alka-Seltzer tablet is placed in red cabbage indicator?

An Alka-Seltzer tablet contains citric acid, aspirin, and sodium bicarbonate (baking soda). Citric acid and aspirin are both acids and baking soda is a base.

Make predictions

1. If an Alka-Seltzer tablet is placed in red cabbage indicator, would you expect a gas to be produced? ______________________________

   What makes you think that?

   ____
   ____
   ____
   ____
   ____
   ____
   ____

2. Would you expect a color change? ______________________________

   What makes you think that? ______________________________

   ____
   ____
   ____
   ____
   ____
   ____

Science in action! (*continued*)

3. Would you expect a change in temperature?__________________________________

What makes you think that?

____

____

____

____

Conduct your experiment

Procedure

Make red cabbage indicator

1. Tear 2 red cabbage leaves into small pieces and place them in a storage grade zip-closing plastic bag.
2. Add about 1 cup of room-temperature water. Get as much air out of the bag as possible and seal the bag securely.
3. While holding the bag, repeatedly squeeze the water and cabbage leaves until the water turns a medium to dark blue. This is your indicator solution.
4. Open a corner of the bag and carefully pour the red cabbage indicator into an empty clear plastic cup, leaving the cabbage pieces behind in the bag.

Conduct the experiment

5. Add 1 tablespoon of indicator solution to each of 2 clear plastic cups.
6. Place a thermometer in one cup. Record the temperature in the chart on the following page. Leave the thermometer in the cup.
7. Your teacher will place an Alka-Seltzer tablet in the cup with the thermometer. Observe the changes and record your observations.
8. After all of the tablet is dissolved, swirl the cup for about 1 minute. What do you observe? Continue swirling until the color matches the color of the control.

Name: ______________________________

Science in action! (*continued*)

How did the temperature change during the reaction?	
Start temperature	
Lowest temperature reached	
Change in temperature	

4. In addition to a temperature change, what other evidence of chemical change did you observe?

____

____

____

5. Describe the color changes as the tablet dissolved.

____

____

____

6. Use the words, “acid”, “base”, and “neutral” to explain the color changes…

- when the Alka-Seltzer tablet was first placed in the indicator solution.

____

____

- while the reaction was taking place.

____

____

- after the reaction was complete.

____

____

Review and apply worksheet

Name: ______________________________

Think about it

A chemical reaction occurs when atoms rearrange themselves and bond together to form one or more new substances. Chemical reactions are part of everyday life. Metal rusting is an example of a chemical reaction. When iron in the metal comes in contact with water and oxygen from the air, a chemical reaction takes place. A new substance called iron oxide (rust) is formed. For this chemical reaction to take place, the atoms of iron and the atoms from water and oxygen rearrange themselves and bond together in a new arrangement to form rust.

Vocabulary

reaction
bond
photosynthesis
cell respiration
substance
exothermic

Burning wood in a fireplace is another type of chemical reaction. If enough heat is added to wood, the carbon and hydrogen atoms in the wood come apart from each other and join with oxygen from the air to produce new substances. The new substances are carbon dioxide and water. In this reaction, a lot of energy is released. Burning wood is very exothermic.

Two of the most important chemical reactions for life on Earth are *photosynthesis* and *cell respiration*.

Photosynthesis

In photosynthesis, a plant uses energy from sunlight to change water (H_2O) and carbon dioxide (CO_2) into a type of sugar called *glucose* ($C_6H_{12}O_6$). This process also produces oxygen (O_2), which the plant releases into the air.

$$\underset{\textbf{Water}}{6H_2O} + \underset{\textbf{Carbon dioxide}}{6CO_2} + \underset{\textbf{Energy}}{\text{Sunlight}} \longrightarrow \underset{\textbf{Glucose}}{C_6H_{12}O_6} + \underset{\textbf{Oxygen}}{6O_2}$$

Cell respiration

In cell respiration, the plant or animal changes glucose ($C_6H_{12}O_6$) and oxygen (O_2) into carbon dioxide (CO_2) and water (H_2O). This process releases energy that the cells of the organism use to function.

$$\underset{\textbf{Glucose}}{C_6H_{12}O_6} + \underset{\textbf{Oxygen}}{6O_2} \longrightarrow \underset{\textbf{Carbon dioxide}}{6CO_2} + \underset{\textbf{Water}}{6H_2O} + \text{Energy}$$

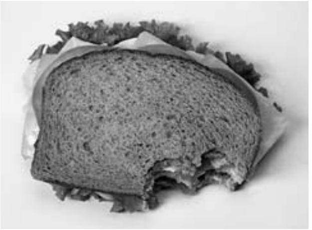
If you look at the chemical equations for photosynthesis and cell respiration, you can see that they are opposites of one another. The molecules on the left side of one are on the right side of the other. Energy is also on opposite sides of the equations. What does all this mean?

Name: ____________________________

Think about it (*continued*)

Well, it means that these two reactions depend on one another and that energy from the sun is the link between them. The great thing about photosynthesis is that in using the sun's energy to change water and carbon dioxide into glucose, some of the energy from sunlight is converted into or "trapped" as chemical energy in the glucose molecule. The plant, or animals that eat plants, can then break down the glucose using cell respiration to get the energy that they need to survive.

Plants and animals couldn't get the energy they need if plants didn't photosynthesize. And plants couldn't photosynthesize without the energy from the sun. So if you think about it, all living things, including you, depend on the energy from the sun to live.



Think about what you ate for lunch today. Maybe you had a turkey, lettuce, and cheese sandwich. What part of your sandwich was made possible by photosynthesis? Fifty percent? One-hundred percent? In the example of a turkey sandwich, lettuce clearly depends on photosynthesis because it is the leaf of a plant. Bread also comes from plants because it is made with flour, which comes from wheat. But what about the turkey and cheese on your sandwich? Do these depend on photosynthesis?

Turkeys cannot use sunlight to make their own food the way that plants can: They can't photosynthesize. However, turkeys do eat corn and other seeds, which are plant parts. Since plants use photosynthesis to make their own food, and turkeys eat seeds from plants, the turkey on your sandwich would not be possible without photosynthesis. Is cheese a result of photosynthesis? Cheese is made from milk, which comes from cows (or sheep or goats) that eat grasses. Since grass photosynthesizes, every part of your sandwich can be linked to photosynthesis.

So in the process of photosynthesis, plants change the sun's energy to a usable form of food. When we eat food made from plants or animals that ate plants, our bodies use the process of cell respiration to get energy that initially came from the sun!

Name: ____________________________

Think about it (*continued*)

1. Photosynthesis uses energy from the _______________ to make food for the plant.
   a. earth
   b. sun
   c. plant's leaves
   d. bacteria

2. What fact might the author want you to remember most?
   a. All living things depend on chemical reactions.
   b. Photosynthesis makes food for plants.
   c. Burning wood is a chemical process.
   d. Cell respiration gets energy from glucose.

3. When wood is burned, the process is exothermic. What does the word *exothermic* mean in this sentence?
   a. Energy is absorbed.
   b. Fire breaks down the wood into ashes.
   c. Energy is released.
   d. Oxygen is produced.

4. Living things are able to get energy out of glucose during cell respiration. Glucose is…
   a. the sun's energy.
   b. a sugar molecule.
   c. a water molecule.
   d. carbon dioxide.

5. During photosynthesis, energy from the sun is trapped as…
   a. water and carbon dioxide.
   b. chemical energy in the glucose molecule.
   c. cell respiration.
   d. oxygen.

6. No matter what food you eat, you can always trace the source of energy back to…
   a. the sun and photosynthesis.
   b. fertilizer.
   c. the heat from the center of the earth.
   d. oxygen and carbon dioxide.

Name: ____________________

Think about it (*continued*)

7. How are photosynthesis and cell respiration similar and different?

8. In a way, everything we eat depends on photosynthesis. Describe how a breakfast of bacon and eggs depends on photosynthesis.

9. One of the reasons plants are important to us is because they reduce the amount of carbon dioxide in the atmosphere and increase the amount of oxygen, which we need to breathe. Explain how this statement relates to the chemical equation for photosynthesis.

10. We need to eat food and breathe in oxygen in order to stay alive. We also breathe out carbon dioxide gas. Explain how these statements relate to the chemical equation for cell respiration.

Review and apply worksheet Name: ____________________________

What's going on here?

In a chemical reaction, atoms are rearranged and then bond together in different ways to create new substances. In a chemical reaction, the atoms, ions, or molecules reacting together are called the *reactants*. The new substances formed as a result of the chemical reaction are called the *products*.

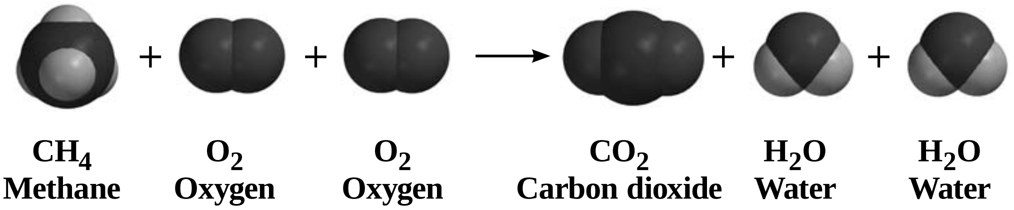
Different words are sometimes used to talk about the substances in a chemical reaction. The term *element* is used for a substance made from only one type of atom. For example, you could have a sample, or piece, of the element carbon. That means that your sample is made of only carbon atoms.

Another word used to describe a substance is *compound*. A compound is a substance made up of all the same molecules. Also, these molecules are made up of more than one type of atom. For example water is a compound because it is made up of all H_2O molecules. Another example of a compound is carbon dioxide. Carbon dioxide (CO_2) is made up of only carbon dioxide molecules, and each molecule is made of more than one type of atom.

Something that is always true in a chemical reaction is that the atoms that make up the reactants always show up in the products. No atoms from the reactants are ever destroyed or disappear, and no atoms are ever newly created in the products. Since the same number of atoms are in the reactants as in the products, a chemical reaction can be described in a mathematical way called a *chemical equation*. In a chemical equation, the reactants are written on the left side of an arrow and the products are written on the right. The arrow means that the reactants *form* the products.

Examples of chemical reactions

A common example of a reaction between two molecules is the reaction that happens when a gas stove is used to cook. The methane gas in the stove has a chemical formula of CH_4. It reacts with oxygen (O_2) from the air to produce carbon dioxide gas (CO_2), water (H_2O), and a great deal of heat. Notice how all of the atoms on the left side of the arrow also appear on the right side of the arrow. They are just rearranged to form different molecules.

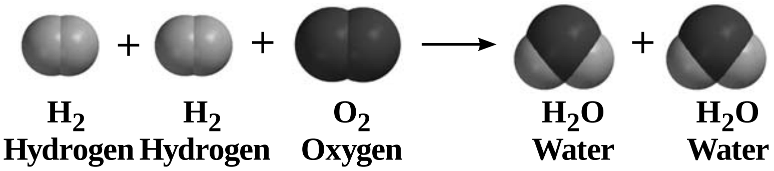


Name: ______________________________

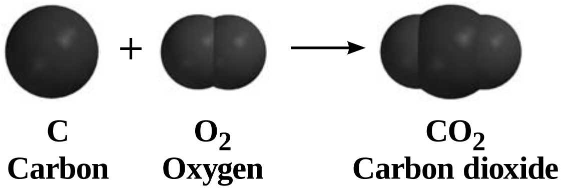
What’s going on here? (*continued*)

In the reaction between methane and oxygen, the carbon that was in the methane becomes part of the carbon dioxide. The hydrogen atoms from the methane become part of the water. And the oxygen atoms from the air end up in both the carbon dioxide and the water.

In the following reaction hydrogen combines with oxygen to form water.



Here, carbon and oxygen combine to create carbon dioxide gas.



In all of these reactions, the bonds that hold one atom to another in the reactants are broken, the atoms rearrange themselves, and bond together in new ways to form the products.

1. What is the difference between *reactants* and *products* in a chemical reaction?

____

____

____

____

2. What is the difference between an *element* and a *compound*?

____

____

____

____

Name: ______________________________

What’s going on here? (*continued*)

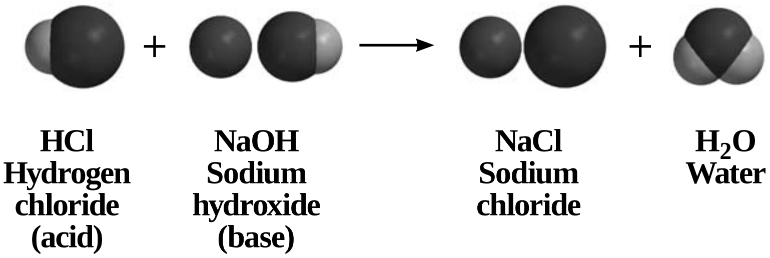
3. In chemical reactions one or more new substances are created.

   Are new *atoms* created? __________

   Use one of the examples of a chemical reaction described in this article to justify your answer.

Cool factoid

It’s pretty amazing how chemical reactions can work. Hydrochloric acid (HCl) is a very strong acid. Sodium hydroxide (NaOH) is a very strong base. Both are dangerous for us to even touch. However, if you combine solutions containing the same number of HCl molecules as NaOH molecules, a chemical reaction will take place, producing something neutral and safe—salt water!



Investigation 6

States of matter

What causes water to change back and forth between water vapor, water, and ice?

Summary

In the first activity, students consider how heating and cooling affect molecular motion. The subsequent activities extend this idea to explore the relationship between temperature and the state changes of water. After considering their own experiences with evaporation and condensation, students discover that adding heat to water increases the rate of evaporation and cooling water vapor increases the rate of condensation. Students then investigate what causes moisture to form on the outside of a cold cup. As an extension, students see that at even lower temperatures water vapor can condense on the outside of a container and then freeze to form ice.

Investigation 6: States of matter

Key concepts for students

- When designing a scientific experiment, it is necessary to identify and control variables.
- Heating increases molecular motion and cooling decreases molecular motion.
- Substances can change from one state to another by heating and cooling.
- Evaporation is a change in state from a liquid to a gas.
- Heating water increases the rate of evaporation.
- Condensation is a change in state from a gas to a liquid.
- Cooling water vapor increases the rate of condensation.
- Cooling water vapor enough can cause it to condense to form liquid water and then freeze to form ice.

Note: Throughout *Inquiry in Action*, explanations on the molecular level are reserved for the supplemental reading in the *Review and apply* section titled, "What's going on here?" But in this investigation, the activities are particularly well-suited to introduce concepts related to atoms and molecules. By watching the demonstrations and participating in the activities, students can begin to develop an understanding of the movement of molecules and the attractions between them.

Learning objectives

Students will be able to:

- Describe changes in the motion of molecules as a substance is heated and cooled.
- Develop an experiment to investigate whether heating water increases the rate of evaporation.
- Identify the role of a control in experiments.
- Use evidence from an experiment to make an inference about molecular motion.
- Explain why heating water increases the rate of evaporation.
- Explain why cooling water vapor increases the rate of condensation.
- Infer that the moisture that forms on the outside of a cold cup is the result of condensation.

Investigation questions

What causes water to change back and forth between water vapor, water, and ice?

- Do heating and cooling have an effect on matter?
- Does adding heat to water increase the rate of evaporation?
- Does cooling water vapor increase the rate of condensation?
- What causes moisture to form on the outside of a cold cup?
- What causes frost to form on the outside of a cold container?

Assessment

The assessment rubric *States of matter*, pp. 372–373, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section on pp. 374–384.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating and cooling.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations involve asking and answering a question.
Scientists use different kinds of investigations depending on the questions they are trying to answer.
Types of investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

6.1 Matter on the move
6.2 Evaporation
6.3 Condensation
6.4a Exploring moisture on the outside of a cold cup
6.4b Exploring moisture on the outside of a cold cup: For dry environments
6.5 From gas to liquid to solid

	Activities					
Each group will need	6.1	6.2	6.3	6.4a	6.4b	6.5
Hot tap water	●	●	●		●	
Cold water	●		●			
Room-temperature water		●		●	●	
Ice			1 cube	3 cups	2 cups	2 cups
Liquid dish detergent	●					
Salt						●
Sugar	●					
Plastic bottle, ½ pint or ½ liter	●					
Tall clear plastic cups			3	4	3	
Wide clear plastic cups	3		3		1	
Film canisters with lids					2	
Clean, empty metal soup can						●
Zip-closing plastic bag, quart size		2				
Zip-closing plastic bag, gallon size				●		
Metal spoon						●
Teaspoon						●
Magnifier			●			
Droppers		2				
Brown paper towels		2				
Paper towels			●	●	●	●

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Hot tap water is sufficiently hot for the activity. Students should use care when handling hot tap water.**
- Use storage grade zip-closing plastic bags.
- Students will develop their own activity in *Activity 6.2* as well as conduct an activity using a provided procedure. The listed materials do not include what students will need to conduct the activities they design. Either provide materials or have students bring them from home.
- *Activities 6.3* and *6.4b* call for both *tall* and *wide* clear plastic cups. Be sure the cups fit together as shown.

- *Activity 6.4a* has a take-home component. Have students empty and dry the cups used during the in-class parts of the activity. Then each student should take one of these clear plastic cups home for the activity.

- In *Activity 6.4b*, you may use film canisters or any other small containers with lids that can fit beneath an inverted tall clear plastic cup as shown. If an ice cube will not fit inside the small container, use crushed ice.
- If possible, use crushed ice for *Activities 6.4b* and *6.5*.

Materials chart for teacher demonstrations

6.1 Matter on the move
6.2 Evaporation

	Activities	
	6.1	6.2
Hot tap water	●	●
Cold water	●	●
Blue food coloring	2	
Yellow food coloring	2	
Tall clear plastic cups	2	
Wide clear plastic cup	1	
Plastic bottle with lid, ½ pint or ½ liter	●	
Petri dish or wide shallow container		●
Sensitive scale or balance		●
Dropper		●

Science background information for teachers

Matter exists in three common states or phases: *solid*, *liquid*, or *gas*. These phases of matter can be affected by changes in heat and pressure. In fact, one state of matter can change to another by heating or cooling and by increasing or decreasing pressure. Because pressure changes are difficult to produce and control in the classroom, the activities in this investigation focus on state changes related to adding or removing heat.

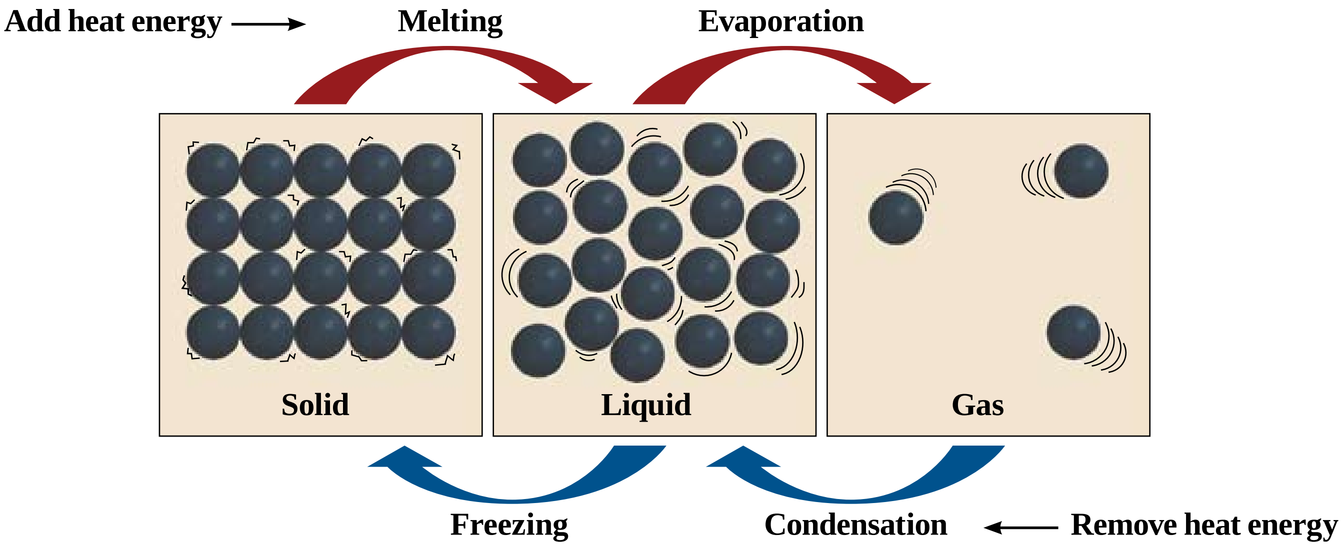
For videos, animations, and other information related to this investigation, go to **www.inquiryinaction.org**

Chemistry concepts

- The position of atoms, ions, or molecules in solids, liquids, and gases is the result of the average energy of these particles and the attractions they have for one another.
- Adding heat to a substance increases the motion of the particles of the substance.
- Cooling a substance decreases the motion of the particles of the substance.
- Temperature is a measure of the average kinetic energy of the particles in a substance.
- Heat is the energy that is transferred from a warmer substance to a cooler one based on the temperature difference between them.
- The processes of melting and evaporation absorb energy to break the associations between the particles of a substance.
- The processes of condensation and freezing release energy as the associations between particles are formed.

Motion and location

The attractions between the atoms, ions, or molecules in a particular substance are the same whether the substance is in the solid, liquid, or gas phase. However, the speed, motion, and position of the particles relative to one another are different.



Adding heat

In solids, the atoms, ions, or molecules that make up the substance are very close to each other and vibrate in fixed positions arranged in an orderly pattern. These properties give solids their definite shape and volume.

When a solid is heated, the motion of the particles increases. The particles are still attracted to each other but their extra movement begins to compete with their attraction. If enough heat is added, the motion of the particles begins to overcome the attraction and the particles move more freely. They begin to slide past each other as the substance begins to change state from a solid to a liquid. This process is called *melting.* The particles of a liquid are only slightly further apart than in a solid. They have more kinetic energy than they did as a solid but their attractions hold them together enough so that they retain their liquid state and do not become a gas.

When heat is added to a liquid, the motion of the particles increases again. If the motion is energetic enough, the particles can completely overcome the attractions between them. When this happens, the particles go into the air as a gas. This process is called *evaporation*. As a gas, particles are very far apart and free to move and their attractions have almost no effect on them.

Removing heat

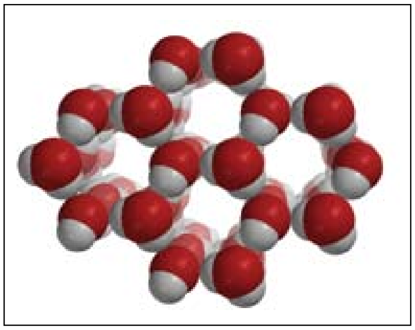
These processes also work in reverse. But instead of adding heat, heat is removed and the substance is cooled. When a gas is cooled, the motion of the particles slows down. If the particles loose enough energy, their attraction for each other can overcome their motion and cause them to associate with one another to become a liquid. This process is called *condensation.*

If the liquid is cooled even more, the particles slow down further. The attractions between the particles cause them to arrange themselves in more fixed and orderly positions to become a solid. This process is called *freezing.*

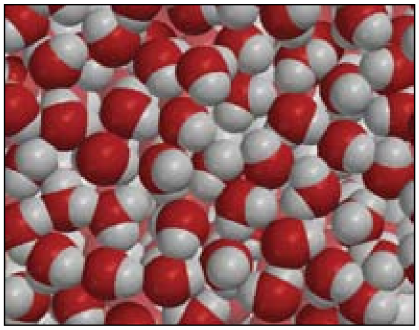
So for any substance, it is the combination of the mutual attraction of the particles and their energy which determines whether the substance is a solid, liquid, or gas.

Phase changes in water

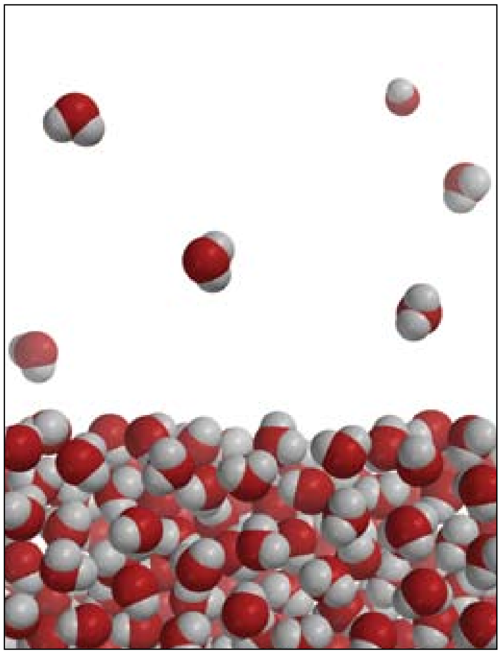
The activities in this investigation focus on the phase changes of water. It is important to note that water does not follow the general rule of becoming most dense as a solid. Typically, the molecules of a substance are closer together as a solid than as a liquid. Water molecules are actually *further apart* from each other in ice than in liquid water. Because of this, ice is less dense and floats on water.



Solid ice



Liquid water



Water vapor

The difference between heat and temperature

In discussions of changes of state, we talk about heating and cooling a substance, such as water, to affect the rate of evaporation or condensation. To understand the nature of heat, it is helpful to distinguish it from temperature.

Temperature is a measure related to the *motion* of the atoms, ions, or molecules of a substance. Since the motion of these particles is based on the energy of the substance, temperature is a measure of the average energy of the particles. Heat is the energy that is *transferred* from one substance to another due to a temperature difference between them.

Here's an example: Place a drop of room-temperature water on your hand. Since the temperature of your hand is higher than the temperature of the water, heat energy moves from your hand into the water. The temperature of the water will increase while the temperature of that part of your hand will decrease (and feel cooler).

Heat energy is always transferred from a substance with a higher temperature to a substance with a lower temperature. It is not possible to make something colder by adding "coldness" to it. A substance can only be cooled by allowing some of its energy to be transferred to something of a lower temperature.

For example, if cans of room-temperature soda pop are placed in a cooler filled with ice, the temperature of the soda goes down. This is because heat energy is transferred from the warmer soda to the cooler ice. A loss of some heat energy from the soda results in less motion of the molecules within the soda, which can be measured as a lower temperature.

Activity 6.1—Matter on the move

Students will see a demonstration where food coloring is placed in hot and cold water. The food coloring moves and mixes faster in the hot water than in the cold. The extra energy in the hot water increases the motion of the water molecules resulting in faster mixing. Students will see a follow-up demonstration where a bottle, with an upside-down lid, is placed in hot tap water. Energy from the hot water is transferred to the air inside the bottle. This energy increases the motion of the molecules, which move faster and push harder in all directions against the inside of the bottle. This increase in air pressure inside the bottle is enough to push up the lid.

Students will place a bottle, with a film of detergent over its opening, into hot water. Energy from the hot water is transferred to the molecules that make up the air in the bottle. This energy increases the motion of the molecules, which move faster and push harder in all directions against the inside of the bottle. This increase in air pressure is enough to make a bubble form at the top of the bottle. When the bottle is placed in ice water, energy is transferred from the warm air in the bottle to the colder water. The molecules that make up the air in the bottle slow down and do not push as hard on the inside of the bottle. This is a decrease in air pressure inside the bottle. The molecules slow down enough and the pressure decreases enough that the normal air pressure outside the bottle pushes on the bubble and causes it to shrink.

In the explanation above, the phrase "energy is transferred" is used several times to state that energy goes from the hot water to the air inside the bottle. But how does this happen? The main process that causes this energy transfer is *conduction*. The water molecules in the hot water are moving quickly. When the bottle is placed in the hot water, the water molecules collide repeatedly with the plastic of the bottle. As a result of these collisions, the molecules of the plastic begin to vibrate faster. These molecules contact the gas molecules inside the bottle, which in turn vibrate and move faster. The gas molecules also bump into each other and continue being contacted by the vibrating plastic molecules until the molecules of the gas are, overall, moving at a greater speed.

Activity 6.2—Evaporation

The water from the wet paper towel evaporates faster when placed on the hot water bag than on the room-temperature water bag. Energy transferred from the hot water bag increases the motion of the water molecules on the paper towel. More of these molecules will have enough energy to break away and become a gas than the water on the paper towel at room-temperature. This is what causes the increased rate of evaporation from the paper towel on the bag of hot water.

One thing to remember is that temperature is not the only factor that affects the rate of evaporation. Another important factor is the amount of water vapor already in the air. Even at higher temperatures, the rate of evaporation will not necessarily increase if there is already a high concentration of water vapor in the air.

Activity 6.3—Condensation

Hot water from the lower cup evaporates and produces water vapor (an invisible gas). The water vapor moves away from the hot water and loses energy to the relatively cooler upper portion of the cup. This decreases the motion of the molecules in the water vapor. These water vapor molecules also cool when they come in contact with the inside surface of the top cup. When the water vapor cools enough, water molecules form associations with one another and change from water vapor to liquid water, resulting in tiny droplets on the inside of the upper cup.

Cooling the water vapor with an ice cube placed on the top cup cools the area at the top of the cup. This slows the movement of the water molecules in the water vapor even more, allowing their attractions to bring them together faster. This extra cooling of the water vapor increases the rate of condensation and forms larger drops of water.

Activity 6.4a—Exploring moisture on the outside of a cold cup

Both *Activities 6.4a* and *6.4b* explore the common phenomenon of water condensing on the outside of a cold cup. If there is enough water vapor in the air, moisture can form on the outside of a cup of ice water but not on a cup of room-temperature water. This difference is because water vapor near the cup of ice water loses energy to the cold cup while water vapor near the room-temperature cup does not lose energy and does not cool. As water vapor molecules cool, they slow down, associate with one another and condense on the cup, forming observable moisture.

Activity 6.4b—Exploring moisture on the outside of a cold cup: For dry environments

If there is not enough water vapor in the air, moisture will not appear on the outside of a cup of ice water or room-temperature water.

To begin this activity, students use their breath as a source of warm water vapor. They will see that more moisture forms on a cup of ice water than on a cup of room-temperature water. As in *Activity 6.4a*, this difference is because water vapor near the cup of ice water loses energy and cools, while the water vapor near the room-temperature cup does not cool as much. As the water vapor from breath contacts the colder cup, the slower-moving molecules form associations and condense on the cup, forming observable moisture.

To investigate whether the amount of water vapor in the air influences whether moisture will form on the outside of a cold cup, students place cold containers in a sample of humid air that they produce and in the drier classroom air. Since there is more water vapor in the humid air cup, more water vapor condenses on the container, resulting in more observable moisture.

Activity 6.5—From gas to liquid to solid

The surface of the can gets so cold that the water vapor in the air around the can condenses and forms moisture on the can. This liquid then freezes to form ice. The purpose of adding salt to the ice is to make the can colder than it would be with ice alone. The reason why adding salt to ice makes the ice–water mixture colder than it would otherwise be is somewhat involved:

If ice is placed in a well-insulated container, some ice will melt to form water and some liquid water will re-freeze to form ice. When a balance is reached between the processes of melting and refreezing, the system is said to be at *equilibrium*.

Melting is a process that requires energy because it takes energy to break the associations between the water molecules in ice. So as ice melts, it actually uses some of the energy from the ice–water mixture, which makes the mixture colder. Freezing is a process that gives off, or releases energy. This is because energy is released as associations between water molecules form to become ice. So as the liquid water re-freezes, it actually makes the ice–water mixture warmer.

So if an ice–water mixture is at equilibrium, with melting and freezing balancing each other, the temperature of the mixture will not change. But adding salt interferes with water's ability to refreeze. This upsets the equilibrium so that more ice melts than refreezes. Since the process of melting uses energy, the mixture gets colder than it would without the salt. Eventually, a new equilibrium is established between melting and refreezing, but at a lower temperature.

Energy and changes of state

The concept that it takes energy to break bonds and that energy is released when bonds are formed is a fundamental principle in chemistry. This concept is used to explain the temperature changes in endothermic and exothermic chemical reactions. It is also useful when considering changes of state.

In *Investigation 5*, dealing with chemical change, the bonds being broken and formed are the bonds holding atoms together within molecules. These are called *intra*molecular bonds. But in the context of changes of state, the "bonds" are the associations between one molecule and another. These are called *inter*molecular bonds.

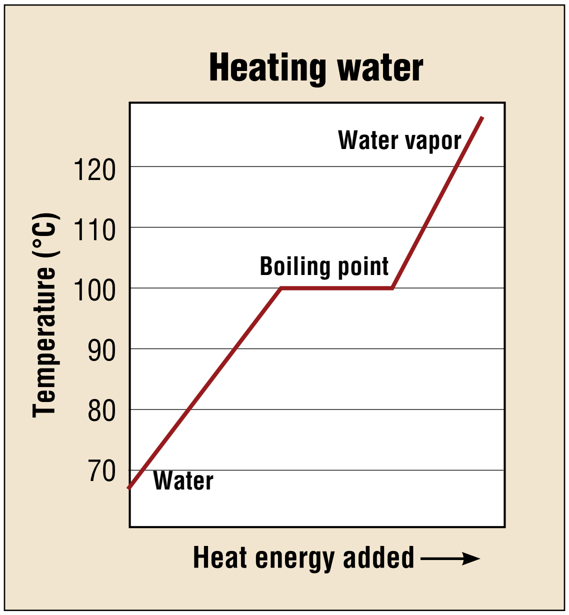
Just as energy is absorbed and released in the breaking and making of intramolecular bonds in chemical reactions, energy is also absorbed and released in the breaking and making of intermolecular bonds, or associations in changes of state.

Although the activities in this investigation do not monitor the actual temperature changes during changes of state, you can review some important concepts about energy and state changes with the following phase change diagrams and explanations.

Phase change diagrams

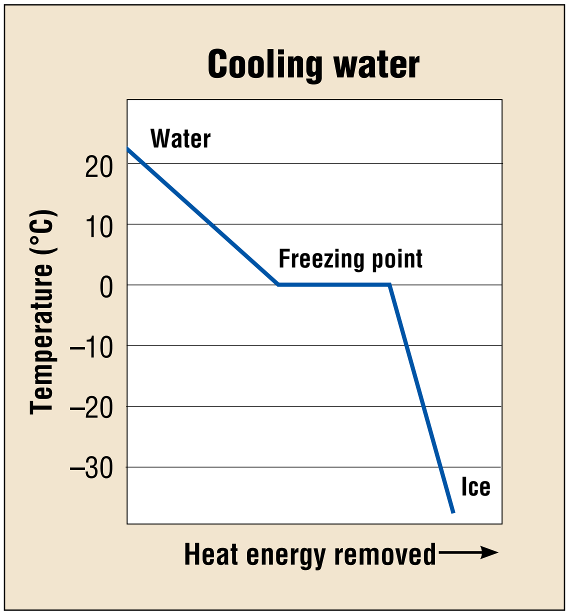
The phase change diagram titled “Heating water” shows how temperature changes as energy is added to water. As water is heated, the motion of the water molecules increases. This faster motion is detected as an increase in temperature.

- The first upward-sloping line on the diagram shows that as energy is added, the temperature of the water increases. As heat is added to the water, the rate of evaporation increases. The process of evaporation uses energy so some of the energy being added to the water is used as water molecules break free to become water vapor.
- At standard atmospheric pressure, the water begins to boil when it reaches 100°C. At this point, the amount of energy being absorbed in the process of evaporation is equal to the amount of energy being added to the water so the temperature does not change. This causes the flat line on the diagram and is called the *boiling point.*
- Once the liquid water has all become water vapor, adding more energy increases the motion of the molecules in the water vapor and the temperature increases again. This is shown in the second upward-sloping line on the diagram.



The phase change diagram titled “Cooling water” shows how temperature changes as energy is removed from water. As water is cooled, the motion of the water molecules decreases. This slower motion is detected as a decrease in temperature.

- The first downward-sloping line on the diagram shows that as energy is removed, the temperature of the water decreases.
- When the water reaches 0°C, ice begins to form. The process of freezing releases energy. So as energy is being removed from the water, some energy is being added by the water molecules associating to become ice. When the amount of energy added by the freezing water molecules equals the amount of energy being removed to cool the water, the temperature does not change. This causes the flat line on the diagram and is called the *freezing point.*
- Once the liquid water has all become ice, removing more energy decreases the motion of the molecules and the temperature decreases again. This is shown in the second downward-sloping line on the diagram.



Activity 6.1
Matter on the move

Do heating and cooling have an effect on matter?

In this two-part demonstration and activity, students will be introduced to the idea that heating and cooling have an effect on matter. They will see that food coloring mixes significantly faster in hot water than in cold water and begin to develop the idea that adding heat energy increases the movement of water molecules. Students will extend this idea to realize that adding heat energy increases the movement of gas molecules, too. Students will also do an activity where they heat and cool the air inside a bottle that is covered with a film of bubble solution. These demonstrations and activities will help students develop a foundation for why substances change from one state to another.

Materials needed for the demonstrations

Hot tap water
Cold water
Blue food coloring
Yellow food coloring
2 Tall clear plastic cups
1 Wide clear plastic cup
Plastic bottle with lid, ½ pint or ½ liter

Materials needed for each group

Hot water
Cold Water
3 Wide clear plastic cups
Bubble solution (made with dishwashing liquid, sugar, and water)
Plastic bottle, ½ pint or ½ liter

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Hot tap water is sufficiently hot for the activity. Students should use care when handling hot tap water.**
- You will need two little squeeze bottles each of blue food coloring and yellow food coloring for the demonstration. This is so that you and a student volunteer can place one drop each of yellow and blue food coloring into containers of hot and cold water at the same time.

Preparing Materials

- Make a bubble solution for the entire class by adding 4 teaspoons of dishwashing liquid and 4 teaspoons of sugar to ½ cup of water.
- Gently stir until the sugar and detergent are dissolved.
- Then place about 1 tablespoon of this bubble solution in a wide clear plastic cup for each group.

Activity sheet

Copy *Activity sheet 6.1—Matter on the move*, pp. 338–342, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.1
Matter on the move

Question to investigate

Do heating and cooling have an effect on matter?

Take a closer look

1. Have students read the introductory story on *Activity sheet 6.1* and ask them to predict how food coloring will move in hot and cold water.

Distribute *Activity sheet 6.1—Matter on the move* and have students read the introductory story. Ask students if they have had similar experiences mixing colored substances in hot or cold liquids. Then explain that as a demonstration, you will place one drop each of yellow and blue food coloring in hot water while a student places one drop of each color in cold water. Ask students what they expect will happen to the drops of color in each cup.

2. Do a demonstration comparing the movement of food coloring in cold water and hot water.

Procedure

1. Add hot tap water and cold water to two separate clear plastic cups until they are about ¾ full.
2. With the help of a student volunteer, add 1 drop of blue and 1 drop of yellow food coloring to each cup at the same time.
3. Do not stir, but watch the colors as they move and mix on their own.

Expected results: **The food coloring in the hot water moves and mixes faster than the coloring in the cold water.**

3. Discuss with students what makes food coloring move faster in hot water than in cold.

Help students begin to think about molecular motion by asking them questions such as the following:

- Are these observations similar to anything you have experienced before?
- Do you think the water is moving in each cup?
- What evidence do you have that suggests something about the water is moving?

Explain that water is made up of tiny particles, called *molecules*, which are too small to see. These particles are always moving, even in very cold water. Since water molecules move, the molecules help mix the food coloring.

However, the color mixed faster in the hot water than it did in the cold. Ask students what this might say about the movement of water molecules in hot and cold water: Do molecules in hot water move faster than they do in cold water? Students should agree that they probably do. The observation of the color moving and mixing faster in the hot water is evidence of this.

Watch this!

4. Do another demonstration to show that heating also affects a gas.

Procedure

1. Add hot tap water to a wide cup until it is about ⅓ full. Make sure students realize you are using hot water.
2. Use your finger and a little water to moisten the rim of the bottle and the top surface of the lid. Then, place the lid upside down on the bottle so that there are no leaks.
3. Carefully push the bottle down into the hot water.

Expected results: The lid rises and falls making a tapping sound.

Note: If you would like to show the demonstration again, you can uncover the opening and let some more air in. Then repeat Steps 2 and 3. If the lid does not tap, check to see that the lid is positioned directly over the opening of the bottle forming a seal.

5. Discuss with students what may be causing the lid to move.

Ask students if there is anything in the bottle that might be causing the lid to go up and down. After all, the bottle appears to be empty. Students should recognize that the bottle is filled with air. Explain that air, like water, is made of tiny particles that are too small to see. In fact air is made up of a mixture of different molecules—nitrogen, oxygen, water vapor, and carbon dioxide, just to name a few.

Ask students questions such as the following:

- Do you think pushing the bottle into hot water warmed the air in the bottle?
- How might heating the molecules inside the bottle change their motion?
- Is it possible that this faster motion could push the lid up?

When the bottle is heated, the particles in the bottle will move faster and push harder against every part of the inside of the bottle. Since the lid is on so loosely, these faster-moving particles can push the lid up.

Explain that students will do a similar activity with a film of bubble solution over the opening of the bottle. Ask students what they think might happen to the film of bubble solution when this bottle is placed in hot water.

Try this!

6. Have students conduct a similar activity with a film of bubble solution over the opening of the bottle.

Procedure

Heating a gas

1. Add hot water to a wide cup until it is about ⅓ full.
2. Lower the open mouth of the bottle into the cup with detergent solution as shown. Carefully tilt and lift the bottle out so that a film of detergent solution covers the opening of the bottle.
3. Slowly push the bottom of the bottle down into the hot water.

Cooling a gas

4. Add cold water to a wide cup until it is about ⅓ full.
5. Re-dip the opening of the bottle in the detergent solution and place it in hot water again to form a bubble.
6. Then slowly push the bottom of the bottle into the cold water. Alternate placing the bottle in hot and cold water. Record your observations on the activity sheet.

Expected results: **The bubble film grows into a bubble when the bottle is placed in hot water. When the bottle is placed in cold water, the bubble shrinks. It may even go down into the bottle and possibly pop.**

7. Discuss student observations and explain them in terms of the movement of molecules.

Ask students questions such as the following:

- What happened to the bubble film when you placed the bottle in hot water?
- What happened to the bubble film when you placed the bottle in cold water?
- What can you say about the movement of molecules inside the bottle when the bottle was placed in hot water and the air inside the bottle was warmed?
- What effect did this increased motion have on the bubble film?
- What can you say about the movement of molecules inside the bottle when the bottle was placed in cold water and the air inside the bottle was cooled?
- What effect did this decreased motion have on the bubble film?

Students should apply the explanation for the colors mixing faster in hot water and the cause of the tapping lid to their observations of the bubble film. Students should recognize that the motion of the molecules inside the bottle increased when it was placed in hot water and decreased when the bottle was placed in cold water.

When the air was warmed, the molecules inside the bottle moved faster and pushed harder against the inside of the container. This pushing occurred in all directions. Because a bubble film is very flexible and easy to push, the faster-moving molecules caused the bubble film to stretch.

When the air is cooled, the molecules inside the bottle move more slowly and push with less force against the inside of the container. The molecules in the air around the bottle move faster than the molecules of the cooler air inside the bottle. These molecules in the air outside the bottle push harder against the flexible bubble film than the molecules inside the bottle do. This causes the bubbles to shrink down and sometimes even get pushed inside the bottle.

What's next?

8. Introduce the idea that heating and cooling matter can cause it to change state.

In the demonstrations and activity, students have seen that heating and cooling affects liquids and gases. Ask students if heating and cooling can affect solids, too. Heating and cooling affects all states of matter—sometimes causing them to change state. For example, cooling water enough can cause it to become ice and heating water enough can cause it to become a gas. Ask students for more examples of heating or cooling that cause matter to change state. Explain that they will do a series of activities to explore the process of water changing back and forth between water vapor (the gaseous form of water), liquid water, and ice.

Student activity sheet
Activity 6.1

Name: ______________________________

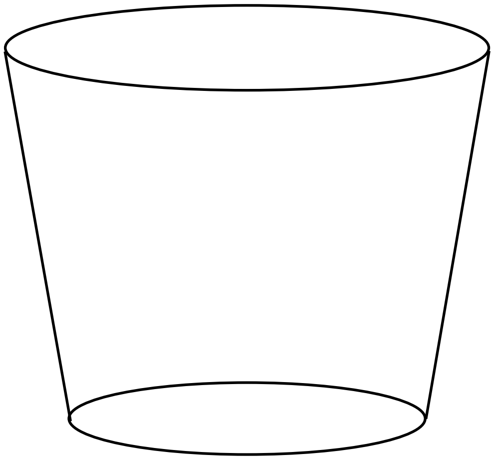
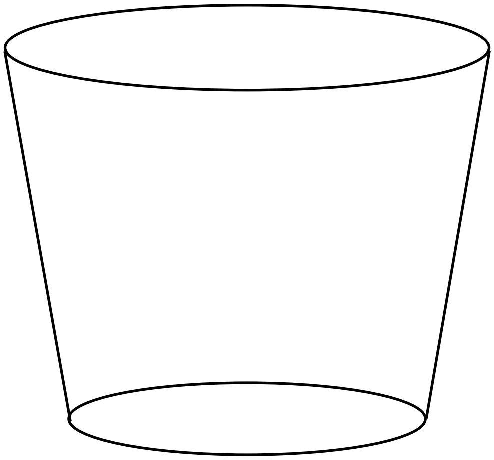
Matter on the move

In art class the other day, we tried making our own watercolor paint. We had food coloring and were adding drops in different combinations to water. Some kids put their drops in and stirred, but I put mine in and just let them mix on their own without stirring. It looked pretty cool. I wondered if it would look any different in hot water, but I didn't get a chance to try it. Later in the day, by coincidence, we were also adding food coloring to water in science. We were seeing how fast colored water moves up a celery stalk. I couldn't try the food coloring in hot water because it might mess up the experiment. Finally, when I got home, I put some ice water in one cup and some hot tap water in another. I added a drop of blue and a drop of yellow food coloring to each. I didn't stir—I just watched. I saw a pretty interesting difference between them.

Do heating and cooling have an effect on matter?

Take a closer look

1. In the demonstration, you saw food coloring move in hot and cold water. What difference did you notice in the way the color moved and mixed in the water in each cup?

Hot water	Cold water
	
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Student activity sheet
Activity 6.1

Name: ______________________________

Matter on the move (*continued*)

2. Adding heat energy makes water molecules move faster. Use this fact to explain your observations.

3. In the second demonstration, you saw your teacher put a bottle with an upside down lid into hot water.

   Describe what happened.

4. Adding heat energy makes the gas molecules in air move faster. Use this fact to explain your observations.

Try this!

5. You will do an activity like the one your teacher did with the bottle. But instead of using a lid, you will place a film of bubble solution over the opening of the bottle. What do you think will happen to this film of bubble solution when you place the bottle in hot water?

   What makes you think that?

Student activity sheet
Activity 6.1

Name: ______________________________

Matter on the move (*continued*)

What happens to a film of bubble solution when the air inside a bottle is warmed and cooled?

Procedure

Heating a gas

1. Add hot water to a wide cup until it is about ⅓ full.

2. Lower the open mouth of the bottle into the cup with detergent solution as shown. Carefully tilt and lift the bottle out so that a film of detergent solution covers the opening of the bottle.

3. Slowly push the bottom of the bottle down into the hot water.

Cooling a gas

4. Add cold water to a wide cup until it is about ⅓ full.

5. Re-dip the opening of the bottle in the detergent solution and place it in hot water again to form a bubble.

6. Then slowly push the bottom of the bottle into the cold water. Alternate placing the bottle in hot and cold water.

Student activity sheet
Activity 6.1

Name: ______________________________

Matter on the move (*continued*)

6. Draw what happened to the bubble film when the bottle was placed in hot and cold water.

Hot water

Cold water

7. Heating a gas makes molecules move faster. Cooling a gas makes molecules move slower. Use these facts to explain your observations.

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____

____

Student activity sheet
Activity 6.1

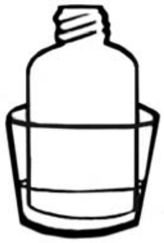
Name: ______________________________

Matter on the move (*continued*)

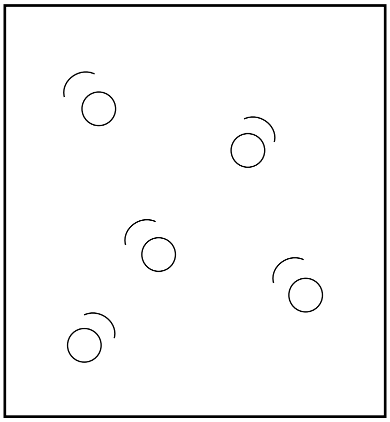
8. Draw a line from each bottle to the picture of molecules that shows about how fast they are moving.

Room-temperature water

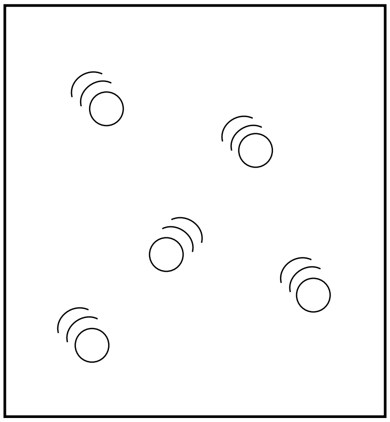
Cold water



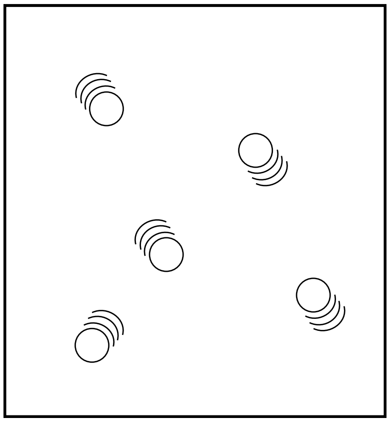
Hot water



Slow



Medium speed



Fast

What’s next?

You have seen that adding heat energy makes molecules move faster and that removing heat energy (cooling) makes molecules slow down. Heating and cooling affect all states of matter—solids, liquids, and gases. Sometimes when matter is heated or cooled enough, we can see pretty dramatic-looking changes. When heated, a solid can become a liquid and then a gas. Or when cooled, a gas can become a liquid and then a solid. You will explore the way water changes state as it’s heated and cooled in the following activities.

Activity 6.2
Evaporation

Does adding heat to water increase the rate of evaporation?

This three-part activity consists of an activity that student groups develop themselves, a given procedure, and an optional demonstration. First, students discuss examples of evaporation and then design and conduct their own test to find out whether heating water has an effect on the rate of evaporation. While waiting for their results, students conduct another evaporation activity using single drops of water on 2 paper towels, one of which is heated. The optional demonstration compares the rate of evaporation of hot and cold water using a sensitive scale or balance. In each of these experiences with evaporation, students will identify variables, consider how to best control them, and use their observations to conclude that heating water increases the rate of evaporation.

Materials needed for each group

Hot tap water
Room-temperature water
2 Zip-closing plastic bags, quart-size
2 Droppers
2 Brown paper towels

Materials needed for the optional demonstration

Hot tap water
Cold water
Petri dish or wide shallow container
Sensitive scale or balance
Dropper

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Hot tap water is sufficiently hot for the activity. Students should use care when handling hot tap water.**
- The materials listed are for the provided procedure only. Student groups will need additional materials based on the evaporation experiment they design and conduct on their own.
- Use storage grade zip-closing plastic bags.

Preparing materials

- Either offer an assortment of materials for the student-designed experiments or have students bring materials from home.

Activity sheet

Copy *Activity sheet 6.2—Evaporation*, pp. 347–349, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.2
Evaporation

Question to investigate

Does adding heat to water increase the rate of evaporation?

1. Discuss with students some of their own experiences with water evaporating.

Ask students questions like the following:

- If you forget your towel when you go swimming, you can dry off by just standing around. How does that happen?
- If you hang wet clothes up, they will eventually get dry. Where do you think the water goes?
- What are some other examples of water drying up?

Students might mention examples such as puddles drying up, dishes on a drying rack, or water in a hot pan on the stove.

Ask students what happened to the water in all these examples. Make it clear that, although you can't see the water anymore, it still exists. It changes into the gas, *water vapor*, which is a common invisible gas in air. Explain to students that when water changes from a liquid to a gas, we say that it *evaporates*. Point out that the word "evaporate" has the word "vapor" in it—water changes to water vapor.

Ask students questions such as the following:

- If you had a wet cloth or paper towel, do you think the water would eventually evaporate?
- What could you do to make the water from the paper towel evaporate faster? Students should mention some way of adding heat to make water evaporate faster.

2. Have students get into groups to design an experiment to test whether heat increases the rate of evaporation.

Distribute *Activity sheet 6.2—Evaporation*. Ask students to think about and discuss a test they could conduct in the classroom that would investigate whether heating increases the rate of evaporation. Students should record their ideas on the activity sheet. Students will continue to use the activity sheet as a guide as they plan their experiment.

As you listen to group plans, help students realize that they will need two samples of water. Students might think of putting water in containers or dampening two samples of material such as paper towels. They should realize that they will need to warm one sample but not the other. Students should mention that they will use the same amount of water in each container or on each sample of material. They should start with the same temperature of water, and the same type of container or material. You may want to suggest that students use a small amount of water so that they don't have to wait very long to see an observable difference.

3. Discuss students’ experimental designs and how they plan to control variables.

Have a class discussion where groups share their experimental designs. Have students consider how each proposed experiment controls variables. Groups may modify their plans based on the feedback they get from you and other students.

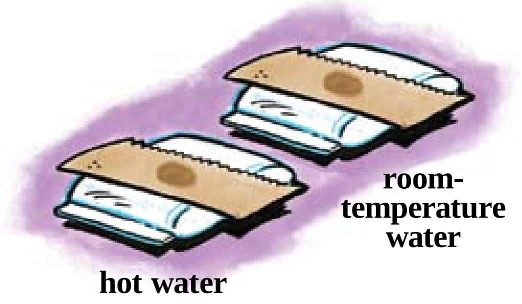
4. Have student groups conduct their experiment to find out whether heating water increases the rate of evaporation.

Depending on students’ experimental designs, observable results may take minutes, hours, or days.

5. Have students conduct the following procedure while they wait for their results.

Procedure

1. Add about 1 cup of *room-temperature* water to a zip-closing plastic bag. Get as much air out as possible, and seal the bag securely. Lay the bag down flat.
2. Add about 1 cup of *hot* tap water to a zip-closing plastic bag. Get as much air out as possible, and seal the bag securely. Lay the bag down flat. This bag will serve as a heat source.
3. You and your partner should each use a dropper to place 1 drop of room-temperature water in the center of 2 separate pieces of brown paper towel at the same time.
4. Allow the drops to spread for about 10–20 seconds until they don’t seem to be spreading any more.
5. At the same time, place 1 paper towel on each bag.
6. Observe every few minutes. Compare the amount of water on each paper towel.



***Expected results*: The water mark on the brown paper lying on the hot water bag should disappear faster than the mark on the paper lying on the room-temperature water bag. This will take about 3–5 minutes.**

6. Discuss the design of this experiment and the results.

While students are waiting to see which drop of water evaporates first, ask students about the design of this experiment. Ask questions such as the following:

- How will you know which sample of water is evaporating faster?
- Why do you think you used the same amount of water on each paper towel?
- What is the purpose of the bag of room-temperature water in this experiment?

Students should recognize that using different amounts of water on each paper towel could influence which sample evaporates first. Since the experiment is about differences in evaporation rates due to temperature, only the temperature of the drops of water should be different. The amount of water placed on each paper towel must be the same. Even the surface each paper towel is placed on should be the same. This is the purpose of the bag of room-temperature water.

Optional

7. Conduct a demonstration to show another way to find out whether hot water evaporates faster than cold water.

Procedure

1. Use a sensitive scale or balance that measures at least to tenths of a gram. Place a shallow Petri dish or yogurt lid on the scale.
2. Add 20 grams of hot tap water to the dish. You may use a dropper to help add or remove small amounts of water to get the mass as accurate as possible.
3. Check and record the mass. Then watch the readout on the scale or the pointer on the balance for 5 minutes. Ask students why the mass is changing.
4. Place 20 grams of very cold water on the scale for the same length of time.

Expected results: **The hot water will lose more mass than the cold water.**

Ask students what the results show about temperature and evaporation. Students should realize that the loss of mass was due to evaporation. Because the hot water sample was at a higher temperature, the molecules had more energy and were able to break away from the liquid and move into the air as the gas water vapor.

8. Discuss the results of the experiments designed and conducted by students.

Ask students questions like the following:

- Does the temperature of water have an effect on its rate of evaporation?
- Which evaporates faster, hot or cold water?
- How can the movement of molecules help explain why hot water evaporates faster?

Students should agree that temperature does affect the rate of evaporation. The experiments conducted show that hot water evaporates faster than cold water. Have student groups share their experiments, results, and conclusions.

Student activity sheet
Activity 6.2

Name: ______________________________

Evaporation

Does adding heat to water increase the rate of evaporation?

In the last activity, you learned that heating molecules makes them move faster and cooling molecules makes them move slower. You observed this in a liquid (water) and a gas (air in a bottle). In this activity, you will compare the rate at which 2 drops of water dry up. When water “dries up”, it seems to disappear, but is still around—somewhere. The water, which was once a liquid, becomes the invisible gas *water vapor* and becomes part of the air.

1. List at least two examples of water “disappearing” as something wet becomes dry.

   ____

   ____

2. What do you think you could do to make the water “dry up” faster in one of your examples?

   ____

   ____

When water “dries up”, changing from a liquid to the gas *water vapor,* we say that it *evaporates.* Notice that the words *evaporate* and *water vapor* both contain the word “vapor”.

Plan your experiment

3. Develop an experiment that you could safely do in your classroom to find out if heating water increases the rate at which it evaporates. Answer the following questions as you think about how you will design your experiment.

   a. How much water will you use? ______________________________

   b. How will you add heat to one sample of water?

   ____

   ____

   c. How will you know when one sample has evaporated more than the other?

   ____

   ____

   ____

   d. What are some things that will need to be kept the same so that the experiment is fair?

   ____

   ____

   ____

Name: ______________________________

Evaporation (*continued*)

4. Now that you have thought about your experiment and how you will design it, briefly describe what you plan to do.

Conduct your experiment

Interpret your observations

5. What did you observe?

6. Does adding heat to water increase the rate of evaporation? ___________________________

7. What evidence do you have from your experiment to help you answer this question?

Student activity sheet
Activity 6.2

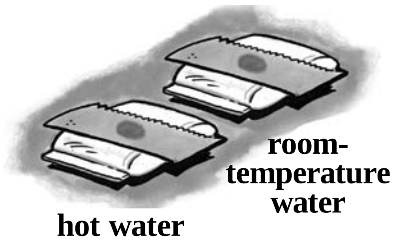
Name: ______________________________

Evaporation (*continued*)

Does adding heat to water increase the rate of evaporation?

Procedure

1. Add about 1 cup of *room-temperature* water to a zip-closing plastic quart storage bag. Get as much air out as possible, and seal the bag securely. Lay the bag down flat.
2. Add about one cup of *hot* tap water to a zip-closing plastic bag. Get as much air out as possible, and seal the bag securely. Lay the bag down flat. This bag will serve as a heat source.
3. You and your partner should each use a dropper to place 1 drop of room-temperature water in the center of 2 separate pieces of brown paper towel at the same time.
4. Allow the drops to spread for about 10–20 seconds until they don't seem to be spreading any more.
5. At the same time, place 1 paper towel on each bag.
6. Observe every few minutes. Compare the amount of water on each paper towel.



Evaluate the design of this experiment

8. Why do you think you used the same amount of water on each paper towel?

____

____

9. Why do you think you used a bag of room-temperature water and a bag of hot water in this experiment?

____

____

Record your observations

10. Which sample of water evaporated faster?

____

11. Does adding heat energy to water increase the rate of evaporation?____________

Activity 6.3
Condensation

Does cooling water vapor increase the rate of condensation?

In the previous activity, students design and conduct experiments and see that heating water increases the rate of evaporation. In this activity, students explore the reverse process—*condensation*. After seeing water vapor condense, students will help design a test to see if cooling water vapor has an effect on the rate of condensation.

Materials needed for each group

Hot tap water
Cold water
Ice cubes
3 Tall clear plastic cups
3 Wide clear plastic cups
Magnifier
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- **Hot tap water is sufficiently hot for the activity. Students should use care when handling hot tap water.**
- This activity calls for both tall and wide clear plastic cups. Be sure the cups fit together as shown.

Activity sheet

Copy *Activity sheet 6.3—Condensation*, pp. 353–354, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.3
Condensation

Question to investigate

Does cooling water vapor increase the rate of condensation?

1. Discuss with students some of their own experiences with condensation.

Ask students about their experiences with condensation using questions such as the following:

- Did you ever notice that if you have a cold drink on a humid day, the outside of the cup or can gets wet?
- Where do you think this moisture comes from?
- You may have made a cold window "cloudy" by breathing on it and then drawn on the window with your finger. Where do you think that cloudiness comes from?
- A cloud is made up of tiny droplets of water. Where do you think they come from?

Help students realize that the moisture in all of these examples came from water vapor in the air. Remind students that water vapor is one of the gases that makes up air.

Distribute *Activity sheet 6.3—Condensation* and have students list two examples of tiny drops of water appearing on a cold surface.

2. Have students conduct an experiment to observe the process of condensation.

Procedure

1. Fill a wide clear plastic cup about ⅔ full of hot tap water. Place a taller clear plastic cup (with a smaller rim) over the top as shown.
2. Watch the cups for 1–2 minutes.
3. Use a magnifier to look at the sides and top of the top cup.
4. Take the top cup off and feel the inside surface.

***Expected results*: The top cup will become cloudy-looking as small drops of liquid water collect on the inside surface of the cup.**

3. Discuss with students what they think is happening inside the cups.

Ask students questions like the following:

- What do you notice about the top cup?
- What do you think is on the inside of the top cup?
- Do you think that some of the water from the bottom cup is evaporating?
- Would you expect there to be more water vapor in the air inside the cups or outside the cups in the classroom air?
- How do you think the drops of water on the inside of the top cup got there?
- When water changes from a liquid to the gas water vapor, we say that it *evaporates*. Since *condensation* is the opposite of *evaporation*, explain what changes take place when water *condenses*.

Students should agree that the inside of the top cup is coated with tiny drops of liquid water. Since students saw in the last activity that heating water increases the rate of evaporation, they should realize that some of the hot water must have been evaporating pretty quickly, filling the air inside the cups with the gas water vapor. As water vapor moves away from the hot water it cools. It also cools when it comes in contact with the inside surface of the top cup. When the water vapor cools enough, it changes state, becoming tiny drops of liquid water. The process of changing from a gas to a liquid is called *condensation*.

4. As a class, discuss an experimental design that could investigate whether cooling water vapor increases the rate of condensation.

Remind students that they discovered that *heating* water increases the rate of *evaporation*. Now ask them if they think the reverse is true: Does *cooling* water vapor increase the rate of *condensation*?

Ask questions such as the following so that students better understand the experimental design described in the procedure below:

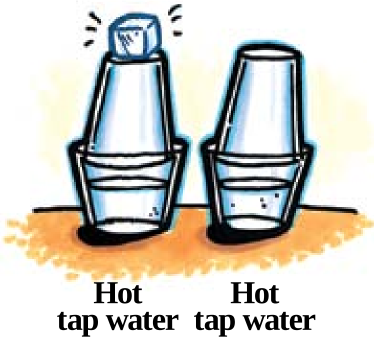
- We will need some water vapor in this experiment. How can we get some?
- How will we cool the water vapor?
- Will we need more than one sample of water vapor?
- Should we cool one sample of water vapor, but not the other?

Students may suggest collecting water vapor as described on the previous page or collecting it over a pot of boiling water. Students may have many ideas for cooling water vapor, like using ice, placing a sample in a refrigerator or cooler filled with ice, or placing a sample of water vapor outside if the weather is cool enough. Students should realize that they will need 2 samples of water vapor, one of which is cooled. By comparing the size of the drops in both samples, students can determine whether cooling water vapor increases the rate of condensation.

5. Have students do an activity to find out whether cooling water vapor increases the rate of condensation.

Procedure

1. Fill two wide clear plastic cups about ⅔ full of hot tap water.
2. Quickly place taller clear plastic cups (with smaller rims) upside down on each cup, as shown.
3. Place a piece of ice on top of one of the cups.
4. Wait 2–3 minutes.
5. Remove the ice and dry the place where the ice was with a paper towel.
6. Use a magnifier to examine the tops of the two upper cups.



Expected results: **There will be bigger drops of water on the top of the cup with ice.**

6. Discuss students' observations and draw conclusions.

Ask students questions such as the following:

- Which top cup appears to have more water on it?
- What does the amount of water have to do with the rate of condensation?
- Does cooling water vapor increase the rate of condensation?

Students should realize that the bigger drops on the cold top cup indicate a greater amount of water and therefore more condensation. Because the water vapor in both sets of cups was condensing for the same length of time, the water vapor in the cooler top cup must have condensed at a faster rate.

Student activity sheet
Activity 6.3

Name: ______________________________

Condensation

Does cooling water vapor increase the rate of condensation?

In the last activity, you saw that heating liquid water makes it turn into water vapor faster. Now, we will see if the opposite is true: We will take water vapor and cool it to see if it turns into liquid water faster.

1. List at least two examples of where you have noticed tiny drops of water appear on a cold surface.

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   ____

   ____

What happens when water vapor is cooled?

Procedure

1. Fill a wide clear plastic cup about ⅔ full of hot tap water.
2. Quickly place a taller clear plastic cup upside down as shown.
3. Watch the cups for 1–2 minutes.
4. Use a magnifier to look at the sides and top of the cup.
5. Take the top cup off and feel the inside surface.

2. What is on the inside surface of the top cup? ________________________________

3. Changing state from a liquid to a gas is called *evaporation*. Changing state from a gas to a liquid is called *condensation*. Do you think that some of the water from the bottom cup is evaporating? ____

4. Would you expect there to be more water vapor in the air inside the cups or outside the cups in the classroom air? ____

5. How do you think the drops of water on the inside of the top cup got there?

   ____

   ____

Student activity sheet
Activity 6.3

Name: ______________________________

Condensation (*continued*)

6. What could you do to water vapor to increase the rate of condensation?
   Hint: To increase the rate of condensation means to make the condensation happen faster.

   ____

   ____

Does cooling water vapor increase the rate of condensation?

Procedure

1. Fill two wide clear plastic cups about ⅔ full of hot tap water.
2. Quickly place the taller, clear plastic cups (with smaller rims) upside down on each cup, as shown.
3. Place a piece of ice on top of one of the cups.
4. Wait 2–3 minutes
5. Remove the ice and dry the place where the ice was with a paper towel.
6. Use a magnifier to examine the tops of the two upper cups.

7 Compare the amount of water on the inside surface of the top of each cup. Which top cup has more water on it?

   ____

   ____

8. Does cooling water vapor increase the rate of condensation? ____________________

   Explain your answer based on your observations.

   ____

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   ____

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Activity 6.4a
Exploring moisture on the outside of a cold cup

What causes moisture to form on the outside of a cold cup?

In the previous activity, students saw the relationship between cooling water vapor and condensation. In this activity, students investigate how condensation causes moisture to form on the outside of a cold cup. To see if the condensed water vapor comes from the air, students use 2 cold cups, but limit the air around one of them by placing it in a plastic bag. Students then compare the amount of moisture that forms on the outside of both cups. They will see that more moisture forms on the exposed cup. Since students determined in the previous activity that water vapor can condense to form liquid water, they can conclude that water vapor from the air must condense to form the moisture on the outside of a cold cup.

Note: Be sure to test this experiment before trying it with students because the amount of water vapor in the air varies in different geographic regions during different times of the year. Place water and ice in a clear plastic cup and leave it undisturbed for 3–5 minutes. If moisture is readily observable on the outside of the cup, do this activity with your students. If not, do *Activity 6.4b*, pp. 362–366.

Materials needed for each group

Ice
Room-temperature water
4 Clear plastic cups
Paper towel
Zip-closing plastic bag, gallon size

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Each group will need about 3 cups of ice.
- This activity has a take-home component. Have students empty and dry the cups used during the in-class parts of the activity. Then each student can take two of these clear plastic cups home. You may need additional cups depending on the number of students in each group.

Activity sheet

Copy *Activity sheet 6.4a—Exploring moisture on the outside of a cold cup*, pp. 359–361.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.4a
Exploring moisture on the outside of a cold cup

Question to investigate

What causes moisture to form on the outside of a cold cup?

1. Discuss with students their experiences with moisture on the outside of a cold cup or other container.

Ask students if they have ever noticed moisture on the outside of a cold cup or can. Then tell students that they will do an experiment to find out where the moisture comes from.

2. Have students explore whether the temperature of a cup has anything to do with the amount of moisture that forms on the outside of the cup.

Procedure

1. Fill 1 cup with ice. Add room-temperature water until the cup is about ¾ filled.
2. Add room-temperature water to another cup until it is about ¾ filled.
3. Wipe the outside of both cups with a paper towel to be sure they are dry.
4. Allow the cups to sit for about 1–3 minutes. Look at the outside of each cup. Use your finger to test for any liquid on the outside of the cups.

Expected results: **More moisture will appear on the outside of the cup with ice water than on the outside of the cup with room-temperature water.**

3. Discuss student observations and possible explanations for the moisture on the outside of the cold cup.

Ask students the following questions to get them thinking about why there is more moisture on one cup than the other. It is not important that students know the correct answers to these questions at this point. They will explore these further in the next part of the activity.

- Which cup had more moisture on the outside?
- What do you think the liquid is on the outside of the cold cup?
- Where do you think the liquid could have come from?
- Why do you think the cold cup has more moisture on the outside than the room-temperature cup?

Students should remember from *Activity 6.3* that cooling water vapor increased the rate of condensation. They should use this prior observation to explain that more moisture forms on the cold cup because cooling water vapor increases the rate of condensation. The cold cup cooled the air surrounding it enough for a noticeable amount of water vapor to condense on the outside of the cup.

4. Conduct an activity to find out whether the moisture that develops on the outside of a cold cup is condensed water vapor from the air.

Tell students that one way to find out if moisture is from water vapor in the air is to limit the amount of air around one cup while leaving the other cup exposed to air.

Procedure

1. Fill 2 cups with ice. Then add room-temperature water until each cup is about ¾ full. Wipe the outside of both cups with a paper towel to be sure they are dry.
2. Carefully place 1 cup in a zip-closing plastic bag. Get as much air out of the bag as possible and then seal the bag tightly.
3. After about 1–3 minutes, observe both cups.

***Expected results*:** **The cup outside of the bag will have more moisture on it than the cup in the bag.**

5. Have students discuss their results.

Ask students questions such as the following:

- Which cup had more moisture on the outside?
- What is the purpose of the bag in the experiment?
- Explain how moisture forms on the outside of a cold cup.

Students should conclude that the moisture on the outside of the cup was caused by water vapor in the air condensing on the cold outside of the cup. The cup inside the bag had less moisture on the outside of it because it was exposed to less air and therefore less water vapor.

6. Conduct an at-home activity to find out whether moisture will develop on the outside of an *empty* cold cup.

Ask students if they think that an *empty* cold cup would develop moisture on the outside of it. Then ask them what they could do to find out. The following procedure is one way to investigate this question. Have students conduct this activity at home. Send them home with 2 empty clear plastic cups and the last page of the activity sheet, p. 361. To be sure students do not have the misconception that the moisture that forms on the outside of a cold cup could be caused by water leaking through, have students conduct the following experiment with an empty cup.

Procedure

1. Place 1 empty clear plastic cup in a freezer while keeping another identical cup out. This identical cup will serve as a control.

2. Leave the cup in the freezer for at least 5 minutes.

3. Remove the cup from the freezer and place it near the control cup.

4. Look at the cups and feel the outside of each.

7. Have students report their findings.

Ask students what they observed on the outside of each cup.

Expected results: **The empty cup that was in the freezer will become cloudy while the empty room-temperature cup will remain clear. The outside of the cup that was in the freezer feels wet while the room-temperature cup feels dry.**

Student activity sheet
Activity 6.4a

Name: ______________________________

Exploring moisture on the outside of a cold cup

What causes moisture to form on the outside of a cold cup?

You may have seen tiny drops of water on the outside of a cold drink or a ring of moisture on a napkin or table beneath a cold drink. This activity explores what causes this moisture to form by considering both the *temperature* of the drink and the amount of *water vapor* in the air.

Does the temperature of a cup affect how much moisture forms on it?

Procedure

1. Fill 1 cup with ice. Add room-temperature water until the cup is about ¾ filled.
2. Add room-temperature water to another cup until it is about ¾ filled.
3. Wipe the outside of both cups with a paper towel to be sure they are dry.
4. Allow the cups to sit for about 1–3 minutes. Look at the outside of each cup. Use your finger to test for any liquid on the outside of the cups.

1. Which cup had more moisture on the outside of it?

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____

2. Condensation is the process where a gas changes to a liquid. Explain how condensation might be the cause of the moisture on the outside one of the cups. **Hint:** Remember that cooling water vapor increases the rate of condensation.

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Name: ______________________________

Exploring moisture on the outside of a cold cup *(continued)*

Does water vapor from the air cause moisture to form on the outside of a cold cup?

If you've ever let your cold drink sit out for a while, you've probably noticed that water forms on the outside of the cup. In this activity, you will explore what causes this moisture to form.

To find out if water vapor from the air causes condensation, you could expose one cold cup to air and keep air away from another. This activity is one way of doing this.

Procedure

1. Fill 2 cups with ice. Then add room-temperature water until each cup is about ¾ filled. Wipe the outside of both cups with a paper towel to be sure they are dry.
2. Carefully place 1 cup in a zip-closing plastic bag. Get as much air out of the bag as possible and then seal the bag tightly.
3. After about 1–3 minutes, observe both cups.

3. Which cup has more moisture on the outside?

____

____

4. What is the purpose of the bag in this experiment?

____

____

5. If you see a cup with moisture on the outside of it, what can you say about the temperature of the cup and the amount of water vapor in the air?

____

____

6. If you see a cup that is completely dry on the outside, what can you say about the temperature of the cup or the amount of water vapor in the air?

____

____

Name: ______________________________

Exploring moisture on the outside of a cold cup (*continued*)

Try this activity at home

Conduct an at-home activity to find out whether moisture will develop on the outside of an *empty* cold cup.

7. Make a prediction. Do you think moisture will form on the outside of an *empty* cold cup? ____________________

   Why?

   ____

   ____

   ____

Procedure

1. Place 1 clear plastic cup in a freezer while keeping another identical cup out. This identical cup will serve as a control.
2. Leave the cup in the freezer for at least 5 minutes.
3. Remove the cup from the freezer and place it near the control cup.
4. Look at the cups and feel the outside of each.

8. Some people might think that the moisture that forms on the outside of a cold drink somehow leaks through the cup. Explain how this experiment could change their minds.

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   ____

   ____

Activity 6.4b

Exploring moisture on the outside of a cold cup: For dry environments

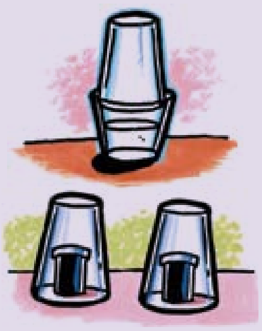
What causes moisture to form on the outside of a cold cup?

If the classroom air is not moist enough to achieve observable condensation in *Activity 6.4a*, students can conduct this activity. Regardless of the time of year or region of the country students live in, they have likely experienced moisture on the outside of a cold drink or other cold surface. In this activity, students will prepare a sample of humid air since the ambient air is too dry. Then students will place a cold container in the sample of humid air while leaving another cold container in the drier classroom air. By comparing the results, students will identify the factors that cause moisture to form the outside of a cold cup.

Materials needed for each group

Ice
Room-temperature water
Hot water
3 Tall clear plastic cups
1 Wide clear plastic cup
2 Film canisters with lids
Paper towel

Notes about the materials



- **Be sure you and the students wear properly fitting goggles.**
- This activity calls for both tall and wide clear plastic cups. Be sure the cups fit together as shown.
- Use film canisters or any other small containers with lids that will fit underneath a tall clear plastic cup as shown.
- Check to see whether an ice cube will fit inside your small container. If not, use crushed ice for this portion of the activity.
- Students will need just enough ice to fill 1 clear plastic cup and the 2 small containers.

Activity sheet

Copy *Activity sheet 6.4b—Exploring moisture on the outside of a cold cup: For dry environments*, pp. 365–366.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.4b
Exploring moisture on the outside of a cold cup: For dry environments

Question to investigate

What causes moisture to form on the outside of a cold cup?

1. Discuss with students their experiences using their breath to make a window "cloudy".

Introduce the activity by asking students if they ever breathed on a window to make it "cloudy". Students may mention breathing on a window in a car or in the house. Students may remember the window feeling wet as they wrote or drew on it with their fingers. They may have also noticed that they can sometimes see "smoke" when they talk or exhale in winter.

2. Conduct an experiment to see whether the temperature of a cup affects whether it becomes "cloudy" when a student breathes on it.

Distribute *Activity sheet 6.4b—Exploring moisture on the outside of a cold cup: For dry environments*. Explain to students that they will breathe on the outside of a cold cup and a room-temperature cup. Then ask them to predict what they might see on the outside of each cup.

Procedure

1. Fill a cup with ice. Add water until the cup is about ¾ full.
2. Place ¾ cup of room-temperature water in another cup.
3. Wipe the outside of both cups with a paper towel.
4. Slowly breathe warm air onto the outside of the room-temperature cup and then the cold cup.
5. Use your finger to feel the outside of each cup.

Expected results: **As student breath hits the side of the room-temperature cup, the cup becomes slightly cloudy and then quickly clears. As student breath hits the side of the cold cup, the side becomes cloudy and stays that way longer. When students feel each of the cups, they should notice moisture on the outside of the cold cup.**

3. Discuss student observations.

Ask students questions such as the following:

- Which cup were you able to make cloudier?
- Why do you think the outside of the cold cup became cloudier than the outside of the room-temperature cup?

Students should recognize that the moisture that forms on the outside of the cold cup is water. They may recall that in *Activity 6.3*, they were able to make more moisture form by cooling water vapor. Ask students whether they think water vapor could be in their breath. Help students understand that the moisture that appears on the outside of the cold cup is caused by water vapor from their breath condensing on the cup.

4. Conduct an activity to find out if the amount of water vapor in the air has an effect on the amount of moisture that appears on the outside of a cold cup.

Explain to students that sometimes moisture will appear on the outside of a cold cup even though no one breathes on it. Ask students if they think the amount of water vapor in the air may vary from season to season and place to place. For example in parts of the country that are often humid, moisture on the outside of a cold cup is a common occurrence. Briefly discuss the current dry conditions in your area. Explain that in the following activity students will place a cold container in a sample of *humid* air that they will make and another cold container in the *dry* classroom air.

Procedure

1. Fill a wide clear plastic cup about ⅔ full with hot tap water.
2. Immediately place a taller plastic cup upside down on top of the wider cup, as shown.
3. Fill 2 plastic film canisters with ice. Add water until they are nearly full, and snap the caps on securely.
4. Wipe the outside of both film canisters with a paper towel to be sure they are dry.
5. Once the tall cup appears cloudy, take it off of the other cup and immediately place it over one of the film canisters. At the same time, place another plastic cup over the other canister. This cup will contain the normal dry classroom air. Wait 2–3 minutes.
6. Remove the tall cups and look at the outside of each canister closely. Use your finger to test for any liquid on the outside of each canister.

Expected results: **More moisture appears on the outside of the film canister that is placed under the cup with a lot of water vapor in it. The film canister under the cup with the dry classroom air has less moisture on it.**

6. Discuss student observations.

Ask students what they observe on the outside of each film canister. Then have students apply this observation to a different situation:

- Consider two cold cups, each in a different place. Imagine that one cup has moisture on the outside and the other doesn't. What can you say about the air in each place?

Student activity sheet
Activity 6.4b

Name: ______________________________

Exploring moisture on the outside of a cold cup: For dry environments

What causes moisture to form on the outside of a cold cup?

If you've ever let a cold drink sit out for a while, you may have noticed that water forms on the outside of the cup. In this activity, you will explore where the water comes from.

Procedure

1. Fill a cup with ice. Add water until the cup is about ¾ full.
2. Place ¾ cup of room-temperature water in another cup.
3. Wipe the outside of both cups with a paper towel.
4. Slowly breathe warm air onto the outside of the room-temperature cup and then the cold cup.
5. Use your finger to feel the outside of each cup.

1. Which cup had more moisture on the outside of it?

____

____

2. Condensation is the process in which a gas changes to a liquid. Explain how condensation might be the cause of the moisture on the outside of one of the cups.

____

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In the procedure on the following page, you can test whether the amount of water vapor in the air has an effect on the amount of moisture that appears on the outside of a cold container.

Student activity sheet
Activity 6.4b

Name: ______________________________

Exploring moisture on the outside of a cold cup: For dry environments (*continued*)

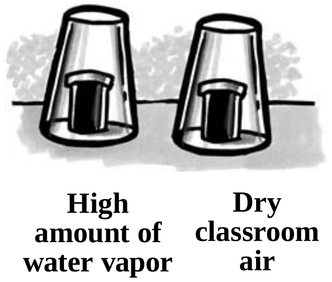
Does water vapor from the air cause moisture to form on the outside of a cold cup?

Procedure

1. Fill a wide clear plastic cup about ⅔ full with hot tap water.
2. Immediately place a taller plastic cup upside down on top of the wider cup, as shown.
3. Fill 2 plastic film canisters with ice. Add water until they are nearly full, and snap the caps on securely.
4. Wipe the outside of both canisters with a paper towel to be sure they are dry.

5 Once the tall cup appears cloudy, take it off of the other cup and immediately place it over one of the film canisters. At the same time, place another plastic cup over the other canister. This cup contains the normal dry classroom air. Wait 2–3 minutes.

6. Remove the tall cups and look at the outside of each canister closely. Use your finger to test for any liquid on the outside of each canister.



3. Which canister had more moisture on the outside of it?

4. Why do you think there is more moisture on the outside of one canister than the other?

5. If you see a container with moisture on the outside of it, what can you say about the temperature of the container and the amount of water vapor in the air?

6. If you see a container that is completely dry on the outside, what can you say about the temperature of the container or the amount of water vapor in the air?

Activity 6.5
From gas to liquid to solid

What causes frost to form on the outside of a cold container?

This activity is an extension of *Activity 6.4a* in which ice is used to make a container cold. As in *Activity 6.4a*, this activity will work only with sufficient water vapor in the air. Here, a metal can is used and salt is added to the ice to make the container even colder. Students have already learned that water vapor in air can condense to become liquid water. In this activity, they will see that the liquid water can change state again and *freeze* to become ice.

Materials needed for each group

Ice
Salt
Clean empty metal can
Metal spoon
Paper towel

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Use soup or vegetable cans.
- It is much easier for students to stir the ice–salt mixture if they use crushed ice instead of ice cubes.
- Students will need enough crushed ice to fill their metal can.

Preparing materials

- Remove the labels from the empty cans and carefully wash the cans.
- Use pliers to carefully press down any sharp or jagged edges around the top of each can. Cover the rim of each can with duct tape.

Activity sheet

Copy *Activity sheet 6.5—From gas to liquid to solid*, pp. 370–371.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 372–373. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 6.5
From gas to liquid to solid

Question to investigate

What causes frost to form on the outside of a cold container?

1. Discuss how cooling can cause changes in state.

Tell students that they discovered that cooling water vapor can change it from a gas to a liquid. Ask students how they could change liquid water to a solid. Students should suggest making the liquid colder until it turns to ice. Tell students that they will do an activity to see whether they can cool water vapor enough to get it to change to a liquid and then to a solid.

2. Add ice and salt to a can to make it very cold.

Distribute *Activity sheet 6.5—From gas to liquid to solid* and have students follow the procedure.

Procedure

1. Dry the outside of a can with a paper towel.
2. Place 3 heaping teaspoons of salt in the bottom of the can. Fill the can about halfway with crushed ice.
3. Add another 3 heaping teaspoons of salt.

4. Add more ice until the can is almost filled and add another 3 teaspoons of salt.
5. Hold the can securely and mix the ice–salt mixture with a sturdy metal spoon for about 1 minute. Remove the spoon, and observe the outside of the can. Do not touch it yet.
6. Wait 3–5 minutes. While you wait, answer the questions on the activity sheet.
7. Look at and touch the outside of the can. Then record your observations.

After completing Step 5, you may choose to have students place a thermometer inside the can because the temperature of the salt and ice mixture will be below the normal freezing point of water, which is 0 °C. The reason for this subfreezing temperature is explained in the *Science background information for teachers,* on page 332.

Expected results**: The outside of the can will become covered with a thin layer of frost. Students will notice this frost on the coldest part of the can at or below the level of the ice. Above the ice, the can is cold but not cold enough to change the moisture on the outside of the can to frost.**

3. Discuss student observations.

Ask students questions such as the following:

- What do you notice on the outside of the can?
- Why do you think there was frost on one part of the can and water on another part?
- Explain how water vapor in the air surrounding the can became frost.

Students should remember from *Activity 6.3* that cooling water vapor causes it to condense to liquid water. In this activity, students see that cooling water enough causes it to *freeze* to form frost.

Explain that this activity can be used as a *model* of what happens to water vapor in the atmosphere. Tell students that models help us to understand objects or processes that cannot easily be seen. In this model, the can represents the cold temperature in the upper atmosphere and the water vapor in your classroom represents the water vapor in the atmosphere. Ask students to use this activity as a model and explain what the liquid and frost on the outside of the can might represent.

Students may suggest that the liquid could be tiny drops of water in clouds or rain and the frost could be tiny ice crystals in clouds or snow.

Student activity sheet
Activity 6.5

Name: ______________________________

From gas to liquid to solid

What causes frost to form on the outside of a cold container?

Procedure

1. Dry the outside of a can with a paper towel.

2. Place 3 heaping teaspoons of salt in the bottom of the can. Fill the can about halfway with crushed ice.

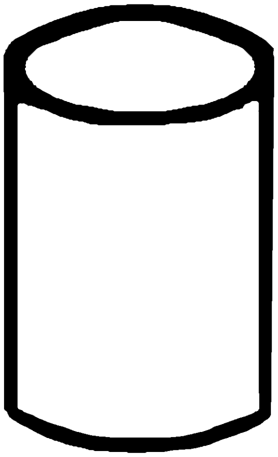
3. Add another 3 heaping teaspoons of salt.

4. Add more ice until the can is almost filled and add another 3 teaspoons of salt.

5. Hold the can near the top and mix the ice–salt mixture with a sturdy metal spoon for about 1 minute. Remove the spoon, and observe the outside of the can. Do not touch it yet.

6. Wait 3–5 minutes. While you wait, begin to answer the questions on the next page. When frost appears, complete question number 1.

1. Draw what you see and include descriptive captions.



Student activity sheet
Activity 6.5

Name: ______________________________

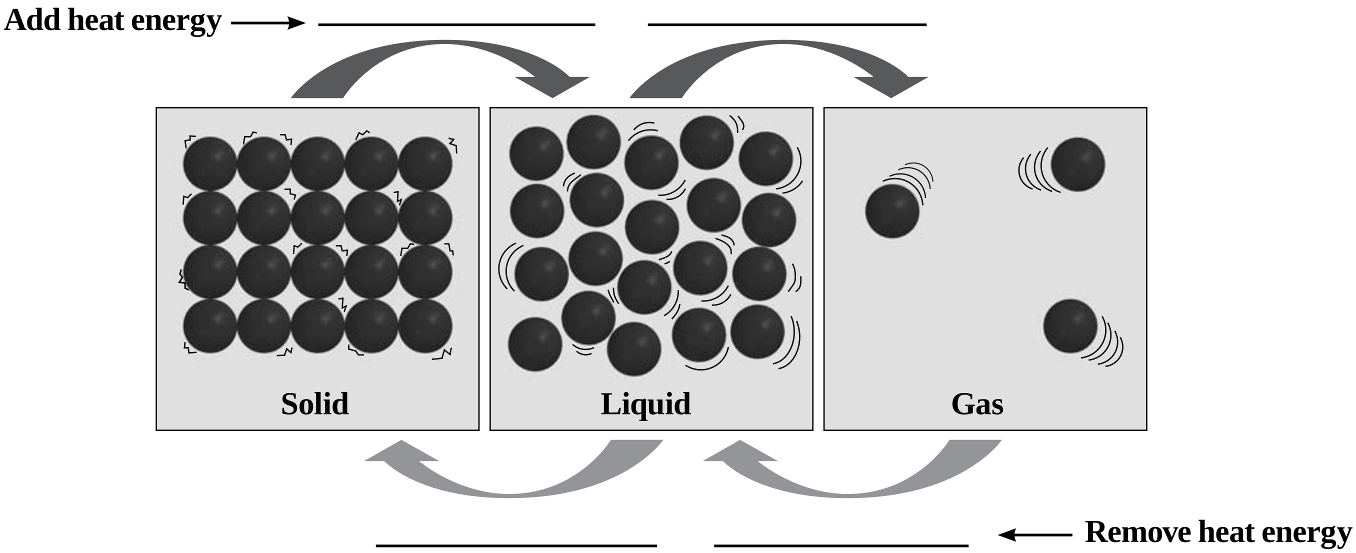
From gas to liquid to solid (*continued*)

2. Why do you think there is frost on one part of the can and water on another part?

3. Use the terms *condense* and *freeze* to answer the question: How does water vapor become frost?

4. In the upper atmosphere, where it's colder, water vapor in the air can change. This activity can be a *model* of what happens to water vapor in the atmosphere. Models help us to understand objects or processes that cannot easily be seen. In this model, the can represents the cold temperature in the upper atmosphere and the water vapor in your classroom represents the water vapor in the atmosphere. Using this model, what do the liquid and frost on the outside of the can represent?

5. Use the terms **evaporation**, **condensation**, **freezing**, and **melting** to label the processes where matter changes from one state to another in the picture below.



Investigation 6—States of matter

Assessment rubric

What causes water to change back and forth between water vapor, water, and ice?

Activity 6.1—Matter on the move

Do heating and cooling have an effect on matter?

G S N
☐ ☐ ☐ Records observations with words and drawings
☐ ☐ ☐ Explains observations in terms of molecular motion
☐ ☐ ☐ Makes a prediction based on observations during the demonstration
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Correlates temperature with the relative speed of molecules

Circle one: Good Satisfactory Needs Improvement

Activity 6.2—Evaporation

Does adding heat to water increase the rate of evaporation?

☐ ☐ ☐ Lists familiar examples of evaporation
☐ ☐ ☐ Describes a method to increase the rate of evaporation
☐ ☐ ☐ Plans and conducts an evaporation experiment with group
☐ ☐ ☐ Controls variables
☐ ☐ ☐ Records observations
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Recognizes the purpose of a control
☐ ☐ ☐ Uses evidence from experiments to answer the question

Circle one: Good Satisfactory Needs Improvement

Activity 6.3—Condensation

Does cooling water vapor increase the rate of condensation?

☐ ☐ ☐ Lists familiar examples of condensation
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Infers the cause of the moisture on the inside of the top cup
☐ ☐ ☐ Describes a method to increase the rate of condensation
☐ ☐ ☐ Uses evidence from experiment to answer the question

Circle one: Good Satisfactory Needs Improvement

Investigation 6—States of matter

Assessment rubric (*continued*)

Activity 6.4a—Exploring moisture on the outside of a cold cup

What causes moisture to form on the outside of a cold cup?

☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Forms a hypothesis about the cause of moisture on the outside of a cold cup
☐ ☐ ☐ Records observations
☐ ☐ ☐ Recognizes the purpose of a control
☐ ☐ ☐ Uses observations from experiment to explain the cause of moisture on the outside of a cold cup
☐ ☐ ☐ Predicts whether moisture will form on the outside of a cold empty cup
☐ ☐ ☐ Uses evidence from experiment to reason that moisture on a cold cup isn't from water leaking from the inside

Circle one: Good Satisfactory Needs Improvement

Activity 6.4b—Exploring moisture on the outside of a cold cup: For dry environments

What causes moisture to form on the outside of a cold cup?

☐ ☐ ☐ Forms a hypothesis about the cause of moisture on the outside of a cold cup
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations
☐ ☐ ☐ Uses observations from experiment to explain the cause of moisture on the outside of a cold container

Circle one: Good Satisfactory Needs Improvement

Activity 6.5—From gas to liquid to solid

What causes frost to form on the outside of a cold container?

☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Records observations
☐ ☐ ☐ Uses evidence to explain why frost and water form on different parts of a cold can
☐ ☐ ☐ Uses the terms *condense* and *freeze* to explain how water vapor from the air became frost on the side of a can
☐ ☐ ☐ Explains what water and frost on the can represent when used as a model of the upper atmosphere
☐ ☐ ☐ Identifies *freezing*, *melting*, *evaporation*, and *condensation* as changes in state caused by changes in temperature

Circle one: Good Satisfactory Needs Improvement

To earn a "**B**", a student must receive a "Good" in each category.

To earn an "**A**", a student must also exhibit some of the following qualities throughout this investigation.

☐ Writes outstanding explanations
☐ Possesses a well-developed understanding of variables and how to control them
☐ Participates well in class discussions
☐ Participates well in group work
☐ Uses scientific thinking
☐ Consistently exhibits exceptional thought and effort in tasks
☐ Other____

Teacher instructions

Review and apply

The following section, titled *Review and apply*, contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 6*, they will reflect on their learning, apply what they learned about state changes to a new activity, and read about the water cycle. An optional reading explains what happens on the molecular level as matter changes from one state to another. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned during the investigation.

Distribute *Review and apply: Let's review*, pp. 376–377, and give students an opportunity to answer questions about the activities. Students will describe how molecular motion is affected when liquids and gases are heated and cooled; recognize the use and purpose of a control; and apply their learning to explain what causes "cloudy" windows in winter and frost on the outside of a container of ice cream.

Science in Action!

2. Have students conduct a simple distillation activity.

Distribute *Review and apply: Science in action!*, p. 378, along with hot tap water, a tall cup, a wide cup, and a white paper towel. **Note:** You may either distribute one bottle of food coloring to each student group, color the hot water ahead of time, or place one drop of food coloring in each group's cup yourself.

Ask students to read over the procedure and then predict whether or not colored water will appear on the inside of the top cup. Give students time to complete the activity and answer the questions.

3. Discuss student observations.

Ask students questions such as the following:

- Do you see any color on the inside of the top cup?
- If the bottom cup were kept hot and the moisture that collected on the inside top cup was constantly removed, what would happen to the colored water in the bottom cup:
  - Would the water level go up, down, or stay the same?
  - Would the color of the water get lighter, darker, or stay the same?

Students should all agree that the water in the top cup is not colored. They should suggest that if they were able to continue distilling the water, the water level would go down and the color would get darker. Have several students share their designs for distilling salt water. Ask the class to identify where the process of evaporation and condensation would occur. Explain that distilled water is sold in grocery stores for a variety of special uses. Distilled water is used when the salts and minerals normally dissolved in tap and bottled water may cause problems. Some science experiments recommend using distilled water.

Think about it

4. Have students read about the role of evaporation and condensation in the water cycle.

Tell students that the processes of evaporation and condensation are important in both the water cycle and the weather. Ask students for examples of water in the weather. They may quickly recognize rain and snow, but you may need to help them realize that clouds, fog, dew, frost, and the humidity in the air are also examples of water in the weather.

Distribute *Review and apply: Think about it*, pp. 379–382. Have students look at the illustration of the water cycle, p. 380. Then, ask them for examples of evaporation and condensation in the water cycle.

Give students time to read the article and answer the questions.

For additional information about weather, go to
www.inquiryinaction.org

What's going on here? *(optional)*

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read an explanation of what goes on at the molecular level to cause substances to change state. Give students time to answer the questions about the reading.

Distribute *Review and apply: What's going on here?*, pp. 383–384. This reading describes how heating or cooling a substance increases or decreases the motion of molecules. After students answer the comprehension questions, explain that the attractions the atoms, ions, or molecules of a particular substance have for each other is the same whether the substance is in its solid, liquid, or gas phase. It is the combination of the motion of the molecules and the attractions the molecules have for one another that causes a substance to be a solid, liquid, or gas.

This type of molecular explanation is not suitable for all students. It is intended for students who have prior experience learning about the structure of atoms and molecules. This content is included for teachers and students who would like to be able to explain common observations on the molecular level.

Material to support this reading can be found at
www.inquiryinaction.org

Name: ______________________________

Let’s review

At the beginning of this investigation, a student did an experiment to see if there was a difference in the way the food coloring moves and mixes in hot and cold water. Your teacher demonstrated this and then you heated and cooled a bottle and saw how it affected a film of bubble solution. You then explored how heating and cooling can make water change state between a gas (water vapor), liquid (water), and solid (ice).

1. Think back to the movement of the color in hot and cold water. Does adding heat energy make water molecules move faster, slower, or have no effect?

2. What did you observe in the demonstration with food coloring in hot and cold water that supports your answer?

3. The speed of molecules can help explain why the bubble film grew and shrunk when you heated and cooled the air inside a bottle. Describe the movement of air molecules inside the bottle…

   When you placed it in warm water.

   When you placed the bottle in cold water.

4. You did an evaporation experiment with a drop of water on two pieces of paper towel. You heated one paper towel and kept the other at room-temperature. Why did you use two paper towels and not just one?

Let’s review (*continued*)

5. If you breathe on a window when it’s cold outside, you will make the window look cloudy. Based on your experiments, explain why this happens.

6. When you take a container of ice cream out of the freezer, you often see frost form on the outside of the container. What causes this frost to form?

Name: ____________________________

Science in action!

If colored water evaporates and then condenses, what do you think is in the liquid water that's produced? Do you think it will be clear colorless water? Or will there be some color in it? Do the following experiment to find out.

When colored water evaporates and condenses, is there any color in the water that is produced?

Procedure

1. Add hot tap water to a wide clear plastic cup until it is about ⅔ full.
2. Add 1 drop of food coloring and stir until the water is completely colored.
3. Turn another clear plastic cup upside down on the cup of hot water as shown. Place an ice cube on the top cup to make condensation happen faster.
4. Wait 1–3 minutes for water vapor to condense to liquid water on the inside surface of the top cup.

1. Does the water on the inside surface of the top cup look colorless or does it seem to have any of the color from the colored water? (You can use a white napkin or paper towel to wipe the inside of the cup to check it for any color.)

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The process described in the procedure is called *distillation*. During distillation, water that has substances dissolved in it can be purified. When the water evaporates and condenses, this pure water can be collected and used.

2. Imagine that you were stranded on an island surrounded by salt water. Use your imagination to describe one way that you could distill salt water to make water that you could drink.

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Review and apply worksheet Name: ______________________________

Think about it

Water cycle

Vocabulary	
evaporation	humidity
condensation	exhale
water vapor	cycle

Did you ever wonder where the water goes when it stops raining? After it rains, sometimes you see water on the ground in a puddle. The puddle eventually dries up, but where does the water go? Let's think about the water molecules in the puddle.

First of all, the water molecules in the puddle are constantly moving. Some of the water molecules at the surface of the puddle may move so fast that they will break away from the other water molecules and go up into the air. These water molecules form an invisible gas called *water vapor.* This process is called *evaporation*. The water vapor mixes in with the rest of the air, and we refer to it as the *humidity* in the air.

Temperature affects the rate of evaporation

Evaporation occurs at any temperature, but it is faster at higher temperatures and slower at lower temperatures. On a warm day, the water warms up and causes the water molecules to move faster than they would on a cold day. The water molecules move and break away faster so the puddle dries up faster. On cooler days, it takes longer for a puddle to evaporate. But temperature isn't the only thing that affects evaporation.

Water evaporates more quickly when the air is dry, and more slowly when the air has more water vapor in it. In some places such as the tropical rain forest, where it rains a lot, the air feels damp and muggy because it contains so much water vapor. Although it's hot in the rain forest, water can stay on the ground for a long time because the air is so humid that the water evaporates slowly.

Temperature affects the rate of condensation

After evaporation, what happens to the water vapor that's in the air? At night, as the sun sets, the air and ground get colder. The invisible water vapor that has evaporated into the air during the day cools down. This causes the molecules in the vapor to move more slowly. When the water molecules in the vapor slow down enough they come together to form tiny droplets of liquid water. This process is called *condensation.* Condensation is also why you can see your breath when you exhale on a cool morning. The gas you exhale contains invisible water vapor. When it hits the cooler air, the water vapor condenses into tiny droplets of liquid water that form a mist you can see.

Name: ____________________________

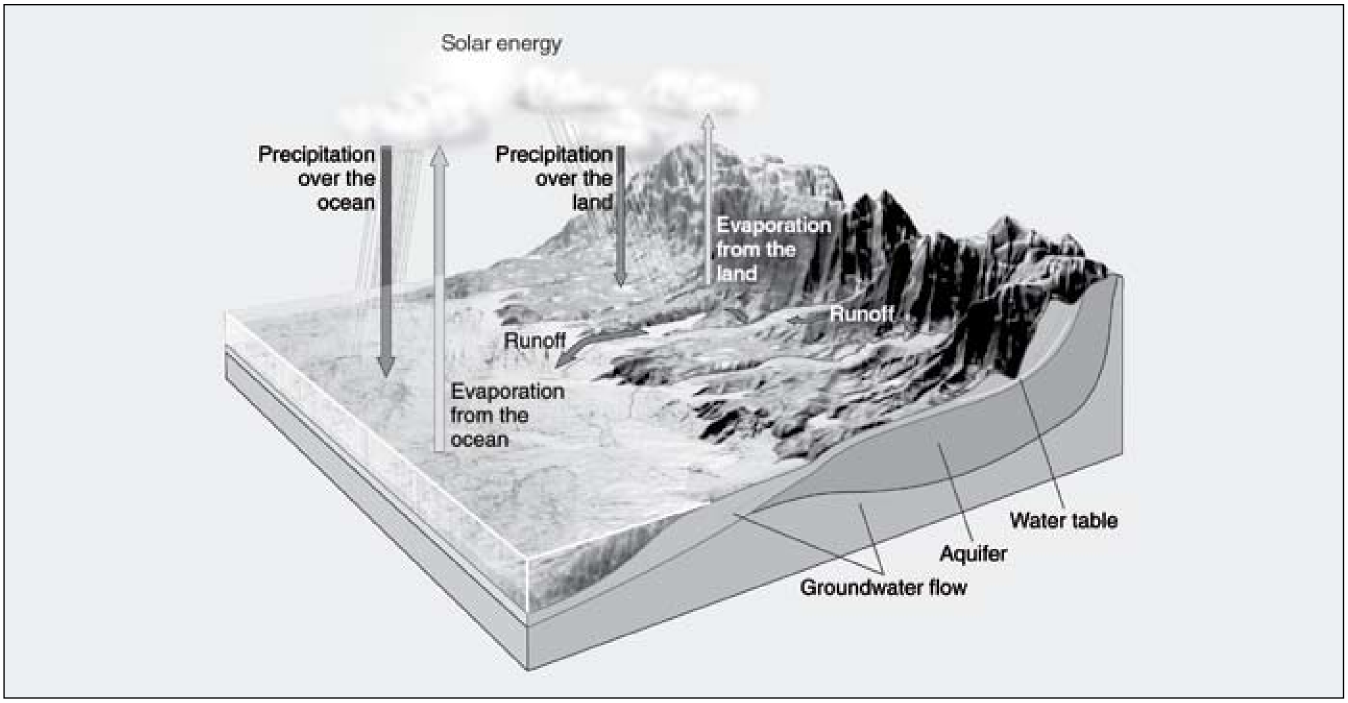
Think about it (*continued*)

Water and the weather

Depending on the amount of water vapor and the temperature of the air and ground, condensation causes a lot of the different types of moisture that we see. With the right combination of water vapor and temperature, condensed water vapor can form a mist that is visible and close to the ground, called *fog*. Condensation is also the cause of *dew*. Dew is liquid water that has condensed from water vapor and is found on leaves, grass, and other outside surfaces like a car or your bike. When it is really cold outside, the water vapor condenses and then freezes into ice crystals called *frost*.

When water vapor from the air rises into the atmosphere, it cools and condenses into tiny droplets of liquid water that are so light they stay in the air. These hanging droplets are called *clouds*. Eventually, the drops of water get bigger and heavier until they fall to the earth as rain. Sometimes the temperature is so cold in the clouds that the water droplets freeze into ice crystals instead. Depending on the temperature, these solid water crystals can join together to make *snow*, *sleet*, or *hail*.

So, water can change from a liquid to a gas and then back to a liquid or even a solid (ice). Eventually, the water will evaporate again and then condense again in a cycle. This cycle continues over and over and is called the *water cycle*. It cycles from the atmosphere and then back down to the earth in different forms and then back up to the atmosphere again. No matter where water is in the cycle, it is still just plain—but amazing—H_2O.



Think about it (*continued*)

1. Water molecules evaporate from a puddle after a rain storm. In this sentence, what does the word *evaporate* mean?
    a. Water molecules in the puddle are in the liquid state, and the molecules are not moving.
    b. Liquid water molecules move fast enough to turn into a gas called water vapor.
    c. Liquid water molecules slow down and form a solid on the ground called ice.
    d. Liquid water molecules stay the same speed, neither moving to the air nor staying on the ground.

2. Solid water crystals can form…
    a. sleet.
    b. hail.
    c. snow.
    d. all of the above.

3. Condensation happens faster if water vapor is…
    a. heated.
    b. cooled.
    c. evaporated.
    d. in the solid state.

4. Clouds are made by the process of…
    a. condensation of water vapor in the air.
    b. cooling ocean water.
    c. mist evaporating from the ground to form a gas.
    d. fog and dew found on the ground forming a liquid.

5. The author probably wrote this article in order to…
    a. tell about the weather patterns over a period of time.
    b. describe how the clouds are made.
    c. persuade people to watch the weather channel.
    d. explain how the water cycle affects weather.

6. Evaporation happens faster if water is…
    a. cooled.
    b. vapor.
    c. heated.
    d. condensed.

Name: ____________________________

Think about it (*continued*)

7. The water cycle is a very important process for life on Earth. Why is it called a *cycle.*

8. In addition to temperature, what else has an effect on how fast a puddle of water evaporates?

9. Your breath contains water vapor. Why can you sometimes see your breath when it's cold outside?

10. When some people see dew on the ground, they might think that it rained. But dew and rain are different. How does dew form?

Name: ____________________________

What’s going on here?

Substances can exist in three different states—*solid*, *liquid*, or *gas*. Regardless of whether the substance is a solid, liquid, or gas, the atoms, ions, or molecules that make up the substance are attracted to each other. The attractions between these particles is what holds the substance together.

Turn up the heat

In a solid, the atoms, ions, or molecules of the substance are held very close together. They vibrate but do not move past each other. This is what gives solids their definite size and shape.

When heat energy is added to a solid, the motion of the particles increases. The particles are still attracted to each other but their extra movement starts to compete with their attraction. If enough heat is added, the motion of the particles begins to overcome the attraction and the particles move more freely. They begin to slide past each other as the substance begins to change its state from a solid to a liquid. This process is called *melting*. The particles in a liquid are only slightly further apart than in a solid. Their attractions hold them together enough so they don’t just fly apart and become a gas.

When heat energy is added to a liquid, the motion of the particles increases again. If enough heat is added, the motion of the particles can completely overcome the attractions between them. When this happens, the particles of the liquid go into the air as a gas. This process is called *evaporation*. As a gas, particles are completely free to move, and their attractions have almost no effect on them.

Cool it

These processes work in reverse also. But instead of adding heat, the substance is cooled by removing heat. When a gas is cooled, the motion of the particles slows down. If the particles slow down enough, their attraction for each other causes them to come together and change from a gas to a liquid. This process is called *condensation*.

If the liquid is cooled even more, the particles slow down even more. The attractions between the particles cause them to arrange themselves in more fixed and orderly positions to become a solid. This process is called *freezing*.

It is the combination of the attraction the particles of a substance have for each other and how much energy they have that determines whether a substance is a solid, liquid, or gas.

Name: ____________________________

What’s going on here? (*continued*)

1. If heat energy is added to a solid like ice, it will begin to melt. What happens to the water molecules in an ice cube as it melts to become liquid water?

   ____

   ____

   ____

2. If heat energy is added to a liquid like water, it will begin to evaporate. What happens to the water molecules in a drop of liquid water as it evaporates to become the gas water vapor?

   ____

   ____

   ____

3. If a gas like water vapor is cooled enough, it will begin to condense. What happens to the water molecules in water vapor as they condense to become tiny drops of liquid water?

   ____

   ____

   ____

4. If liquid water is cooled enough, it will begin to freeze. What happens to the water molecules in water as they freeze to become ice?

   ____

   ____

   ____

Cool factoid

When we think of changes of state, we usually think of a substance changing between solid, liquid, and gas. But the common gas, carbon dioxide, is different. When carbon dioxide gas is cooled enough, it doesn’t change into a liquid like most gases, it just changes directly to a solid. But this doesn’t happen until the temperature reaches –78 °C or –108 °F. That’s pretty cold! It works the other way too. When solid carbon dioxide (dry ice) is warmed, it skips the liquid state and changes right to a gas! But don’t be fooled. When dry ice makes all that cool special-effects “smoke”, that’s not carbon dioxide you are seeing. The dry ice cools the air enough so that the smoke you see is really condensed water vapor. The carbon dioxide gas is invisible.

Investigation 7

Density

What causes a substance to sink or float in a liquid?

Summary

In this investigation, students will explore the concept of density through the familiar experiences of sinking and floating. Students begin by observing a small rock sink while a bigger and heavier wooden block floats. By comparing the weight of the wood and rock to equal volumes of water, students realize that both the object and the water are important in determining whether an object sinks or floats. Students then compare the weight of equal volumes of wax, clay, and water to predict whether wax and clay will sink or float. This idea is extended to liquids as students investigate why water, corn syrup, and vegetable oil orient themselves in the same layers regardless of the order in which they are poured. Students then add salt to water and notice that a carrot slice that sinks in water can be made to float as more and more salt is added. Students also consider the density differences of cold and hot water as they add colored hot and cold water to cups of room-temperature water. Next, students add another material to an object that sinks in order to increase its overall volume. Then they experiment with changing the shape of a piece of clay to make an object with a greater volume that floats.

Investigation 7: Density

Key concepts for students

- When designing a scientific experiment, it is necessary to identify and control variables.
- The volume of an object is the amount of space it takes up.
- The volume of water displaced by a submerged object equals the volume of the object.
- The density of a substance depends on both its weight and its volume.
- When comparing equal volumes of different substances, the one that weighs more is more dense.
- Whether a substance sinks or floats in a liquid depends on the density of the substance and the density of the liquid.
- Density is a characteristic property of a substance.
- The density of a substance is the same regardless of the size of the sample.

Note: "Weight" rather than "mass" is used in most of the activities in this investigation. For a discussion of the distinction between mass and weight, see pp. 390–391.

Learning objectives

Students will be able to:

- Determine the volume of an object through the water displacement method.
- Use the volume and weight of different substances to compare their relative densities.
- Explain that density depends on both the weight and the volume of an object.
- Recognize that if an object is more dense than a liquid, the object will sink and if it is less dense than the liquid, the object will float.
- Use the floating or sinking of objects in different liquids to draw conclusions about the relative densities of the objects and liquids.

Investigation questions

What causes a substance to sink or float in a liquid?

- Do heavy things always sink and light things always float?
- How can you predict whether an object will sink or float in water?
- How do the densities of vegetable oil, water, and corn syrup help them to form layers in a cup?
- Can the density of a liquid be changed?
- Is there a difference in density between hot and cold water?
- How can you make an object float when it ordinarily sinks?
- Can changing the shape of an object affect whether it sinks or floats?

Assessment

The assessment rubric, *Density*, pp. 437–439, enables teachers to document student progress as they design and conduct activities and complete the activity sheets. Students will demonstrate their understanding of both the physical science and inquiry content as they complete the activity, readings, and worksheets in the *Review and apply* section on pp. 440–452.

Relevant *National Science Education Standards*

K–4

Physical science

Properties of objects and materials

Objects have many observable properties, including size, weight, and shape.
Those properties can be measured using tools, such as rulers and balances.
Objects can be described by the properties of the materials from which they are made, and those properties can be used to separate or sort a group of objects or materials.

Science as inquiry

Abilities necessary to do scientific inquiry

Ask a question about objects.
Plan and conduct a simple investigation.
Use simple equipment and tools to gather and extend the senses.
Use data to construct a reasonable explanation.
Communicate investigations and explanations.

Understandings about scientific inquiry

Scientific investigations include describing objects…and doing a fair test.
Good explanations are based on evidence from investigations.

5–8

Physical science

Properties and changes of properties in matter

A substance has characteristic properties—such as density—all of which are independent of the amount of the sample.

Science as inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Communicate scientific procedures and explanations.

Understandings about scientific inquiry

Different kinds of questions suggest different kinds of scientific investigations.
Scientific explanations emphasize evidence and have logically consistent arguments.
Scientific investigations sometimes result in new ideas and phenomena for study that can lead to new investigations.

Materials chart for student activities

7.1 Defining density
7.2 Comparing the density of an object to the density of water
7.3 Comparing the density of different liquids
7.4 Changing the density of a liquid—Adding salt
7.5 Changing the density of a liquid—Heating and cooling
7.6 Changing the density of an object—Adding material
7.7 Changing the density of an object—Changing shape

	Activities						
Each group will need	7.1	7. 2	7.3	7.4	7.5	7.6	7.7
Room-temperature water	●	●	●	●	●	●	●
Hot water colored yellow					●		
Cold water colored blue					●		
Vegetable oil			●				
Corn syrup			●				
Block of wood	●						
Rock	●						
Tealight candles in metal containers		2					
Clay		●					●
Paperclips			●				
Crayon piece			●				
Toothpick or popsicle piece			●				
Raw pasta			●				
Carrot slice				●			
Salt				●			
Small cups, 3½-ounce			7		2		
Tall clear plastic cup	5		●	●			
Wide clear plastic cup		●			2		
Wide plastic deli container or bowl	●						●
Plastic teaspoon				●			
Dropper					2		
Ruler		●	●				
Pencil		●	●				
Permanent marker		●	●				
Tape		●	●			●	
Small sinking object						●	
Small items that float						●	
Rubber bands						●	
String						●	

Materials chart for teacher demonstrations

	Activities 7.1	 7.4	 7.5	 7.6	 7.7
Room-temperature water	●	●	●	●	●
Hot water			●		
Cold water			●		
Yellow food coloring			●		
Blue food coloring			●		
Wooden block	●				
Rock	●				
Clay					●
Clear plastic cup	●	2			
Small jars			2		
Plastic bowl					●
Large clear plastic container				●	
Water-resistant card			●		
Balance	●				
Sensitive scale					●
Plastic teaspoon		●			
Salt		●			
Carrot slice		2			
Coffee stirrer, straw, or spoon			●		
Paper towels			●	●	
Can of regular cola				●	
Can of diet cola				●	
Bubble wrap				●	
Scissors				●	
Tape				●	

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- The rock and block of wood should be small enough to fit inside a tall clear plastic cup.
- It is best to use tealight candles in which the wax comes all the way to the top and has a flat surface.
- In *Activity 7.2*, each group will need 1 ball of clay that is a bit more than will be needed to fill a metal container from a tealight candle. In *Activity 7.7*, each group will need 2 balls of clay about the size of golf balls.
- Each group will need about 50 paperclips.
- One carrot will be more than enough for an entire class to do this activity.
- Either use a single playing card from a deck of cards or laminate an index card. The card should completely fit over the opening of the jars.
- Be sure that the two jars have exactly the same-sized openings so that one jar can be inverted on top of the other with no gaps.
- In *Activity 7.6*, students will attach lightweight objects with a large volume to a small water-resistant item, such as a plastic toy figure, that sinks. The items students use to make their sinking objects float will vary. Either provide an assortment of materials or have students bring them from home.

Science background information for teachers

An understanding of the concept of density is useful because density applies to many areas of science. In chemistry, density (like solubility or melting point) can be used to help distinguish one substance from another. In the context of earth science, the density of rock determines layers within Earth's crust. In life science, the changing density of water with temperature affects the cycling of nutrients for organisms within a body of water. In astronomy, the density of stars helps determine how hot and bright they are. In this investigation, students will explore sinking and floating to develop an understanding of density.

For videos, animations, and other information related to this investigation, go to
www.inquiryinaction.org

Chemistry concepts

- The density of a substance is its mass divided by its volume.
- Mass is the amount of matter in a substance and is determined by the mass of the atoms, ions, or molecules that make up the substance.
- Volume is the amount of room these particles take up and is determined by the size of the particles and how closely they are packed together.
- Density is determined by a combination of the mass of the particles and the volume they occupy.
- Weight is a measure of the force of gravity on an object of a certain mass.
- Whether a substance floats or sinks in a liquid depends on the density of the substance and the density of the liquid.
- If an object placed in a liquid is more dense than the liquid, the object will sink.
- If an object placed in a liquid is less dense than the liquid, the object will float.

What is density?

The *density* of a substance is measured by the *mass* of the substance divided by its *volume*. The mass of a substance is determined by the mass of the atoms, molecules, or ions that make up the substance. The volume is determined by the size of these particles and how closely they are packed together. A common misconception is that the density of a substance is determined only by how closely packed or squeezed together the particles are that make up the substance. This is the use of "density" as in a densely packed bus or the population density of a country. But the closeness of packing is only part of the story. The mass of the particles is very important, too. It is possible that a substance with very heavy particles spaced a little further apart could be more dense than a substance with lighter particles packed more closely together. So the density of a substance is a result of the mass of its particles and how closely they are packed in the substance. Since the particles that make up a substance have unique masses and arrange themselves together in particular ways, density is a fundamental or characteristic property of that substance.

Mass vs. weight

The formula for density is in terms of *mass*, but often some confusion arises about the difference between "mass" and "weight". Mass is a measure of the amount of matter in an object. Weight is a measure of the force of gravity on an object of a certain mass. So if we could move an object from Earth to the moon, for example, where there is less gravity, its mass would stay the same but its weight would be less. Since weight = (mass × acceleration of gravity), weight is directly proportional to mass. If one object has more mass than another, it will also weigh more. If one object has less mass than another, it will also weigh less.

When comparing two objects of the same volume to compare their densities, it doesn't matter if you measure them in units of mass or weight. If one has a greater mass it will also have a greater weight and therefore, a greater density. If it has less mass it will weigh less and have a lower density. So for finding *relative* densities—if one substance or object is more or less dense than another—using either mass or weight is fine. Since the activities in this investigation are the same whether measuring mass or weight, the terms "weigh" and "weight" are used throughout *Investigation 7*. If you need an *actual* value of density for a substance or object, then you would need to measure in units of mass.

Devices that measure mass or weight

Different scales are designed to measure either mass or weight. For example, a scale that measures in pounds has been designed and calibrated to display a number representing the force with which gravity pulls down on the mass of the object on the scale. This scale measures the weight of the object. This same object could also be placed on a scale that measures in kilograms. Of course, gravity still pulls down on the object, but the scale has been designed and calibrated to factor out the value for the force of gravity and to display only the value for mass.

One interesting mass/weight fact is that when you use a balance, you are measuring mass. Let's say that you have a simple balance like a ruler with cups on the ends and is balanced in the middle on a pencil. If you wanted to find the mass of a certain amount of water, for instance, you would put that amount of water in one cup. In the other cup, you could add uniform small objects such as paper clips. When the end with the water lifts from the table, you would know that the mass of the water is about equal to the total mass of the paper clips in the other cup. The reason why this is a measure of mass is because gravity is pulling down with the same amount of force on both sides of the balance so it can be factored out. The water and the paper clips would still balance on the moon or anywhere else, so a balance gives a measure of mass.

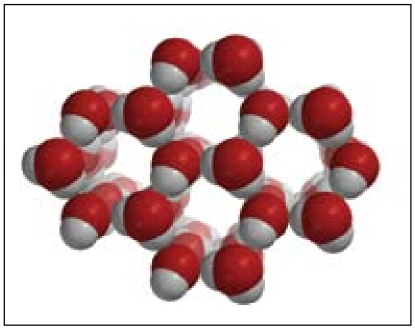
So a balance is a convenient way to compare the densities of different substances. Place *equal volumes* of each substance on the opposite ends of a balance. If Substance A has more mass than Substance B, then Substance A is more dense than substance B. Conversely, Substance B is less dense than Substance A.

Using floating and sinking to learn about density

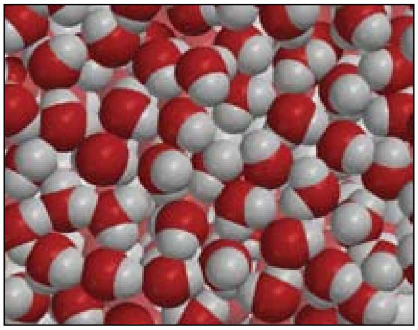
In this investigation, sinking and floating are used in a familiar and convenient context for teaching different aspects of *density*. The purpose of the activities is not to teach the physics of buoyancy or the buoyant force, but to use sinking and floating to develop and test ideas about density. In *Activity 7.7*, dealing with changing an object's shape to affect its overall density, concepts related to some of these more physics-based aspects of floating and sinking could be addressed.

Why ice floats

A familiar example of floating and sinking is ice floating on water. As liquids get colder, their molecules get closer together and the liquid becomes more dense. When most liquids freeze, the molecules get even closer together as they form the crystal structure of a solid (see p. 328). A solid is almost always more dense than its liquid and will sink when placed in its liquid phase. But this is not true of water. When water freezes, the molecules arrange themselves in a crystal structure in which the molecules are actually further apart than they were as a liquid. Since the same number of water molecules takes up a greater volume as ice than as liquid water, ice is less dense and will float on liquid water.



Solid ice



Liquid water

Activity 7.1—Defining density

Whether a substance floats or sinks in a liquid depends on the density of the substance and the density of the liquid. If the substance is more dense than the liquid, the object will sink. If it is less dense than the liquid, the substance will float. The density of a substance is not affected by the size of the sample. For instance, wood is a substance that is less dense than water. A small piece of wood floats and so does a very large piece, like a tree trunk. Similarly, if a substance is more dense than water, it sinks, regardless of the size of the sample. For example, rock is more dense than water. A huge boulder will sink and so will a tiny grain of sand.

In the demonstration, students see that the wood weighs more than the rock but the wood floats and the rock sinks. These observations may seem counterintuitive to students. After a discussion of the factors that might be causing the heavy wood to float and the lighter rock to sink, students are introduced to the concept of *density*. Students then consider why the block of wood floats. When using the water displacement method for finding a volume of water equal to the volume of wood, be sure students understand that the wood is taking up all the space where water used to be. So the amount of water that spilled out equals the space or volume taken up by the wood.

Activity 7.2—Comparing the density of an object to the density of water

This activity shows that to determine whether an object will sink or float in water, the weight of the object is compared to the weight of a volume of water equal to the volume of the object. Students find that wax weighs *less* than an equal volume of water. This means that wax is less dense than water and should float. Since clay weighs *more* than an equal volume of water, it is more dense than water and should sink.

Activity 7.3—Comparing the density of different liquids

Students will need to compare the weights of equal volumes of vegetable oil, water, and corn syrup. From this information, they can determine the *relative* densities of all the liquids and order them from most dense to least dense. Water and oil have different densities but they also do not mix, which helps to maintain the distinct line between them when they are poured in the same cup. Water and corn syrup have very different densities but they do mix in one another. They will stay separated for some time but will eventually mix.

Activity 7.4—Changing the density of a liquid—Adding salt

Since the carrot sinks in fresh water, it must be more dense than fresh water. Dissolving salt in water increases the mass of the salt water solution but doesn't increase its volume very much. This extra mass with less than a corresponding increase in volume makes salt water more dense than fresh water. When enough salt is dissolved in the water, the solution becomes more dense than the carrot, and the carrot floats.

Activity 7.5—Changing the density of a liquid—Heating and cooling

When water is heated, the molecules move faster and a little farther apart from one another. Since the mass does not change and the water takes up a little more volume, the density of hot water is less than the density of room-temperature water. When water is cooled the molecules slow down and become a little closer together. Since the mass doesn't change but the water takes up less volume, the density of cold water is *greater* than the density of room-temperature water. The difference in density is great enough that hot water will float on room-temperature water and cold water will sink in room-temperature water.

Activity 7.6—Changing the density of an object: Adding material

Surrounding a can of soda pop with a piece of bubble wrap changes the density of the overall can-wrap object. While the mass of the bubble wrap is very small, its volume is comparatively large. So adding the bubble wrap to the can of soda adds a significant amount of volume to the can while adding very little mass. This decreases the overall density of the can-wrap object to the point where it is less dense than water and floats.

Activity 7.7—Changing the density of an object: Changing shape

The density of the clay itself is not changed, but the density of the overall object is increased by changing the shape of the object. Since density = mass/volume, increasing the volume of an object without increasing its mass must decrease its density. The volume of these clay boxes = length × width × height. One or more of these dimensions can be increased to increase the volume of the object and decrease the overall density. The trick is to increase the volume enough so that the corresponding decrease in density will make the clay box less dense than water so it will float.

There is another related way of explaining why clay, which ordinarily sinks, can be made to float. An object that sinks weighs *more* than the weight of the water it displaces. An object that floats weighs the *same* as the weight of the water it displaces. So a solid ball of clay weighs more than the weight of water it displaces. One way to make it float is to change its shape so that the resulting clay object displaces a mass of water equal to the mass of the newly shaped object. This can be done by shaping the clay into a bowl, box, or boat-shape. A final shape can be achieved where a combination of the mass and volume of the clay “boat” displaces a volume of water whose mass is equal to the mass of the boat. Then the clay boat will float. This is why an enormous and heavy ship can float. It is designed with a combination of mass and volume so that it displaces a volume of water whose mass is equal to the mass of the ship.

Activity 7.1
Defining density

Do heavy things always sink and light things always float?

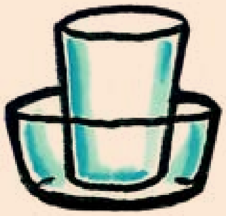
In this introductory demonstration and activity, students are introduced to the concept of density as they explore a rock and a wooden block in water. First students address the misconception that heavy things sink and light things float by observing a small rock and a larger heavier wooden block on a balance and then in a tank of water. The lighter rock sinks while the heavier wooden block floats. Students realize that there must be something more to sinking and floating than size or weight. Students investigate further by using the water displacement method to find volumes of water equal to a block of wood and a rock. After comparing the weight of each object with the weight of an equal volume of water, students can generalize an important rule about sinking and floating: Objects that are less dense than water float, and objects that are more dense than water sink.

Materials needed for the demonstration

Water
Clear plastic cup or larger container
Wooden block
Rock
Balance

Materials needed for each group

Water
Block of wood
Rock
5 Tall clear plastic cups
Wide plastic deli container or bowl



Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- The rock you use in the demonstration should be smaller and lighter than the wooden block.
- The rock students use should be about the size of a golf ball. It does not need to be round.
- The wood and the rock need to fit inside a clear plastic cup.
- The wide plastic container should be big enough to hold a clear plastic cup as shown.

Activity sheet

Copy *Activity sheet 7.1—Defining density*, pp. 398–401, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.1
Defining density

Question to investigate

Do heavy things always sink and light things always float?

Take a closer look

1. Have students read the investigation story on *Activity sheet 7.1* and watch the demonstration.

Procedure

1. Place a rock that weighs *less* than a wooden block on one end of a balance.

2. Place the wood on the other end.

3. Ask students which is heavier, the rock or the wood. Ask them to predict which will sink and which will float. Then, place the rock and wooden block in water.

Expected results: **Even though the rock weighs less than the wood, the rock sinks and the wood floats.**

2. Discuss students' ideas about why the lighter rock sinks and the heavier wood floats.

Ask students why they think the smaller lighter rock sinks and the bigger heavier wood floats. Some students may say that even though the rock is light, it's also small and actually *heavy* for its size. And even though the wood is heavier, it's bigger and actually *light* for its size. This answer is moving in the right direction because it shows an awareness that the relationship between the weight of the object and its size is important. Let students know that this relationship, between the *weight* of an object and its volume (the amount of space an object takes up), is called *density.*

Ask students questions like the following to get them to think about how density might apply to sinking and floating:

- Which do you think is more dense, the rock or the wood?
- Why do you think that?

Students should realize that the rock must be more dense than the wood. Tell students that they will do an activity where they compare the density of wood to the density of water.

Distribute *Activity sheet 7.1—Defining density*.

Try this!

3. Have students compare the weight of a wooden block to the weight of an equal volume of water.

Pass out a small wooden block to each group. Tell students that the size and shape of the wood determine how much space it takes up. The amount of space the block takes up is called its *volume*.

Procedure

1. Place the wood in a cup and look at the wood to see about how much space or volume it takes up.
2. Lift the cup to get a sense of the weight of the wood. Do you think the same volume of water would weigh more or less than the wood?
3. Pour an amount of water that you think is about the same volume as the wood into another cup.
4. Lift both cups to see which seems heavier, the wood or the water.

Expected results: **The water should feel heavier than the block of wood.**

4. Discuss students' observations.

Ask students questions such as the following:

- Which feels heavier, the wood or the water?
- Which is probably more dense, the water or the wood?
- Do you think this might have anything to do with why the wood floats?

Students will probably say that the water weighs more. Tell students that if you compare two things that take up exactly the same amount of space, the heavier one is more dense. Explain that the method students used was not very accurate, so next they will learn a better way to figure out how much space a block of wood takes up.

5. Have students use the water displacement method to find a volume of water that is equal to the volume of the wood.

Procedure

1. Label 2 cups **displaced water—wood** and **displaced water—rock**. You will also need two cups which are unlabeled.
2. Stand one unlabeled cup inside the larger container. Pour water into the cup until it is filled as high as possible without overflowing.
3. Gently place the wood in the water and slowly push it down until it goes just beneath the surface of the water. Water should overflow into the container.
4. Carefully remove the inside cup and put it aside. Then pour the water that overflowed into the cup labeled "displaced water—wood". Remove the wood from the water and place it in an empty cup.
5. Lift the cup with the wood in it and the cup with the displaced water to see which feels heavier.

Expected results: **The water should feel heavier than the block of wood.**

6. Discuss the water displacement method and weigh samples of wood and water from each student group.

Explain to students that when they push the wood into the water, the wood takes up the space where there was once water. So the wood pushed away or *displaced* a volume of water equal to the volume of the wood. The volume of water that overflowed into the outside container is equal to the volume of the wood.

Choose a block of wood and its displaced water from any group and weigh them. The water will weigh more than the wood. Ask students whether the water or the wood is more dense. Review with students that since they are comparing the same volume of water and wood, the one that weighs less must be less dense. Explain that the wood floats because it is less dense than water.

7. Have students use the water displacement method to compare the weight of a rock to the weight of an equal volume of water.

Procedure

1. Stand an unlabeled cup inside the larger container. Pour water into the cup until it is filled as high as possible without overflowing.
2. Gently place the rock in the water. Water should overflow into the container.
3. Carefully remove the inside cup and put it aside. Then pour the water that overflowed into the cup labeled "displaced water—rock". Pour the water out so that only the rock is left in the cup.
4. Lift the cup with the rock in it and the cup with the displaced water to see which feels heavier.

***Expected results*: The rock should feel heavier than the water.**

Ask students which they think weighs more, the rock or an equal volume of water. Choose a rock and its displaced water from any group and weigh them. The rock will weigh more than the water. Ask students whether the rock or the water is more dense. Review with students that since they are comparing the same volume of water and rock, the one that weighs more must be more dense. Explain that the rock sinks because it is more dense than water.

What's next?

8. Ask students to predict whether wax and clay will float or sink in water.

Tell students that in the next activity, they will compare equal volumes of wax, clay, and water and then predict which will float and which will sink.

Ask students questions like the following:

- Do you think wax will sink or float in water?
- Would you expect wax to weigh more or less than an equal volume of water?
- Do you think clay will sink or float in water?
- Would you expect clay to weigh more or less than an equal volume of water?

Remind students that objects that weigh less than an equal volume of water are less dense and float. Objects that weigh more than an equal volume of water are more dense and sink.

Student activity sheet
Activity 7.1

Name: ______________________________

Defining density

I like throwing stones into ponds or lakes or almost any water for that matter. I like to skim stones, or throw them at stuff floating in the water. Anyway, I was at a lake recently with some friends. I found a tree branch and threw it out into the water as far as I could. Then we each took three rocks and took turns seeing who could hit the floating branch. It was pretty fun. Then we found this really heavy branch that was really more like a log. It took two of us to lift it and throw it in. It made a huge splash but floated even though it was so heavy. As we threw rocks at it, I started to think that it seemed weird. This really heavy piece of wood floats and these rocks, which are so much lighter, sink. I know that wood floats and rocks sink but when you think about how the real heavy one floats and the much lighter ones sink, it seems strange.

Take a closer look

Do heavy things always sink and light things always float?

1. Do you think heavy things *always* sink and light things *always* float? ______________

   Give at least one example of a heavy object that floats and one example of a light object that sinks.

   ____

   ____

   ____

2. In the demonstration, you saw that the heavier wood floats and the lighter rock sinks.

   Which do you think is more dense, the rock or the wood? ______________________

   Why do you think that?

   ____

   ____

   ____

   ____

Name: ______________________________

Defining density (*continued*)

Try this!

Which weighs more, wood or the same amount of water?

Procedure

1. Place the wood in a cup and look at the wood to see about how much space or volume it takes up.

2. Lift the cup to get a sense of the weight of the wood. Do you think the same volume of water would weigh more or less than the wood?

3. Pour an amount of water that you think is about the same volume as the wood into another cup.

4. Lift both cups to see which seems heavier, the wood or the water.

3. Which do you think weighs more, the wood or a similar volume of water?

____

____

4. Which do you think is more dense, the wood or the water?

____

____

You can measure a volume of water equal to the volume of the wood by using a more accurate method. This is called the *water displacement method*.

Student activity sheet

Name: ______________________________

Activity 7.1

Defining density (*continued*)

Procedure

1. Label 2 cups **displaced water—wood** and **displaced water—rock**. You will also need two cups which are unlabeled.

2. Stand 1 unlabeled cup inside the larger container. Pour water into the cup until it is filled as high as possible without overflowing.

3. Gently place the wood in the water and slowly push it down until it goes just beneath the surface of the water. Water should overflow into the container.

4. Carefully remove the inside cup and put it aside. Then pour the water that overflowed into the cup labeled "displaced water—wood". Remove the wood from the water and place it in an empty cup.

5. Lift the cup with the wood and the cup with the displaced water to see which feels heavier.

5. Which do you think feels heavier? ________________________

6. Explain why the water displaced by the wood has the same volume as the wood.

____

____

____

7. You or your teacher should weigh the wood and the water to see which one weighs more. Which one weighs more? ____

8. Since the wood weighed less than an equal volume of water, the wood is less dense than the water. Do you think the density of the wood compared with the density of water has anything to do with why the wood floats? ____________________________________

Student activity sheet Name: ______________________________

Activity 7.1

Defining density (*continued*)

Use the water displacement method to compare the weight of a rock to the weight of an equal volume of water.

Procedure

1. Stand an unlabeled cup inside the larger container. Pour water into the cup until it is filled as high as possible without overflowing.

2. Gently place the rock in the water. Water should overflow into the container.

3. Carefully remove the inside cup and put it aside. Then pour the water that overflowed into the cup labeled “displaced water—rock”. Pour the water out so that only the rock is left in the cup.

4. Lift the cup with the rock and the cup with the displaced water to see which feels heavier.

9. Which do you think feels heavier? ________________________

10. You or your teacher should weigh the rock and the water to see which one weighs more.
Which one weighs more? ________________________________

11. Since the rock weighed more than an equal volume of water, the rock is more dense than the water. Do you think the density of the rock compared with the density of water has anything to do with why the rock sinks? ______________________________________

Activity 7.2
Comparing the density of an object to the density of water

How can you predict whether an object will sink or float in water?

In this activity, students use tealight candle holders and a student-made balance to compare the weight of equal volumes of wax, water, and clay. Students then apply their understanding of density from *Activity 7.1*, to predict whether the wax and clay will sink or float. Students will discover that since the wax weighs less than an equal volume of water, it is less dense than water and will float. And since the clay weighs more than an equal volume of water, it is more dense and will sink.

Materials needed for each group

Water
1 Clear plastic cup or container
2 Tealight candles in metal containers
Ruler
Tape
Pencil
Permanent marker
Clay

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- It may be difficult for students to pour water into the small metal container of a tealight candle. Using a small cup or a squirt bottle filled with water makes filling this small container easier.
- It is best to use tealight candles in which the wax comes all the way to the top and has a flat surface. Some have rounded tops, which make it difficult to match the height of the wax with an equal height of water in another container.

Preparing materials

- Each group will need 1 ball of clay. Roll the clay into a ball bigger than what will be needed to completely fill the metal container of a tealight candle.
- If you plan to do this activity again, there is no need to pull the clay out of the metal containers. Store the clay-filled containers in a plastic bag until the next use.

Activity sheet

Copy *Activity sheet 7.2—Comparing the density of an object to the density of water,* pp. 406–408, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.2
Comparing the density of an object to the density of water

Question to investigate

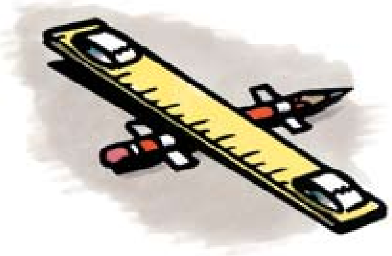
How can you predict whether an object will sink or float in water?

1. Have students construct a simple balance scale.

Distribute *Activity sheet 7.2—Comparing the density of an object to the density of water.* Tell students that in order to predict whether an object will sink or float in water, they will have to know about the density of the object compared with the density of water. Tell students that a balance scale, like the kind they will make, will help them compare these densities.

Procedure

1. Tape the pencil down as shown. Roll two small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite ends of the ruler.



2. Remove both candles from their metal containers. Place an empty metal container on each piece of tape. Be sure that the edge of the metal container lines up with the end of the ruler as shown.

3. Lay the ruler on the pencil so that it is as balanced as possible. (Don't worry if you can't make it balance exactly.) The spot on the ruler directly above the center of the pencil is your *balance point.* Mark the ruler with a pencil or permanent marker at this point.

2. Have students compare the weight of equal volumes of wax and water.

Procedure

1. Carefully place one of the candles back into its metal container on one end of the ruler. Make sure the same balance point is directly over the center of the pencil.

2. Carefully pour water into the metal container on the other end of the ruler. Be sure to fill the container with water to the same height as the wax fills the other container.

Note: If using a tealight candle with a rounded top, judge how much water to add to the other candle container. This extra volume of wax should be taken into account and a little extra water should be added to attempt to match the actual volume of the wax.

Expected results: **The water weighs more than an equal volume of wax and is therefore more dense than wax**.

3. Discuss student observations.

Ask students the following questions:

- Which weighs more, the wax or an equal volume of water?
- Which is more dense, wax or water?

4. Ask students to predict whether wax will sink or float in water.

Once students have made a prediction, ask them to explain their reasoning. Then have students test their prediction by placing the wax in a cup of water.

Expected results: **The wax floats in water. This is because wax is less dense than water.**

Remind students that the *density* of an object has two parts: the volume of the object and how much the object weighs. Tell them that they weighed the same volume of wax and water. Since the wax weighed less than an equal volume of water, the wax is less dense. When students put the wax in water, they noticed that it floated. Objects that are less dense than water will float. The density of an object compared with the density of water will determine whether or not an object will sink or float.

5. Have students determine whether clay will sink or float in water.

Procedure

1. Set up the ruler balance with the empty metal containers on each end. Check your balance point.
2. Fill one metal container with clay and replace it on the end of the ruler. Make sure the balance point is centered on the ruler.
3. Slowly and carefully add water to the empty container until it is filled.

Expected results: **The clay weighs more than an equal volume of water and is therefore more dense than water.**

6. Discuss students' observations and ask them to predict whether clay will sink or float in water.

Ask students questions like the following:

- Which weighs more, the clay or an equal volume of water?
- Which is more dense, clay or water?
- Do you think clay will sink or float in water? Why?

Students should have some clay left over after filling the metal container. Have students test their prediction by placing this left-over piece of clay in a cup of water.

Expected results: **The clay sinks in water. This is because clay is more dense than water.**

Note: If some students suggest that the clay could be made to float by changing its shape, tell them that they will investigate the effect of changing an object's shape in *Activity 7.7.*

7. Have students explain, in terms of density, why a very heavy object like a log floats and why a very light object like a pebble sinks.

Ask students:

- Use what you know about density to explain why a heavy object like a log floats and why a very light object like a pebble sinks.
- How could you predict whether or not an object will sink or float?

Students should recognize that a log will float because wood is less dense than water. If you could weigh a large amount of water that has the same volume as the log, the log will weigh less than the water. Therefore, the log floats. A pebble will sink because rock is more dense than water. If you could weigh a small amount of water that has the same volume as the pebble, the pebble will weigh more than the water. Therefore, the pebble sinks.

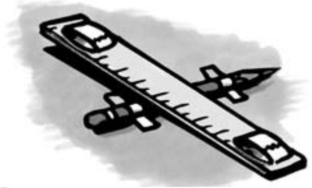
Students should realize that if an object weighs more than an equal volume of water, it is more dense and will sink; and if it weighs less than an equal volume of water, it is less dense and will float.

Student activity sheet Name: ____________________________

Activity 7.2

Comparing the density of an object to the density of water

How can you predict whether an object will sink or float in water?



Procedure

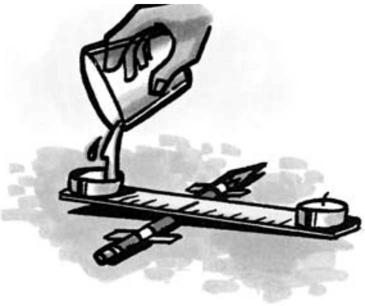
Build a balance

1. Tape the pencil down as shown. Roll two small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite ends of the ruler.

2. Remove both candles from their metal containers. Place an empty metal container on each piece of tape. Be sure that the edge of the metal container lines up with the end of the ruler as shown.

3. Lay the ruler on the pencil so that it is as balanced as possible. (Don't worry if you can't make it balance exactly.) The spot on the ruler directly above the center of the pencil is your *balance point*. Mark the ruler with a pencil or permanent marker at this point.

Compare the weight of wax and water



4. Carefully place one of the candles back into its metal container on one end of the ruler. Make sure the same balance point is directly over the center of the pencil.

5. Carefully pour water into the metal container on the other end of the ruler. Be sure to fill the container with water to the same height as the wax fills the other container.

Which is heavier, the wax or the water? ____

Make a prediction. Do you think the wax will float or sink in water?________________

Student activity sheet Name: ______________________________

Activity 7.2

Comparing the density of an object to the density of water

(*continued*)

6. Pour water into a plastic cup until it is about ¾ filled. Then place the wax in the water to find out whether it sinks or floats.

Write the word "floats" or "sinks" on the line beneath the illustration to describe what happens when you place the wax candle in water.

____

Compare the weight of clay and water

7. Set up the ruler balance with the empty metal containers on each end. Check your balance point.

8. Fill one metal container with clay and replace it on the end of the ruler. Make sure the balance point is centered on the ruler.

9. Slowly and carefully add water to the empty container until it is filled.

Which is heavier, the clay or the water? ____

Make a prediction. Do you think the wax will float or sink in water? _________________

10. You had some clay left over after filling the metal container. Place that piece of clay in the water to find out whether clay sinks or floats.

Write the word "floats" or "sinks" on the line beneath the illustration to describe what happens when you place the clay in water.

____

You made sure that you poured the same amount of water as wax and the same amount of water as clay. Since the amount of space each material took up was the same, you compared *equal volumes* of wax and water and *equal volumes* of clay and water. "Equal volume" is a more accurate way of saying the "same amount".

Student activity sheet Name: ______________________________

Activity 7.2

Comparing the density of an object to the density of water

(*continued*)

Density has two parts: the amount of space a substance takes up (volume) and the weight of the substance. If something is more dense than water it will sink, and if it's less dense than water it will float.

1. Fill in the blanks below with "more dense" or "less dense".
    - If a substance weighs *less* than an equal volume of water, it is ___________________ than water.
    - If a substance weighs *more* than an equal volume of water, it is___________________ than water.

Whether or not an object sinks or floats in water has to do with its density compared to the density of water.

2. Fill in the blank with "float" or "sink" to help predict if an object will float or sink.
    - If a substance is more dense than water, it will ________________________________.
    - If a substance is less dense than water, it will ________________________________.

3. An ice cube will float in a cup of water.

   What would you expect if you compared the weight of the ice cube to the weight of an equal volume of liquid water?

   ____

   ____

   Use evidence from your experiment to justify your answer.

   ____

   ____

   ____

Activity 7.3
Comparing the density of different liquids

How do the densities of vegetable oil, water, and corn syrup help them to form layers in a cup?

Students will carefully pour vegetable oil, water, and corn syrup in any order into a cup and discover that regardless of the order they are poured, the liquids arrange themselves in layers the same way. Students will then weigh the liquids and use their results, along with what they understand about density, to explain why the liquids form layers as they do.

Materials needed for each group

Water
Vegetable oil
Corn syrup
Ruler
Tape
Pencil
Permanent marker

Paperclips
Piece of a crayon
Piece of raw pasta
Piece of toothpick or popsicle stick
1 Clear plastic cup
7 Small cups

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Each group will need about 50 paperclips.
- Three of the seven cups will be labeled by the teacher and used as source cups for each liquid.

Preparing materials

- Label 3 small cups **water**, **oil**, and **corn syrup**.
- Pour about 1/4 cup of each liquid in its labeled cup.

Activity sheet

Copy *Activity sheet 7.3—Comparing the density of different liquids*, pp. 413–415, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.3
Comparing the density of different liquids

Question to investigate

How do the densities of vegetable oil, water, and corn syrup help them to form layers in a cup?

1. Have students pour the three liquids in a cup in any order they choose.

Distribute *Activity sheet 7.3—Comparing the density of different liquids.*

Procedure

1. Slowly and carefully pour about about half of the water, corn syrup, and vegetable oil (in any order you choose) into one empty clear plastic cup.

2. Record your obervations.

***Expected results*:** **Corn syrup will sink to the bottom, water will be in the middle, and vegetable oil will float on the top.**

2. Have groups compare their results.

Students will notice that regardless of the order in which the liquids are poured, they will arrange themselves in the same way. Tell students that they will explore what causes these liquids to arrange themselves as they do. Ask students to think of the liquids in terms of sinking and floating. Which liquid floats on water. Which liquid sinks in water? Put the cup with the layered liquids aside but do not throw it away. Students will need the cup of layered liquids for the last part of the activity.

Point out that the water is in the middle and that the oil *floats* on the water and that the corn syrup *sinks* in the water. Ask students, based on their experience with sinking and floating, what this means about the density of oil compared with the density of water, and about the density of corn syrup compared with the density of water. Students should realize that the vegetable oil is less dense than water and that the corn syrup is more dense than water.

3. Discuss with students how they could compare the weight of *equal* volumes of the liquids.

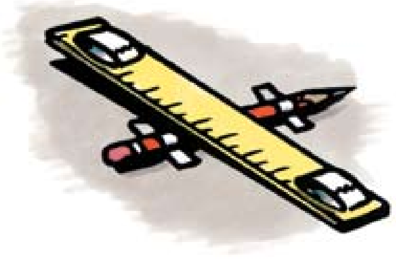
Ask students if they were to weigh equal volumes of the three liquids, which they would expect to be the heaviest, lightest, and in-between. Since students know the relative densities of the liquids based on the way they form layers in the cup, they should realize that if they weigh equal volumes of the liquids, corn syrup should be the heaviest, vegetable oil the lightest, and water in-between. Ask students how they might go about weighing equal volumes of the liquids. Students may make or use a balance scale, like the one constructed in *Activity 7.2*, p. 406, to compare the weight of equal volumes of the liquids on each side of the scale. You could also suggest another method to students, in which they weigh each liquid against nonstandard units like paperclips, or some other unit. This method is described in the procedure on the following page.

4. Have students compare the weights of equal volumes of the liquids.

The following procedure has students measure equal volumes of each liquid by marking 1 cm up on a small cup and pouring the liquids directly into the marked cups. Using a spoon to measure equal volumes of these liquids is not accurate because vegetable oil and corn syrup tend to stick to the spoon.

Procedure

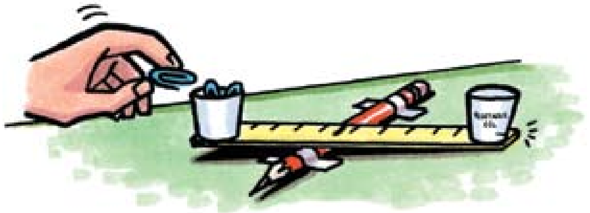
1. Use a permanent marker to label 3 small cups **vegetable oil**, **corn syrup**, and **water**. Use your ruler to measure 1 cm up from the bottom of the cup and make a line with the marker.



2. Tape the pencil down as shown. Roll 2 small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite ends of the ruler.

3. Place the empty vegetable oil cup on one piece of tape and the empty unlabeled cup on the other. Be sure that the edge of the cup comes right to the end of the ruler. Lay the ruler on the pencil so that it is as balanced as possible. (Don't worry if you can't make it balance exactly.) Use a pencil or permanent marker to mark the spot on the ruler directly above the center of the pencil. This is the *balance point.*

4. Remove the vegetable oil cup and very carefully add vegetable oil until the oil reaches the mark on the cup. Replace the cup on the ruler. Be sure the edge of the cup is at the end of the ruler and that the marked balance point is directly over the pencil.



5. Add paperclips, one at a time, to the empty cup on the other end. Count the paperclips until the weight of the paperclips causes the oil cup to just lift from the table. Record this number in the chart on the activity sheet.

6. Repeat Steps 4 and 5 for water and corn syrup.

Expected results: **Depending on the paperclips students used and the amount of liquid poured in each cup, students' results may vary a bit. However, it should be clear that the vegetable oil weighs less than the water and that corn syrup weighs more than the water.**

Liquid	**Weight in paperclips**
Vegetable oil	**24**
Water	**29**
Corn syrup	**41**

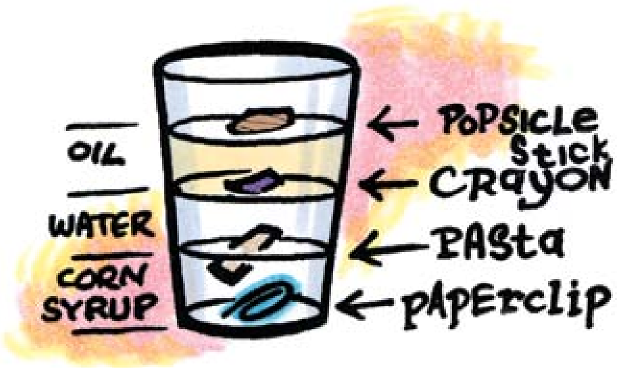
5. Have students discuss their results.

Ask students questions like the following:

- Why is it important to weigh *equal volumes* of each liquid?
- Do your results from weighing the liquids agree with your observation of the layered liquids?

6. Have students place a crayon piece, paperclip, piece of pasta, and piece of popsicle stick into the cup of liquids.

Students should use the cup of layered liquids they made at the beginning of this activity. When students place objects in the liquids, the objects will position themselves in different layers. Ask students to explain, in terms of density, why the objects end up where they do.



Student activity sheet
Activity 7.3

Name: ______________________________

Comparing the density of different liquids

How do the densities of vegetable oil, water, and corn syrup help them to form layers in a cup?

1. In the following procedure you will pour vegetable oil, water, and corn syrup in any order into a cup. Decide with your group which order you will pour the liquids and indicate which you will pour in first, second, and third.

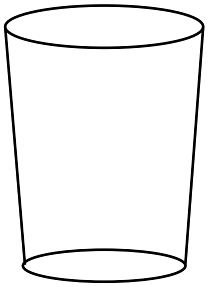
First ________________________

Second ________________________

Third ________________________

Procedure

1. Slowly and carefully pour about about half of the water, corn syrup, and vegetable oil (in the order you chose) into one empty clear plastic cup.
2. Record your observations by drawing in and labeling the cup.
3. Keep your cup of layered liquids. You will need it again at the very end of this activity.



2. Think of the liquids as sinking and floating in water.

Which liquid seems to be floating on the water? ______________________________

Which liquid seems to be sinking in the water?______________________________

3. When you think of the liquids as floating or sinking on water, you can make a guess about the density of each liquid compared to the density of water.

Which liquid is less dense than water?______________________________

Which liquid is more dense than water?______________________________

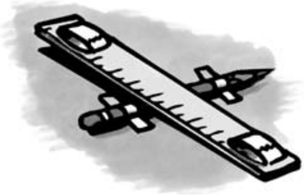
Student activity sheet
Activity 7.3

Name: ______________________________

Comparing the density of different liquids (*continued*)

Procedure

1. Use a permanent marker to label 3 small cups **vegetable oil**, **corn syrup**, and **water**. Use your ruler to measure 1 cm up from the bottom of the cup and make a line with the marker.



2. Tape the pencil down as shown. Roll 2 small pieces of tape so that the sticky side is out. Stick each piece of tape to the opposite ends of the ruler.

3. Place the empty vegetable oil cup on one piece of tape and the empty unlabeled cup on the other. Be sure that the edge of the cup comes right to the end of the ruler. Lay the ruler on the pencil so that it is as balanced as possible. (Don't worry if you can't make it balance exactly.) Use a pencil or permanent marker to mark the spot on the ruler directly above the center of the pencil. This is the *balance point.*

4. Remove the vegetable oil cup and very carefully add vegetable oil until the oil reaches the mark on the cup. Replace the cup on the ruler. Be sure the edge of the cup is at the end of the ruler and that the marked balance point is directly over the pencil.

5. Add paperclips, one at a time, to the empty cup on the other end. Count the paperclips until the weight of the paperclips causes the oil cup to just lift from the table. Record this number in the chart below.

6. Repeat Steps 4 and 5 for water and corn syrup.

Liquid	Weight in paperclips
Vegetable oil	
Water	
Corn syrup	

Student activity sheet
Activity 7.3

Name: ______________________________

Comparing the density of different liquids (*continued*)

4. What did you do in the experiment to make sure that you compared *equal volumes* of water, vegetable oil, and corn syrup?

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5. Since you used equal volumes of water, vegetable oil, and corn syrup, you can compare the weight of each to find out about the density of each liquid. Use your data from this experiment to list the liquids in order from the *least dense* to the *most dense.*

____

____

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6. How does the density of each liquid explain the layering of each liquid in the cup?

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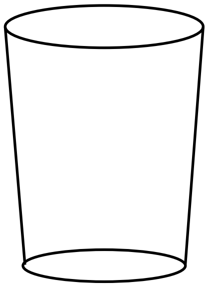
____

____

Place a crayon piece, paperclip, piece of pasta, and piece of popsicle stick into your cup of layered liquids.



7. Draw and label the liquids and objects in the cup.

8. Use what you know about density to explain why the objects are positioned where they are.

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Activity 7.4
Changing the density of a liquid—Adding salt

Can the density of a liquid be changed?

In this activity, students will see that a carrot slice sinks in fresh water and floats in saltwater. Considering the placement of the carrot slice in water and salt water, students will infer that the density of salt water must be greater than the density of fresh water. As a challenge, students will adjust the density of the salt water until they get the carrot slice to hover somewhere in the middle of the cup.

Materials needed for the demonstration
Water
Salt
2 Clear plastic cups
Plastic teaspoon
2 Carrot slices

Materials needed for each group
Water
Salt
Clear plastic cup
Plastic teaspoon
Carrot slice

Notes about the materials
- **Be sure you and the students wear properly fitting goggles.**
- One carrot will be more than enough for an entire class to do this activity.

Preparing materials
- Slice a carrot into round pieces about ½ cm thick. Each group will need only one slice. Test one carrot slice by placing it in a cup of water ahead of time. It should sink.

Activity sheet
Copy *Activity sheet 7.4—Changing the density of a liquid—Adding salt*, pp. 419–420, and distribute one per student when specified in the activity.

Assessment
An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.4
Changing the density of a liquid—Adding salt

Question to investigate

Can the density of a liquid be changed?

Demonstration

1. Do a demonstration to show students that a carrot slice sinks in fresh water but can float in salt water.

Procedure

1. As students watch, pour ⅔ cup of fresh water into 2 clear plastic cups. Place 1 similar-sized carrot slice in each cup. The carrot slices will sink.

2. Add about 1 teaspoon of salt to one of the cups and stir. The carrot should begin to rise. Continue adding salt and stirring until the carrot floats to the top and stays there.

Expected results: **The carrot slice in the salt water floats, while the carrot slice in the fresh water sinks.**

2. Ask students what this demonstration tells them about density.

Ask students questions like the following:

- Before I added salt to the water, how did the density of the carrot compare with the density of the water?
- What happened to the density of the water as salt was added?
- What can you conclude about the weight of a carrot slice compared with the weight of an equal volume of fresh water? Salt water?

Since the carrot sinks in fresh water, the density of the carrot must be greater than the density of the fresh water. Students should suggest that adding salt to the water increases the density of the water and causes the carrot to float. Since the carrot sinks in fresh water, a carrot slice must weigh more than an equal volume of fresh water. Since the carrot floats in salt water, it must be less dense than salt water. Therefore, a carrot slice must weigh *less* than an equal volume of salt water.

3. Challenge students to make a carrot slice “hover” in a cup of salt water.

Tell students that they can make a carrot slice “hover” in the middle of a cup of salt water. By adding small amounts of salt and fresh water, they can adjust the density of the water so that the carrot doesn’t float or sink, but “hovers” in the water.

Distribute *Activity sheet 7.4—Changing the density of a liquid—adding salt.*

Procedure

1. Half-fill a tall clear plastic cup with room-temperature water.
2. Place a slice of carrot in the cup. It should sink because it is more dense than water.
3. Add about 1 teaspoon of salt and stir with a spoon until as much salt dissolves as possible.

4. Continue adding salt and stirring until the carrot floats to the top.
5. Very carefully add fresh water to the top of the salt water until the carrot begins to sink.
6. If the carrot sinks to the bottom, add small amounts of salt and fresh water as needed to cause it to hover.

4. Have students discuss their procedures and results.

The carrot slice will hover when the density of the salt water and the density of the carrot slice are about the same.

Ask students what affects whether something will sink or float in a liquid. Students should realize that whether or not something sinks or floats in a liquid will depend on its density compared to the density of the liquid.

Student activity sheet
Activity 7.4

Name: ______________________________

Changing the density of a liquid—Adding salt

Can the density of a liquid be changed?

Procedure

1. Half-fill a tall clear plastic cup with room-temperature water.

2. Place a slice of carrot in the cup.

Does the carrot slice float or sink? ____

What does this say about the density of the carrot slice compared to the density of water?

____

____

____

3. Add about 1 teaspoon of salt and stir with a spoon until as much salt dissolves as possible.

4. Continue adding salt and stirring until the carrot floats to the top.

Does the carrot slice float or sink at this point? _________________

What does this say about the density of the carrot slice compared to the density of this salt water?

____

____

____

5. Very carefully add fresh water to the top of the salt water until the carrot begins to sink.

6. If the carrot sinks to the bottom, add small amounts of salt and fresh water as needed to cause it to hover.

Student activity sheet

Name: ______________________________

Activity 7.4

Changing the density of a liquid—Adding salt (*continued*)

1. Once your carrot slice is hovering, what do you know about the density of the carrot slice compared to the density of this salt water?

   ____

   ____

2. Let's say that you tried the same activity with a piece of potato. If potato is more dense than carrot, would you need to dissolve more or less salt in the water to make the potato float?

   ____

   Explain your answer.

   ____

   ____

   ____

   ____

Activity 7.5
Changing the density of a liquid—Heating and cooling

Is there a difference in density between hot and cold water?

In *Activities 7.3* and *7.4,* students saw that different liquids have different densities. In this activity, students will investigate whether the temperature of water affects its density. Students will place colored hot and cold water in a cup of room-temperature water to see that cold water sinks while hot water floats. Then they will use this experience to suggest how colored hot and cold water should be stacked to prevent mixing.

Materials needed for each group

Room-temperature water
Hot water (colored yellow)
Cold water (colored blue)
2 Droppers
2 Clear plastic cups
2 Small cups

Materials needed for the demonstration

Room-temperature water
Hot water
Cold water
Yellow food coloring
Blue food coloring
Water-resistant card
2 Small jars
Coffee stirrer, straw, or spoon
Paper towels

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Either use a single playing card from a deck of cards or laminate an index card. The water-resistant card should completely fit over the opening of the jars.
- Be sure that the two jars have exactly the same-sized openings so that one jar can be inverted on top of the other with no gaps.

Preparing materials

- Label one small cup **hot water** and another **cold water**.
- Place one drop of yellow food coloring in the cup labeled "hot water".
- Place one drop of blue food coloring in the cup labeled "cold water".
- Immediately before distributing to students, place 2 tablespoons of hot and very cold water into the labeled cups.
- You may wish to practice the demonstration a couple of times before demonstrating for students.

Activity sheet

Copy *Activity sheet 7.5—Changing the density of a liquid—Heating and cooling,* pp. 424–426, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either "Good", "Satisfactory", or "Needs Improvement".

Activity 7.5
Changing the density of a liquid—Heating and cooling

Question to investigate

Is there a difference in density between hot and cold water?

1. Discuss with students their ideas about whether heating and cooling can affect the density of a substance.

Ask students if anyone has ever noticed that water at the bottom of a lake feels colder than water at the surface. Ask students if this temperature difference—warm water near the surface and cooler water down below—might have something to do with density. Since student experiences suggest that warm water floats on cooler water, maybe different temperatures of water have different densities and can form layers.

2. Have students place colored hot and cold water in colorless room-temperature water.

Distribute *Activity sheet 7.5—Changing the density of a liquid—Heating and cooling.*

Procedure

1. Fill 2 clear plastic cups about ⅔ of the way with room-temperature water.

2. Fill one dropper with cold water colored blue. Poke the end of the dropper a little beneath the surface of the colorless room-temperature water. While observing from the side, gently squeeze the dropper so that the cold water slowly flows into the room-temperature water.
3. Fill another dropper with hot water colored yellow. Poke the end of the dropper a little beneath the surface of the room-temperature water. While observing from the side, gently squeeze the dropper so that the hot water slowly flows into the room-temperature water.

4. In a separate cup of room-temperature water, push a dropper filled with hot yellow water to the bottom of the cup. While observing from the side, gently squeeze so that the hot water slowly flows into the room-temperature water.
5. Push a dropper filled with cold blue water to the bottom of the cup. While observing from the side, gently squeeze so that the cold water slowly flows into the room-temperature water.
6. Record your observations on the activity sheet.

Expected results:

Liquids placed just beneath the surface:
- **The cold blue water will flow down and collect at the bottom of the room-temperature water.**
- **The hot yellow water will collect at the surface.**

Liquids placed at the bottom:
- **The hot yellow water will flow up and collect at the surface.**
- **The cold blue water will collect at the bottom of the cup.**

3. Discuss student observations.

Ask students questions such as the following:

- What does your experiment say about the relative densities of hot, room-temperature, and cold water?
- Based on your observations, would you expect equal volumes of hot, room-temperature, and cold water to weigh the same?
- Which temperature of water would you expect to weigh the most?
- Which would you expect to weigh the least?
- Which would you expect to weigh somewhere in between?

Cold water is the most dense, hot water is the least dense, and room-temperature water is somewhere in-between. The weight of equal volumes of hot, room-temperature, and cold water is slightly different. Although these measurements are very difficult to make in a classroom setting, hot water weighs less than room-temperature water, and cold water weighs more than room-temperature water.

Demonstration

4. Do a demonstration to highlight the difference in density between hot and cold water.

Tell students that you are going to try to place one jar filled with colored water upside down over another one and that you want the colors to stay separate. Ask students if you should use hot and cold water to do this, or if the temperature of the water doesn't matter. Then ask students which temperature of water should be on the top and which should be on the bottom to improve the chances of the colors staying separate.

Procedure

1. Completely fill a baby food jar with hot tap water and 2 drops of yellow food coloring.
2. Completely fill another baby food jar with very cold water and add 2 drops of blue food coloring. Stir the water in both jars so that the coloring is well-mixed in both. Place the cold water jar on a paper towel.
3. Hold a water-resistant card, like a playing card or a laminated index card, over the top of the hot water jar.
4. While holding the card against the jar opening, carefully turn the jar upside down.
5. With the card still in place, position the jar of hot water directly over the jar of cold water so that the tops line up exactly.
6. Slowly and carefully remove the card so that the hot water jar sits directly on top of the cold water jar.

***Expected results*: Although removing the card may result in some mixing, for the most part, the hot yellow water will remain in the top jar and the cold blue water will remain in the bottom jar.**

Ask students to predict what would happen if you placed the cold blue water on top of the hot yellow water and then removed the card. Use the same procedure as above, but place the jar of cold water upside down over the jar of hot water. The colors will immediately mix, resulting in green water throughout.

Name: ______________________________

Student activity sheet

Activity 7.5

Changing the density of a liquid—Heating and cooling

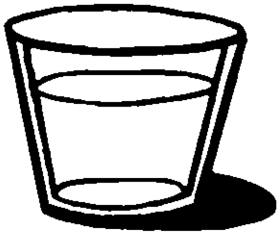
Is there a difference in density between hot and cold water?

Hot and cold just beneath the surface

Procedure

1. Fill 2 clear plastic cups about ⅔ of the way with room-temperature water.
2. Fill one dropper with cold water colored blue. Poke the end of the dropper a little beneath the surface of the colorless room-temperature water.
3. While observing from the side, gently squeeze the dropper so that the cold water slowly flows into the room-temperature water.

4. Fill another dropper with hot water colored yellow. Poke the end of the dropper a little beneath the surface of this same cup of room-temperature water.
5. While observing from the side, gently squeeze the dropper so that the hot water slowly flows into the room-temperature water.



1. Color in and label areas of this cup to show where the colored hot and cold water ended up after you released them into the room-temperature water.
2. Describe the movement of the hot and cold water after each liquid was released.

____

____

____

Hot and cold at the bottom of the cup

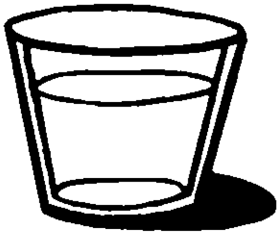
Procedure

1. In a separate cup of room-temperature water, push a dropper filled with yellow hot water to the bottom of the cup.

2. While observing from the side, gently squeeze so that the hot water slowly flows into the room-temperature water.

3. Push a dropper filled with blue cold water to the bottom of this same cup of room-temperature water.

4. While observing from the side, gently squeeze so that the cold water slowly flows into the room-temperature water.



3. Color in and label areas of this cup to show where the colored hot and cold water ended up after you released them into the room-temperature water.

4. Describe the movement of the hot and cold water after each liquid was released.

____

____

____

5. Which temperature of water is the *most* dense? ________________________________

   Which is the *least* dense? ____

Student activity sheet

Activity 7.5

Changing the density of a liquid—Heating and cooling (*continued*)

6. If you went scuba diving, would you expect the water temperature to get warmer or colder as you dove deeper beneath the surface?________________________________

   What evidence do you have from your experiment to support this?

   ____

   ____

   ____

7. During late fall and early winter, the water at the surface of a lake may suddenly get colder than the water below it. What do you think happens to this water?

   ____

   Use the word “density” to explain why this happens.

   ____

   ____

   ____

Activity 7.6
Changing the density of an object—Adding material

How can you make an object float when it ordinarily sinks?

In this activity, students see that a can of regular cola sinks while a can of diet cola floats. As a demonstration, bubble wrap is taped to the can of regular cola to make it float. This high-volume but light-weight material increases the volume of the object more than it increases the weight. This decreases the density enough for the can-and-bubble wrap object to float. Students will use this idea to make an object that is more dense than water float.

Materials needed for the demonstration

Water
Large clear plastic container
Can of regular cola
Can of diet cola
Bubble wrap
Scissors
Tape
Paper towel

Materials needed for each group

Small water-resistant item that sinks
Small water-resistant items that float like zip-closing plastic bags, styrofoam pieces, cork, empty film canisters with lids, etc.
Tape, rubber bands, string, etc.

Notes about the materials

- **Be sure you and the students wear properly fitting goggles.**
- Have students bring in small water-resistant items that sink such as plastic toy figures.
- The items students use to make their sinking objects float will vary. Either provide an assortment of materials or have students bring them from home.

Preparing materials

- Test your cans of regular and diet cola ahead of time by following the procedure on p. 428. The regular cola should sink, while the diet cola floats.

Activity sheet

Copy *Activity sheet 7.6—Changing the density of an object—Adding material*, pp. 430–431, and distribute one per student when specified in the activity.

Assessment

An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.6
Changing the density of an object—Adding material

Question to investigate

How can you make an object float when it ordinarily sinks?

Demonstration

1. Do a demonstration to show students that a can of regular cola sinks and a can of diet cola floats.

Procedure

1. Fill a large clear container about ¾ full of room-temperature water.

2. Holding the cans sideways, place a can of regular cola and a can of diet cola in the water.

Expected results: **The can of regular cola should sink and the can of diet cola should float.**

2. Discuss student observations.

Tell students that the cans are made of the same material and have the same volume and are filled with the same amount of soda.

Ask students questions such as the following:

- Why do you think one can sinks and the other floats?
- Since the volumes are the same, what must be different about the sodas?

Tell students that the mass of the regular soda is greater than the mass of the diet soda. The regular soda has 30–40 grams of sugar dissolved in it. The diet soda is sweetened with an artificial sweetener that takes many fewer grams to achieve a similar level of sweetness.

3. Discuss ways to get the can of regular cola to float.

Ask students how they might make the can of regular cola float without opening the can. Students may suggest shaking the can. This may cause some gas to come out of the solution, which would decrease the overall density if the gas could somehow make the can get bigger. Since the can won't expand, shaking the soda won't increase the volume of the can or decrease it's mass, so it won't affect the density. You may choose to shake the can and put it back in the water to show students that shaking will not affect density.

Students may suggest putting something on the can to increase its volume. Ask students if they can think of something that would add volume to the can but not add much weight. One procedure for making the can of regular soda float is suggested on the following page.

4. As a demonstration, add a high-volume but lightweight material to an object that ordinarily sinks in water to make it float.

Procedure

1. Use a paper towel to dry off the outside of the can of regular cola.
2. Cut a piece of bubble wrap so that it is as wide as the height of the can. The length of the bubble wrap should be just enough to go around the can once.
3. Wrap the bubble material around the can, and use tape to attach the wrap securely in place.
4. Place the can-and-bubble wrap object back in the water.

Expected results: **The object should float.**

5. Discuss why the can-and-bubble wrap object floats.

Ask students to use the terms *mass*, *volume*, and *density* to explain why adding the bubble wrap helped the can float. Be sure students understand that it is the *combined* mass and volume of the can and the bubble wrap that makes the can-and-bubble wrap object less dense than water so that it floats.

Tell students that life jackets work in a similar way. Ask students why a life jacket helps a person to float. Explain that a person wearing a life jacket floats because of the combination of the body and the life jacket is less dense than water.

Distribute *Activity sheet 7.6—Changing the density of an object—Adding material.*

6. Have students make an object float which ordinarily sinks.

Challenge students to make a small object, which ordinarily sinks, float. They can bring in small objects like plastic figures, marbles, or keys that sink. Either provide materials that float such as cork, zip-closing plastic bags, or styrofoam or have students bring them from home. Give students time to assemble their objects and test them in a container of water.

7. Discuss with students how adding volume without adding much weight makes the items float.

Have students explain how they made their objects float. Ask students what all of these floating objects have in common. Students should realize that mass is increased slightly, while volume is increased much more. When the density of this larger combined object is less than the density of water, it floats.

Student activity sheet

Name: ______________________________

Activity 7.6

Changing the density of an object—Adding material

How can you make an object float when it ordinarily sinks?

1. The can of regular soda pop sinks in water. What does this observation tell you about the density of the can of soda pop compared to the density of water?

____

____

____

2. The can of diet soda pop floats in water. What does this observation tell you about the density of the can of diet soda pop compared to the density of water?

____

____

____

3. Use the terms *weight*, *volume*, and *density* to explain why adding bubble wrap makes a can of regular soda pop float in water.

____

____

____

4. Explain why life jackets are made of lightweight material and are large.

____

____

____

Student activity sheet Name: ____________________________

Activity 7.6

Changing the density of an object—Adding material (*continued*)

How can you make an object float when it ordinarily sinks?

Procedure

1. Select an object like a marble, key, or plastic toy and place it a container of water to show that it sinks.
2. Add material to this object and test it in a container of water. Continue to add material and test until your object floats.

1. Draw and label your object and what you added to make it float.

2. Your object originally sunk in water. What can you say about the density of your object compared to the density of water?

____

____

____

3. After adding material your object floated. What can you say about the density of the object-and-material compared to the density of water?

____

____

____

____

4. Density is the relationship between the mass of an object and its volume.

   When you add material to your sinking object, what do you change more, mass or volume?

   ____

   How does increasing the volume of an object affect its density?

   ____

   ____

Activity 7.7
Changing the density of an object—Changing shape

Can changing the shape of an object affect whether it sinks or floats?

Throughout the activities in this investigation, students may have wondered how a boat made out of steel, which is more dense than water, can float. This activity addresses that question. Students will see that changing the shape of an object, like a clay ball, that is more dense than water, can affect whether the object will sink or float. The density of the clay used in this activity does not change, but the volume of the object made from the clay increases. This increase in volume decreases the overall density of the object, making it float.

Materials needed for the demonstration
Water
2 Clay balls
Plastic bowl
Sensitive scale

Materials needed for each group
Water
2 Clay balls
Clear plastic cup, deli container, or bowl

Notes about the materials
- **Be sure you and the students wear properly fitting goggles.**

Preparing materials
- Roll 2 balls of clay for the demonstration and for each group. The balls should be close in size, about 3 cm in diameter.

Activity sheet
Copy *Activity sheet 7.7—Changing the density of an object—Changing shape*, pp. 435–436, and distribute one per student when specified in the activity.

Assessment
An assessment rubric for evaluating student progress during this activity is on pp. 437–439. For this formative assessment, check a box beside each aspect of the activity to indicate the level of student progress. Evaluate overall progress for the activity by circling either “Good”, “Satisfactory”, or “Needs Improvement”.

Activity 7.7
Changing the density of an object—Changing shape

Question to investigate

Can changing the shape of an object affect whether it sinks or floats?

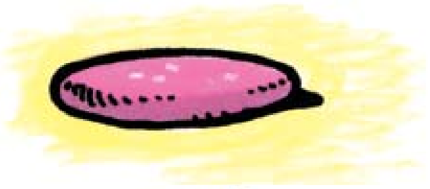
1. Introduce the idea that substances that are more dense than water can be made to float.

Tell students that most metal, like steel, sinks but that many big boats are made of out of steel. Explain that this activity will help students understand how something that is more dense than water can be made to float. Remind students that a lump of clay also sinks. Then ask students if they think changing the shape of clay might help make it float.

Demonstration

2. As a demonstration, make a clay box that will sink.

Procedure



1. Flatten one ball of clay into a small fat pancake shape about 5 cm or more in diameter.

2. Bend the edges up on the clay pancake to make a small thick-sided open box.

3. Add water to a plastic bowl until it is about ¾ full.

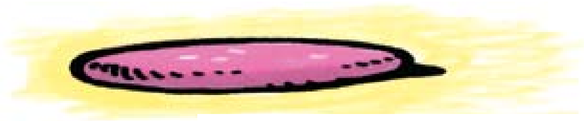
4. Slowly and carefully place the clay box on the surface of the water. It should sink.

5. Remove the clay box from the water and use a ruler to measure its length, width, and height in centimeters. Find the value for the volume (l × w × h) of the clay box and write it on the board. Your answer should be in cubic centimeters.

3. Have students make a clay "box" that floats.

Distribute *Activity sheet 7.7—Changing the density of an object—Changing shape*. Show students the small thick-sided clay box that they saw sink in water in the demonstration. Ask students if they think making the box bigger would make it float. Have students try making a larger box and seeing if it floats.

Procedure



1. Flatten one ball of clay into a large thin pancake shape about 10 cm or more in diameter.
2. Bend the edges up on the clay pancake to make a large shallow open box.
3. Add water to a plastic bowl until it is about ¾ full.
4. Slowly and carefully place your clay box on the surface of the water. It should float. If it does not float, remove it from the water and try increasing its volume again.

5. After you get the clay box to float, remove it from the water and use a ruler to measure its length, width, and height in centimeters. Find the value for the volume (l × w × h) and write it on the activity sheet. Your answer should be in cubic centimeters.

Expected results: **Students' larger thin-sided boxes should float. Their calculated volumes should be greater than the volume of the small thick-sided box used in the demonstration.**

4. Discuss student observations.

Ask students: Why did your clay box float better than mine? Students should realize that the larger volume of their box caused it to float.

Weigh (in grams) the small thick-sided clay box from the demonstration and calculate its density using density = mass/volume. Make a chart on the board and record the values for the density, mass, and volume of your clay box. Then weigh some of the students' clay boxes and record their masses and volumes in the chart. Have students calculate the densities of these clay boxes.

Expected results: **The density of the students' boxes should be less than yours. Theirs should be less than the density of water, which is 1 g/cm^3, while yours should be greater than the density of water.**

Ask students questions such as the following:

- What do you notice about the volume compared to the mass for the clay boxes that float in water?
- How is this relationship different than the volume and mass for the clay box used in the demonstration?
- Use what you know about density to explain why your clay box floats.
- Why do you think a heavy ship made out of steel can float?

Students should realize that clay boxes with a value for volume greater than the value for mass will float. Increasing the volume of the box without increasing the mass decreases the overall density of the object. When the density of an object is less than the density of water, it will float. Explain that the density of the clay itself doesn't change when it is reshaped, but the density of the clay box, as an object, does. This same idea can be used to explain why a heavy steel ship can float. Although the density of steel is greater than water, the steel is shaped so that the ship has a large volume. Increasing the volume decreases the density. The ship floats because the density of the ship is less than the density of water.

Student activity sheet Name: ______________________________

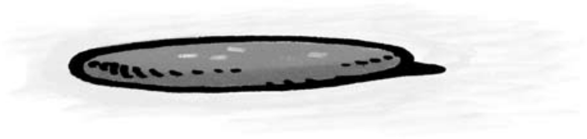
Activity 7.7

Changing the density of an object—Changing shape

Can changing the shape of an object affect whether it sinks or floats?

Procedure

1. Flatten one ball of clay into a large thin pancake shape about 10 cm or more in diameter.



2. Bend the edges up on the clay pancake to make a large shallow open box.

3. Add water to a plastic bowl until it is about ¾ full.

4. Slowly and carefully place your clay box on the surface of the water. It should float. If it does not float, remove the clay box from the water and try increasing its volume again.

5. Once your box floats, remove it from the water and use a ruler to measure its length, width, and height in centimeters. Find the value for the volume (l × w × h). Your answer should be in cubic centimeters.

Length _______________ cm

Width _______________ cm

Height _______________ cm

Volume _______________ cm^3

1. How does the volume of your clay box compare to the volume of the box your teacher made in the demonstration?

   ____

2. Use “volume” and “density” to explain why your clay box floats and your teacher’s clay box sinks?

   ____

   ____

   ____

Name: ______________________________

Changing the density of an object—Changing shape (*continued*)

3. In earlier experiments, you have seen substances that are more dense than water—like corn syrup, cold water, and a carrot slice—sink. A solid piece of aluminum is also more dense than water. However, aluminum is often used to build canoes. Based on what you now know, explain why a canoe made out of aluminum can float.

    ____

    ____

    ____

    ____

    ____

4. You learned that cold water sinks, but did you ever notice that *ice floats in water*? When water freezes, the ice that forms takes up more space than it did when it was liquid water. You can see this for yourself if you place a small plastic container full of water with a lid in the freezer. The ice that forms will expand and push the lid up. Knowing this unusual property of water, explain why ice floats in water. Use the terms *weight*, *volume*, and *density* in your explanation.

    ____

    ____

    ____

    ____

    ____

Investigation 7—Density

Assessment rubric

What causes a substance to sink or float in a liquid?

Activity 7.1—Defining density
Do heavy things always sink and light things always float?

G S N
☐ ☐ ☐ Recognizes that some heavy objects float and some light objects sink
☐ ☐ ☐ Uses the terms "more dense" and "less dense" to explain why a rock sinks and a heavier piece of wood floats
☐ ☐ ☐ Uses the water displacement method to find volumes of water equal to a piece of wood and a rock
☐ ☐ ☐ Explains the water displacement method for measuring volume
☐ ☐ ☐ Considers the density of water when explaining why an object sinks or floats

Circle one: Good Satisfactory Needs Improvement

Activity 7.2—Comparing the density of an object to the density of water
How can you predict whether an object will sink or float in water?

G S N
☐ ☐ ☐ Builds a balance to compare the mass of equal volumes of wax, clay, and water
☐ ☐ ☐ Uses evidence to predict whether wax and clay will float or sink in water
☐ ☐ ☐ Records observations
☐ ☐ ☐ Recognizes that substances that weigh more than an equal volume of water are more dense than water and sink
☐ ☐ ☐ Recognizes that substances that weigh less than an equal volume of water are less dense than water and float
☐ ☐ ☐ Infers that an ice cube on a balance would be lighter than an equal volume of water

Circle one: Good Satisfactory Needs Improvement

Activity 7.3—Comparing the density of different liquids
How do the densities of vegetable oil, water, and corn syrup help them to form layers in a cup?

G S N
☐ ☐ ☐ Plans with group which order to pour the liquids in a cup
☐ ☐ ☐ Uses evidence from floating and sinking liquids to infer their relative densities
☐ ☐ ☐ Builds and uses a balance to weigh equal volumes of vegetable oil, water, and corn syrup
☐ ☐ ☐ Records the weight of each liquid using nonstandard units
☐ ☐ ☐ Describes method of measuring equal volumes
☐ ☐ ☐ Uses results from weighing to order liquids from least to most dense
☐ ☐ ☐ Explains, in terms of density, why the liquids orient themselves in layers as they do
☐ ☐ ☐ Places objects in cup of layered liquids and records observations
☐ ☐ ☐ Infers the relative densities of objects based on evidence

Circle one: Good Satisfactory Needs Improvement

Investigation 7—Density

Assessment rubric (*continued*)

Activity 7.4—Changing the density of a liquid—Adding salt
Can the density of a liquid be changed?

G S N
☐ ☐ ☐ Records observations
☐ ☐ ☐ Infers that a carrot slice is more dense than water because it sinks
☐ ☐ ☐ Infers that a carrot slice is less dense than salt water because it floats
☐ ☐ ☐ Adds salt and water to make a carrot slice “hover”
☐ ☐ ☐ Applies experience to explain why more salt would be needed to make a more dense piece of potato float

Circle one: Good Satisfactory Needs Improvement

Activity 7.5—Changing the density of a liquid—Heating and cooling
Is there a difference in density between hot and cold water?

G S N
☐ ☐ ☐ Follows given procedures
☐ ☐ ☐ Records observations with labeled drawings
☐ ☐ ☐ Describes the movement of hot and cold water in room-temperature water
☐ ☐ ☐ Infers the relative densities of hot and cold water
☐ ☐ ☐ Uses evidence to infer why water is warmer at the surface of a lake and colder in deeper water
☐ ☐ ☐ Uses density to explain why cold water at the surface of a lake would sink

Circle one: Good Satisfactory Needs Improvement

Activity 7.6—Changing the density of an object—Adding material
How can you make an object float when it ordinarily sinks?

G S N
☐ ☐ ☐ Recognizes that regular soda sinks because it is more dense than water
☐ ☐ ☐ Recognizes that diet soda floats because it is less dense than water
☐ ☐ ☐ Explains that adding bubble wrap increases volume, which decreases the overall density
☐ ☐ ☐ Applies observation to explain the light weight and large volume of life jackets
☐ ☐ ☐ Adds material to a sinking object to make it float
☐ ☐ ☐ Describes floating object-and-material with drawings and labels
☐ ☐ ☐ Uses the comparative densities of water and the object-and-material to to explain why it floats.

Circle one: Good Satisfactory Needs Improvement

Investigation 7—Density

Assessment rubric (*continued*)

Activity 7.7—Changing the density of an object—Changing shape

Can changing the shape of an object affect whether it sinks or floats?

G S N
☐ ☐ ☐ Follows given procedure
☐ ☐ ☐ Measures clay box in centimeters and calculates its volume
☐ ☐ ☐ Explains why the larger-volume clay box floats while the smaller-volume one sinks
☐ ☐ ☐ Explains why a boat made out of a material more dense than water can be made to float
☐ ☐ ☐ Uses idea of *increasing volume* to explain why ice floats in water

Circle one: Good Satisfactory Needs Improvement

To earn a “**B**”, a student must receive a “Good” in each category.

To earn an “**A**”, a student must also exhibit some of the following qualities throughout this investigation.

☐ Writes outstanding explanations
☐ Possess a well-developed understanding of variables and how to control them
☐ Participates well in class discussions
☐ Participates well in group work
☐ Uses scientific thinking
☐ Consistently exhibits exceptional thought and effort in tasks
☐ Other: ______________________________________

Teacher instructions

Review and apply

The following section, titled *Review and apply,* contains activities, worksheets, and information that can serve as a summative assessment. Once students have completed the activities in *Investigation 7,* they will reflect on their learning, apply what they learned about density to a new activity, and identify the role of density in real-life applications. An optional reading explains the meaning of actual quantitative values for density. Answers to the worksheet questions for this section are available at **www.inquiryinaction.org**

Let's review

1. Review with students what they learned in the density investigation.

Distribute *Review and apply: Let's Review*, pp. 442–443, and give students an opportunity to answer questions about the activities. Students will use what they remember from their experiments and what they have learned about density to explain why objects sink or float in water. Students will also make predictions based on the results from their experiments.

Science in action!

2. Have students compare how an ice cube floats in water, vegetable oil, and mineral oil.

Ask students which is more dense, hot water or cold water. Students should remember from *Activity 7.5* that hot water floats in room-temperature water while cold water sinks. This means that cold water is more dense. Then ask students if *ice* floats or sinks. Students may need to think of examples like ice cubes in a cup of water, ice skating on a pond or lake, ice fishing, or partly frozen puddles with a layer of ice on top to realize that ice floats on water. It may seem odd that cold water sinks while even colder ice floats. Explain that this is a very unusual property of water—the solid (ice) floats on the liquid (water). Ask students if they think ice is more or less dense than water. Students should realize that ice is less dense than water and this is why it floats.

Distribute activity sheet, *Review and apply: Science in action!*, pp. 444–445, along with 3 labeled clear plastic cups half-filled with water, vegetable oil, and mineral oil, and 3 ice cubes. Tell students that first they will use the way an ice cube floats to compare the densities of water, vegetable oil, and mineral oil.

3. Discuss student observations.

Ask students to share the results of their experiments and their conclusions with questions like the following:

- Which is the most dense, water, vegetable oil, or mineral oil?
- Which is the least dense, water, vegetable oil, or mineral oil?
- How did the ice cube help you compare the densities of the liquids?

Students should reason that water is the most dense because ice floats highest in water compared to the the vegetable oil. Mineral oil is the least dense because ice floats lowest in it.

4. Have students predict how water, vegetable oil, and mineral oil would layer themselves in a cup and do a demonstration to find out whether students are correct.

Ask students whether they think water, vegetable oil, and mineral oil would form layers if they were poured into one cup. Explain that the vegetable and mineral oils might mix, so it is important that the liquids are poured in the order of most dense to least dense. Ask students which liquid should be poured first, second, and third to improve the chances of getting the liquids to form layers.

Then as a demonstration, carefully pour about ¼ of a cup of water into a clear plastic cup. Add a similar amount of vegetable oil. Then carefully pour a similar amount of mineral oil. You may need to place a dark piece of paper behind the cup to help students see the layers.

Think about it

5. Have students read about some common applications of density.

Distribute *Review and apply: Think about it*, pp. 446–449. Ask students what people use to help them float in water. Then ask students to describe the mass and volume of these devices. Students should realize that wearing a life jacket or hanging on to a float adds more volume than mass. Tell students that they will read about water wings, life jackets, swim bladders in bony fish, and ballast tanks in submarines to learn how changes in mass and volume can affect floating and sinking.

For additional information about flotation go to
www.inquiryinaction.org

What’s going on here? (*optional*)

Molecular explanations for students

If you think the content is developmentally appropriate for your students, have them read about how density is calculated and what these values mean in terms of sinking and floating in water.

Distribute *Review and apply: What’s going on here?*, pp. 450–452. This reading explains how density is calculated and gives values for the density of some common substances. By comparing the actual values for the density of different substances to the density of water, students can determine which substances will float and which will sink.

Material to support this reading can be found at
www.inquiryinaction.org

Name: ____________________________

Let’s review

At the beginning of this investigation, a student was wondering why a heavy wooden log floats and lighter rocks sink.

1. If he was able to weigh a volume of water equal to the volume of the log, which would weigh more, the water or the log? ____________________________________

   Explain your answer.

   ____

   ____

   ____

2. When you compared the weight of wax to an equal volume of water on your ruler balance, you saw that the water weighed more than the wax. Which was more dense, the wax or the water? ____

3. If you had an enormous piece of wax the size of a house, do you think it would float or sink if it was placed in water like in a lake or huge swimming pool? Explain your reasoning.

   ____

   ____

   ____

4. Each liquid has its own density. Let’s say that you had two liquids and needed to know which one was more dense than the other. You could carefully pour both liquids into a cup and see if one layered on top of or beneath the other.

   What is another way to find out which liquid is more dense than the other?

   ____

   ____

   ____

Let’s review (*continued*)

5. A carrot slice sinks in fresh water and floats in salt water.

   If you put a carrot slice on one end of a balance and an equal volume of *water* on the other end, what would you expect the balance to do?

   ____
   ____

   If you put a carrot slice on one end of a balance and an equal volume of *salt water* on the other end, what would you expect the balance to do?

   ____
   ____

6. Hot water is less dense than cold water. Let’s say you had a sample of hot water and a sample of cold water and they had exactly the same weight. Which one would have more volume?

   ____

   Explain.

   ____
   ____
   ____

7. Explain why adding volume can make an object float that ordinarily sinks.

   ____
   ____
   ____
   ____

Review and apply worksheet Name: ___________________________

Science in action!

How can you use an ice cube to compare the density of water, vegetable oil, and mineral oil?

The density of water is an important factor that affects whether a substance sinks or floats. You have seen that the density of water changes when it is heated and cooled. Hot water is less dense than room-temperature water and cold water is more dense. But when water gets cold enough and freezes to form ice, it becomes less dense than liquid water. That's why ice floats on water.

Ice can float in other liquids, too. If you wanted to compare the density of different liquids, you could place an ice cube in them. The higher the ice floats in the liquid (more ice above the surface of the liquid), the more dense the liquid. The lower the ice floats (less ice above the surface of the liquid), the less dense the liquid.

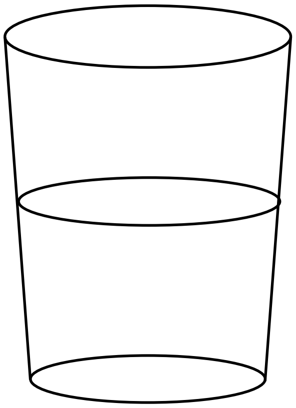
Procedure

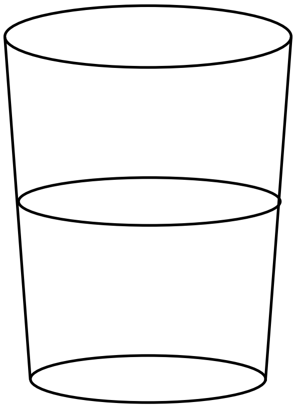
1. Half-fill 3 clear plastic cups with water, vegetable oil, and mineral oil.

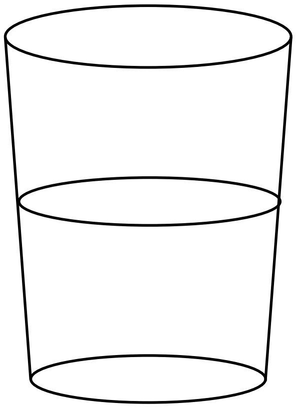
2. At the same time, gently place an ice cube in the liquid in each cup.

3. Look from the side to see which ice cube seems to be floating higher in its liquid.

1. Draw and label what you see in each cup. Be sure to compare the level the ice cube floats in each liquid.


Water


Vegetable oil


Mineral oil

Name: ____________________________

Science in action! (*continued*)

2. The level an ice cube floats in different liquids can help you compare the density of the liquids.

   What do you know about the density of the liquid if the ice cube floats high in the water?

3. Based on your observations, rank the three liquids from most dense to least dense.

4. Do you think water, vegetable oil, and mineral oil could form layers if they are carefully poured in a cup? ______________________________

   Why do you think that?

5. In what order should water, vegetable oil, and mineral oil be poured to get them to form layers in a cup? **Hint:** In order to prevent mixing, the most dense liquid should be poured first.

Name: ______________________________

Think about it

Vocabulary
density
bladder
ballast

Did you ever wonder how water wings help a little kid float? Water wings are those inflatable "doughnuts" filled with air and worn on each arm. They take up a lot of space (volume) but are not very heavy. These wings can increase the volume of the person without adding much to the person's mass. When the volume is increased without much increase in mass, the person and the wings together have a better chance of floating. The relationship between mass and volume that affects sinking and floating is called *density*. An object that has a large volume compared to its mass has a low density. An object that has a large mass compared to its volume has a higher density.

If an object is less dense than water, it floats. If it is more dense than water, it sinks. With the water wings on and filled with air, the person and wings together are less dense than the water, and therefore float. If the person takes off the water wings, the person's volume decreases, but they still have about the same mass. This means that the person becomes more dense and had better know how to swim!

A life jacket works in a similar way. A life jacket is filled with a very light foam material. If you've ever worn one, you know the life jacket increases your volume but doesn't increase your mass by much. This causes the person and the life jacket together to be less dense than water, and therefore float.

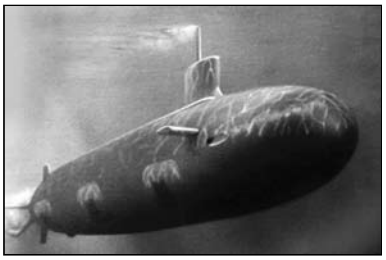
Fish also need a way to help them float or sink. Many fish have a special balloon-like bladder in their bodies to help them adjust their depth in the water. This built-in swim bladder keeps the fish at the right depth so it doesn't have to waste energy keeping itself in place. Gas in the fish's blood can move into the bladder to increase the bladder's volume or move out of the bladder to decrease the volume. When the fish swims down into deeper water, gas moves out of the

Name: ____________________________

Think about it (*continued*)

swim bladder. This decreases the volume of the bladder and the entire fish. This decrease in volume *increases* the density of the fish and helps it stay down in deeper water. When the fish rises to the surface, gas moves into the swim bladder. This increases the volume of the bladder and the entire fish. This increase in volume *decreases* the density of the fish and helps it stay closer to the surface. Some fish such as sharks don't have swim bladders at all. To help keep itself at the correct depth, sharks have large oily livers, which are less dense than water and specially shaped fins, which they use for adjusting their depth in the water.

People usually float better when they take a deep breath and hold it. When they do, they fill their lungs with air and their chests expand. This increases their volume which decreases their density and helps them float. When they exhale, their volume decreases, they become more dense, and they tend to sink.



Submarines can also control their sinking and floating. But instead of taking in and releasing gas, submarines take in and release sea water. Submarines are built with special tanks called *ballast* tanks. Submarines can sink, rise, and float by adjusting the amount of water and air in these tanks. The sub is built so when the tanks are full of air, the sub's volume and mass make it float. When the ballast tanks are filled with sea water instead of air, the sub has the same volume as before, but greater mass. This increases the sub's density and makes it sink. To rise again, the sub reduces its mass by pushing the sea water out. Now the sub has the same volume but less mass. This decreases the sub's density and the sub moves up toward the surface. To stay at a particular depth below the surface, enough water is brought into the tanks so that the density of the sub is equal to the density of the water surrounding it.

Think about it (*continued*)

1. Which of the following is the best summary of this passage?
   a. Water wings and life jackets can help you float.
   b. Life jackets increase your volume quite a bit without increasing your mass very much.
   c. Fish, life jackets, and submarines all can float.
   d. Density is a relationship between mass and volume, which explains why things sink or float.

2. When kids wear water wings, their…
   a. mass increases quite a bit and volume increases quite a bit.
   b. mass decreases slightly and volume increases quite a bit.
   c. mass increases slightly and volume increases quite a bit.
   d. mass and volume both stay the same.

3. Gas moves into or out of a fish's swim bladder to…
   a. help the fish swim faster.
   b. help the fish stay at the right depth in the water.
   c. help the fish get more worms from fishing hooks.
   d. help the fish increase its mass.

4. In the first paragraph, the word *volume* refers to…
   a. how heavy something is.
   b. how much space something takes up.
   c. how dense you are in water.
   d. how well you can float.

5. When you inhale and hold your breath, you float more easily because…
   a. your mass decreases.
   b. your volume increases.
   c. your volume and mass both decrease.
   d. your volume stays the same.

6. Submarines take in or release sea water from their ballast tanks to…
   a. enable them to become more or less dense than the surrounding water.
   b. bring water in for the people inside the submarine to drink.
   c. clean the sea water of pollution.
   d. move faster in the ocean.

Think about it (*continued*)

7. Most wood floats in water but samples of a type of wood called ebony can sink. Based on the reading, what would you say about the density of this sinking wood compared to the density of water?

____

____

____

____

8. Almost all rocks sink but a type of rock called pumice floats. Based on the reading, what would you say about the density of this floating rock compared to the density of water?

____

____

____

____

9. If a fish with a swim bladder needs to go deeper in the water, explain how the swim bladder helps the fish stay in deeper water.

____

____

____

____

____

10. If a submarine is far under water and needs to rise toward the surface, explain how ballast tanks are used to help the submarine go up.

____

____

____

____

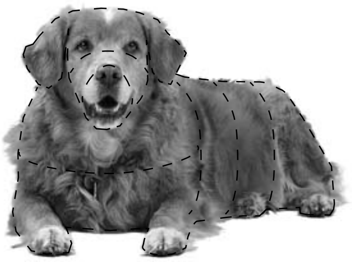
____

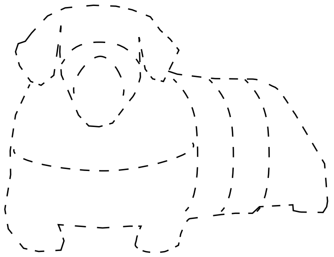
Review and apply worksheet Name: ____________________________

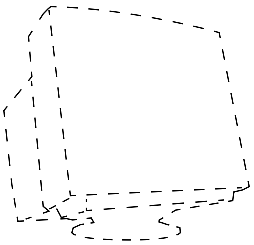
What's going on here?

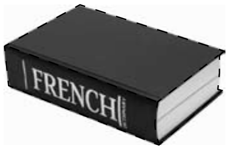
One of the common definitions of matter is that matter has mass and takes up space. Let's first look at *mass*. There can be some confusion about the difference between "mass" and "weight". Mass is a measure of the amount of matter in an object. Weight is a measure of the force of gravity on an object of a certain mass. So if we could move an object from Earth to the moon, for example, where there is less gravity, its mass would stay the same but its weight would be less. Since mass and weight are directly related, if one object has more mass than another, it will also weigh more. If one object has less mass than another, it will weigh less.

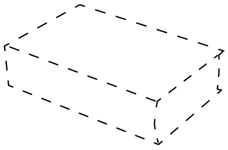
So matter has mass and also takes up space. The measure of the amount of space an object takes up is called *volume*. When you think of the volume of an object, you can think about its overall shape or the amount of space it takes up in three dimensions. These pictures show the idea that every object has volume that takes up 3-dimensional space.

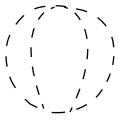


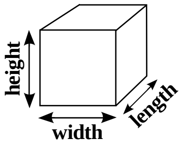












A common way to measure the volume of a cube, for example, is length × width × height. If the cube is 1 centimeter long, 1 cm wide, and 1 cm high, then the volume of the cube is 1 cm × 1 cm × 1 cm = 1 cm^3 and takes up 1 cm^3 of space.

So what is density? Density has to do with both mass and volume. Density is a measure of the amount of mass in a certain amount of volume.

The formula for density is D = mass/volume. For example, if the cube above was a solid cube of clay and had a mass of 2 grams, its density would be 2 grams/cm^3. What if you used more clay to make a bigger cube?

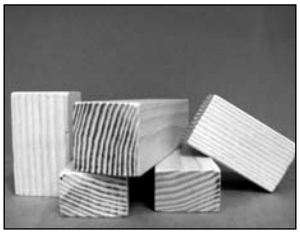
What's going on here? (*continued*)

If the cube was 2 cm long, 2 cm wide, and 2 cm high, then the volume of the cube is 2 cm × 2 cm × 2 cm = 8 cm^3. What would be the density of this bigger cube? If you weighed this cube, you would find that it weighs 16 grams. Since the mass is 16 grams and the volume is 8 cm^3, the density of this clay cube is 16 grams/8 cm^3 = 2 grams/cm^3. Whether you have a big or small solid piece of clay, the clay will always have the same density—it will always be 2 grams/cm^3. That's why density is considered a characteristic property of a substance.

The density of substances such as iron, salt, or sugar is determined by the mass of the atoms, ions, or molecules that make up the substance and how closely they are packed together. The same is true for all other substances. A piece of pine wood has a density of about 0.55 grams/cm^3. Whether it is a small piece of pine or the entire tree trunk, the density of both will be the same. Lead has a density of about 11.30 grams/cm^3. Whether you have a tiny piece of lead or a gigantic piece of lead, the density of both will be the same.

Here are some examples of approximate densities of some common substances:

Wood (pine)	0.55 grams/cm^3
Wax (tealight candle)	0.75 grams/cm^3
Vegetable oil	0.85 grams/cm^3
Water	1.00 grams/cm^3
Clay	2.00 grams/cm^3
Iron	7.90 grams/cm^3
Lead	11.30 grams/cm^3


Wood


Vegetable oil


Clay


Wax

Name: ____________________________

What's going on here? (*continued*)

One way to find out whether a substance will float or sink in a liquid is to compare the density of the substance to the density of the liquid. If the substance is less dense than the liquid, the substance will float. If the substance is more dense than the liquid, the substance will sink. You can answer some questions related to density and sinking and floating below.

1. Of the substances listed, which ones will float in water and which will sink?

   ____

   ____

   ____

   ____

2. Mineral oil has a density of about .8 grams/cm^3. What substances from the list on p. 451 will float or sink in mineral oil?

   ____

   ____

   ____

   ____

3. The metal iron has a density of about 7.9 g/cm^3.
   What is the density of a solid cube of iron that is 2 cm long, 2 cm wide, and 2 cm high?

   ____

   What is the density of a solid cube of iron that is 10 cm long, 10 cm wide, and 10 cm high?

   ____

Cool factoid

The Dead Sea is a body of water in the Middle East that is extremely salty. The water has different amounts of salt dissolved in it depending on the depth. The saltiest water is near the bottom and is about 9 times as salty as normal ocean water but the water at the surface is very salty, too. The water is so salty that no fish or plants can survive in it. Its high salt content makes the water very dense so floating in the Dead Sea is very easy.

Appendix

National Science Education Standards

Content Standards: K–4...454
Science as Inquiry 454
Physical Science..456

Content Standards: 5–8...458
Science as Inquiry...458
Physical Science..461

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Inquiry and the National Science Education Standards: A Guide for Teaching and Learning

Frequently asked questions about inquiry 463

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Content Standards: K–4

Science as Inquiry

CONTENT STANDARD A:
As a result of activities in grades K–4, all students should develop

- **Abilities necessary to do scientific inquiry**
- **Understandings about scientific inquiry**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

From the earliest grades, students should experience science in a form that engages them in the active construction of ideas and explanations and enhances their opportunities to develop the abilities of doing science. Teaching science as inquiry provides teachers with the opportunity to develop student abilities and to enrich student understanding of science. Students should do science in ways that are within their developmental capabilities. This standard sets forth some abilities of scientific inquiry appropriate for students in grades K–4.

In the early years of school, students can investigate earth materials, organisms, and properties of common objects. Although children develop concepts and vocabulary from such experiences, they also should develop inquiry skills. As students focus on the processes of doing investigations, they develop the ability to ask scientific questions, investigate aspects of the world around them, and use their observations to construct reasonable explanations for the questions posed. Guided by teachers, students continually develop their science knowledge. Students should also learn through the inquiry process how to communicate about their own and their peers' investigations and explanations.

There is logic behind the abilities outlined in the inquiry standard, but a step-by-step sequence or scientific method is not implied. In practice, student questions might arise from previous investigations, planned classroom activities, or questions students ask each other. For instance, if children ask each other how animals are similar and different, an investigation might arise into characteristics of organisms they can observe.

Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others. In elementary grades, students begin to develop the physical and intellectual abilities of scientific inquiry. They can design investigations to try things to see what happens—they tend to focus on concrete results of tests and will entertain the idea of a "fair" test (a test in which only one variable at a time is changed). However, children in K–4 have difficulty with experimentation as a process of testing ideas and the logic of using evidence to formulate explanations.

GUIDE TO THE CONTENT STANDARD
Fundamental abilities and concepts that underlie this standard include

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

ASK A QUESTION ABOUT OBJECTS, ORGANISMS, AND EVENTS IN THE ENVIRONMENT. This aspect of the standard emphasizes students asking questions that they can answer with scientific knowledge, combined with their own observations. Students should answer their questions by seeking information from reliable sources of scientific information and from their own observations and investigations.

PLAN AND CONDUCT A SIMPLE INVESTIGATION. In the earliest years, investigations are largely based on systematic observations. As students develop, they may design and conduct simple experiments to answer questions. The idea of a fair test is possible for many students to consider by fourth grade.

EMPLOY SIMPLE EQUIPMENT AND TOOLS TO GATHER DATA AND EXTEND THE SENSES.
In early years, students develop simple skills, such as how to observe, measure, cut, connect, switch, turn on and off, pour, hold, tie, and hook. Beginning with simple instruments, students can use rulers to measure the length, height, and depth of objects and materials; thermometers to measure temperature; watches to measure time; beam balances and spring scales to measure weight and force; magnifiers to observe objects and organisms; and microscopes to observe the finer details of plants, animals, rocks, and other materials. Children also develop skills in the use of computers and calculators for conducting investigations.

USE DATA TO CONSTRUCT A REASONABLE EXPLANATION. This aspect of the standard emphasizes the students' thinking as they use data to formulate explanations. Even at the earliest grade levels, students should learn what constitutes evidence and judge the merits or strength of the data and information that will be used to make explanations. After students propose an explanation, they will appeal to the knowledge and evidence they obtained to support their explanations. Students should check their explanations against scientific knowledge, experiences, and observations of others.

COMMUNICATE INVESTIGATIONS AND EXPLANATIONS. Students should begin developing the abilities to communicate, critique, and analyze their work and the work of other students. This communication might be spoken or drawn as well as written.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

- Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.
- Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).
- Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.
- Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations.
- Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.
- Scientists review and ask questions about the results of other scientists' work.

Physical Science

CONTENT STANDARD B:
As a result of the activities in grades K–4, all students should develop an understanding of
- **Properties of objects and materials**
- **Position and motion of objects**
- **Light, heat, electricity, and magnetism**

DEVELOPING STUDENT UNDERSTANDING

During their early years, children's natural curiosity leads them to explore the world by observing and manipulating common objects and materials in their environment. Children compare, describe, and sort as they begin to form explanations of the world. Developing a subject-matter knowledge base to explain and predict the world requires many experiences over a long period. Young children bring experiences, understanding, and ideas to school; teachers provide opportunities to continue children's explorations in focused settings with other children using simple tools, such as magnifiers and measuring devices.

Physical science in grades K–4 includes topics that give students a chance to increase their understanding of the characteristics of objects and materials that they encounter daily. Through the observation, manipulation, and classification of common objects, children reflect on the similarities and differences of the objects. As a result, their initial sketches and single-word descriptions lead to increasingly more detailed drawings and richer verbal descriptions. Describing, grouping, and sorting solid objects and materials is possible early in this grade range. By grade 4, distinctions between the properties of objects and materials can be understood in specific contexts, such as a set of rocks or living materials.

Young children begin their study of matter by examining and qualitatively describing objects and their behavior. The important but abstract ideas of science, such as atomic structure of matter and the conservation of energy, all begin with observing and keeping track of the way the world behaves. When carefully observed, described, and measured, the properties of objects, changes in properties over time, and the changes that occur when materials interact provide the necessary precursors to the later introduction of more abstract ideas in the upper grade levels.

Students are familiar with the change of state between water and ice, but the idea of liquids having a set of properties is more nebulous and requires more instructional effort than working with solids. Most students will have difficulty with the generalization that many substances can exist as either a liquid or a solid. K–4 students do not understand that water exists as a gas when it boils or evaporates; they are more likely to think that water disappears or goes into the sky. Despite that limitation, students can conduct simple investigations with heating and evaporation that develop inquiry skills and familiarize them with the phenomena.

Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others.

When students describe and manipulate objects by pushing, pulling, throwing, dropping, and rolling, they also begin to focus on the position and movement of objects: describing location as up, down, in front, or behind, and discovering the various kinds of motion and forces required to control it. By experimenting with light, heat, electricity, magnetism, and sound, students begin to understand that phenomena can be observed, measured, and controlled in various ways. The children cannot understand a complex concept such as energy. Nonetheless, they have intuitive notions of energy—for example, energy is needed to get things done; humans get energy from food. Teachers can build on the intuitive notions of students without requiring them to memorize technical definitions.

Sounds are not intuitively associated with the characteristics of their source by younger K–4 students, but that association can be developed by investigating a variety of concrete phenomena toward the end of the K–4 level. In most children's minds, electricity begins at a source and goes to a target. This mental model can be seen in students' first attempts to light a bulb using a battery and wire by attaching one wire to a bulb. Repeated activities will help students develop an idea of a circuit late in this grade range and begin to grasp the effect of more than one battery. Children cannot distinguish between heat and temperature at this age; therefore, investigating heat necessarily must focus on changes in temperature.

As children develop facility with language, their descriptions become richer and include more detail. Initially no tools need to be used, but children eventually learn that they can add to their descriptions by measuring objects—first with measuring devices they create and then by using conventional measuring instruments, such as rulers, balances, and thermometers. By recording data and making graphs and charts, older children can search for patterns and order in their work and that of their peers. For example, they can determine the speed of an object as fast, faster, or fastest in the earliest grades. As students get older, they can represent motion on simple grids and graphs and describe speed as the distance traveled in a given unit of time.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

PROPERTIES OF OBJECTS AND MATERIALS

- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Those properties can be measured using tools, such as rulers, balances, and thermometers.
- Objects are made of one or more materials, such as paper, wood, and metal. Objects can be described by the properties of the materials from which they are made, and those properties can be used to separate or sort a group of objects or materials.
- Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating or cooling.

POSITION AND MOTION OF OBJECTS

- The position of an object can be described by locating it relative to another object or the background.
- An object's motion can be described by tracing and measuring its position over time.
- The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the strength of the push or pull.
- Sound is produced by vibrating objects. The pitch of the sound can be varied by changing the rate of vibration.

LIGHT, HEAT, ELECTRICITY, AND MAGNETISM

- Light travels in a straight line until it strikes an object. Light can be reflected by a mirror, refracted by a lens, or absorbed by the object.
- Heat can be produced in many ways, such as burning, rubbing, or mixing one substance with another. Heat can move from one object to another by conduction.
- Electricity in circuits can produce light, heat, sound, and magnetic effects. Electrical circuits require a complete loop through which an electrical current can pass.
- Magnets attract and repel each other and certain kinds of other materials.

Content Standards: 5–8

Science as Inquiry

CONTENT STANDARD A:
As a result of activities in grades 5–8, all students should develop

- **Abilities necessary to do scientific inquiry**
- **Understandings about scientific inquiry**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

Students in grades 5–8 should be provided opportunities to engage in full and in partial inquiries. In a full inquiry students begin with a question, design an investigation, gather evidence, formulate an answer to the original question, and communicate the investigative process and results. In partial inquiries, they develop abilities and understandings of selected aspects of the inquiry process. Students might, for instance, describe how they would design an investigation, develop explanations based on scientific information and evidence provided through a classroom activity, or recognize and analyze several alternative explanations for a natural phenomenon presented in a teacher-led demonstration.

Students in grades 5–8 can begin to recognize the relationship between explanation and evidence. They can understand that background knowledge and theories guide the design of investigations, the types of observations made, and the interpretations of data. In turn, the experiments and investigations students conduct become experiences that shape and modify their background knowledge.

With an appropriate curriculum and adequate instruction, middle-school students can develop the skills of investigation and the understanding that scientific inquiry is guided by knowledge, observations, ideas, and questions. Middle-school students might have trouble identifying variables and controlling more than one variable in an experiment. Students also might have difficulties understanding the influence of different variables in an experiment—for example, variables that have no effect, marginal effect, or opposite effects on an outcome.

Teachers of science for middle-school students should note that students tend to center on evidence that confirms their current beliefs and concepts (i.e., personal explanations), and ignore or fail to perceive evidence that does not agree with their current concepts. It is important for teachers of science to challenge current beliefs and concepts and provide scientific explanations as alternatives.

Several factors of this standard should be highlighted. The instructional activities of a scientific inquiry should engage students in identifying and shaping an understanding of the question under inquiry. Students should know what the question is asking, what background knowledge is being used to frame the question, and what they will have to do to answer the question. The students' questions should be relevant and meaningful for them. To help focus investigations, students should frame questions, such as "What do we want to find out about…?", "How can we make the most accurate observations?", "Is this the best way to answer our questions?", and "If we do this, then what do we expect will happen?"

Students in grades 5–8 can begin to recognize the relationship between explanation and evidence.

The instructional activities of a scientific inquiry should involve students in establishing and refining the methods, materials, and data they will collect. As students conduct investigations and make observations, they should consider questions such as "What data will answer the question?" and "What are the best observations or measurements to make?" Students should be encouraged to repeat data-collection procedures and to share data among groups.

In middle schools, students produce oral or written reports that present the results of their inquiries. Such reports and discussions should be a frequent occurrence in science programs. Students' discussions should center on questions, such as "How should we organize the data to present the clearest answer to our question?", "How should we organize the evidence to present the clearest answer to our question?", or "How should we organize the evidence to present the strongest explanation?" Out of the discussions about the range of ideas, the background knowledge claims, and the data, the opportunity arises for learners to shape their experiences about the practice of science and the rules of scientific thinking and knowing.

The language and practices evident in the classroom are an important element of doing inquiries. Students need opportunities to present their abilities and understanding and to use the knowledge and language of science to communicate scientific explanations and ideas. Writing, labeling drawings, completing concept maps, developing spreadsheets, and designing computer graphics should be a part of the science education. These should be presented in a way that allows students to receive constructive feedback on the quality of thought and expression and the accuracy of scientific explanations.

This standard should not be interpreted as advocating a "scientific method." The conceptual and procedural abilities suggest a logical progression, but they do not imply a rigid approach to scientific inquiry. On the contrary, they imply codevelopment of the skills of students in acquiring science knowledge, in using high-level reasoning, in applying their existing understanding of scientific ideas, and in communicating scientific information. This standard cannot be met by having the students memorize the abilities and understandings. It can be met only when students frequently engage in active inquiries.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

IDENTIFY QUESTIONS THAT CAN BE ANSWERED THROUGH SCIENTIFIC INVESTIGATIONS. Students should develop the ability to refine and refocus broad and ill-defined questions. An important aspect of this ability consists of students' ability to clarify questions and inquiries and direct them toward objects and phenomena that can be described, explained, or predicted by scientific investigations. Students should develop the ability to identify their questions with scientific ideas, concepts, and quantitative relationships that guide investigation.

DESIGN AND CONDUCT A SCIENTIFIC INVESTIGATION. Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables. They should also develop the ability to clarify their ideas that are influencing and guiding the inquiry, and to understand how those ideas compare with current scientific knowledge. Students can learn to formulate questions, design investigations, execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures.

USE APPROPRIATE TOOLS AND TECHNIQUES TO GATHER, ANALYZE, AN INTERPRET DATA. The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design. The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, using hardware and software designed for these purposes.

DEVELOP DESCRIPTIONS, EXPLANATIONS, PREDICTIONS, AND MODELS USING EVIDENCE. Students should base their explanation on what they observed, and as they develop cognitive skills, they should be able to differentiate explanation from description—providing causes for effects and establishing relationships based on evidence and logical argument. This standard requires a subject matter knowledge base so the students can effectively conduct investigations, because developing explanations establishes connections between the content of science and the contexts within which students develop new knowledge.

THINK CRITICALLY AND LOGICALLY TO MAKE THE RELATIONSHIPS BETWEEN EVIDENCE AND EXPLANATIONS. Thinking critically about evidence includes deciding what evidence should be used and accounting for anomalous data. Specifically, students should be able to review data from a simple experiment, summarize the data, and form a logical argument about the cause-and-effect relationships in the experiment. Students should begin to state some explanations in terms of the relationship between two or more variables.

RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND PREDICTIONS. Students should develop the ability to listen to and respect the explanations proposed by other students. They should remain open to and acknowledge different ideas and explanations, be able to accept the skepticism of others, and consider alternative explanations.

COMMUNICATE SCIENTIFIC PROCEDURES AND EXPLANATIONS. With practice, students should become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations.

USE MATHEMATICS IN ALL ASPECTS OF SCIENTIFIC INQUIRY. Mathematics is essential to asking and answering questions about the natural world. Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

- Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve discovery of new objects and phenomena; and some involve making models.
- Current scientific knowledge and understanding guide scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding.
- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances.

- Science advances through legitimate skepticism. Asking questions and querying other scientists' explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations.
- Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data. All of these results can lead to new investigations.

Physical Science

CONTENT STANDARD B:
As a result of their activities in grades 5–8, all students should develop an understanding of

- **Properties and changes of properties in matter**
- **Motions and forces**
- **Transfer of energy**

DEVELOPING STUDENT UNDERSTANDING

In grades 5–8, the focus on student understanding shifts from properties of objects and materials to the characteristic properties of the substances from which the materials are made. In the K–4 years, students learned that objects and materials can be sorted and ordered in terms of their properties. During that process, they learned that some properties, such as size, weight, and shape, can be assigned only to the object while other properties, such as color, texture, and hardness, describe the materials from which objects are made. In grades 5–8, students observe and measure characteristic properties, such as boiling points, melting points, solubility, and simple chemical changes of pure substances and use those properties to distinguish and separate one substance from another.

Students usually bring some vocabulary and primitive notions of atomicity to the science class but often lack understanding of the evidence and the logical arguments that support the particulate model of matter. Their early ideas are that the particles have the same properties as the parent material; that is, they are a tiny piece of the substance. It can be tempting to introduce atoms and molecules or improve students' understanding of them so that particles can be used as an explanation for the properties of elements and compounds. However, use of such terminology is premature for these students and can distract from the understanding that can be gained from focusing on the observation and description of macroscopic features of substances and of physical and chemical reactions. At this level, elements and compounds can be defined operationally from their chemical characteristics, but few students can comprehend the idea of atomic and molecular particles.

In grades 5–8, students observe and measure characteristic properties, such as boiling and melting points, solubility, and simple chemical changes of pure substance, and use those properties to distinguish and separate one substance from another

The study of motions and the forces causing motion provide concrete experiences on which a more comprehensive understanding of force can be based in grades 9–12. By using simple objects, such as rolling balls and mechanical toys, students can move from qualitative to quantitative descriptions of moving objects and begin to describe the forces acting on the objects. Students' everyday experience is that friction causes all moving objects to slow down and stop. Through experiences in which friction is reduced, students can begin to see that a moving object with no friction would continue to move indefinitely, but most students believe that the force is still acting if the object is moving or that it is "used up" if the motion stops. Students also think that friction, not inertia, is the principal reason objects remain at rest or require a force to move. Students in grades 5–8 associate force with motion and have difficulty understanding balanced forces in equilibrium, especially if the force is associated with static, inanimate objects, such as a book resting on the desk.

The understanding of energy in grades 5–8 will build on the K–4 experiences with light, heat, sound, electricity, magnetism, and the motion of objects. In 5–8, students begin to see the connections among those phenomena and to become familiar with the idea that energy is an important property of substances and that most change involves energy transfer. Students might have some of the same views of energy as they do of force—that it is associated with animate objects and is linked to motion. In addition, students view energy as a fuel or something that is stored, ready to use, and gets used up. The intent at this level is for students to improve their understanding of energy by experiencing many kinds of energy transfer.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

PROPERTIES AND CHANGES OF PROPERTIES IN MATTER

- A substance has characteristic properties such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.
- Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties. In chemical reactions, the total mass is conserved. Substances often are placed in categories or groups if they react in similar ways; metals is an example of such a group.
- Chemical elements do not break down during normal laboratory reactions involving such treatments as heating, exposure to electric current, or reaction with acids. There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances that we encounter.

MOTIONS AND FORCES

- The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.
- An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

TRANSFER OF ENERGY

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
- Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.
- Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object—emitted or scattered from it—must enter the eye.
- Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.
- In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers.
- The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Frequently Asked Questions About Inquiry

Science teachers, administrators, and teacher educators (both preservice and inservice) often face difficult questions about inquiry-based teaching and learning. Many of these questions they raise themselves. Others come from teachers, administrators, preservice teachers, students, and parents who are unfamiliar with this perspective on learning and teaching science. This chapter presents answers to some of the most commonly asked questions.

Q *In inquiry-based teaching, is it ever okay to tell students the answers to their questions?*

A Yes. Understanding requires knowledge, and not all the knowledge that is needed can be acquired by inquiry. Decisions about how to respond to students' questions depend on the teacher's goals and the context of the discussion. For example, a student may pose the question "What is the boiling point of water at sea level?" One way to respond to that question would be to set up a simple investigation to find out. The investigation could set the stage for more complex inquiries. If learning to use reference material is important, a teacher might have the student look up the information. Or, if there is a higher priority for how the student spends his or her time, the teacher could simply provide the answer.

The important point is that investigations lead to deeper understanding and greater transfer of knowledge. Decisions about responding to students' questions should reflect that fact.

Q *Should a teacher ever say "no" to an investigation that students propose themselves?*

A Yes. As noted in the previous answer, a teacher's response should depend on his or her goals for the students. What might they learn if they conducted the inquiry? Are there cost or safety concerns that might weigh against doing a particular investigation? What topics and approaches are most feasible in light of the school science curriculum and guiding standards? Would it be best for students to design their own investigations or conduct investigations proposed either by the teacher or provided by the instructional materials?

A large number of learning outcomes, particularly inquiry abilities, are best learned through investigations, and those motivated by students' own questions can be invaluable learning opportunities. Students also learn the characteristics of questions that can be properly investigated if they have opportunities to pose and investigate questions. One approach might be for teachers to ask students (or help them determine) what learning goals they will achieve by pursuing their questions and which goals they will not achieve.

The fact that students are motivated to ask questions and inquire into them is an indication that the teacher is making science relevant and exciting. But not all investigations that students propose will be worth pursuing.

Q

Is it more important for students to learn the abilities of scientific inquiry or the scientific concepts and principles?

A

They need to learn both. Furthermore, as the *National Science Education Standards* make clear, these are equally important learning outcomes that support each other.

In many teaching and learning sequences, students employ inquiry abilities to develop understanding of scientific concepts. Sometimes teachers assume that students develop inquiry abilities just because they use them. However, there is no guarantee of this. Instead, teachers have to work to ensure a proper balance between learning scientific concepts and inquiry abilities.

The development of inquiry abilities should be an explicit student learning outcome. Teachers can select specific abilities on which to focus and develop strategies to achieve those outcomes.

Learning science content and improving inquiry abilities can be symbiotic. Scientific concepts and inquiry abilities switch from primary to secondary focus and back again as needed to promote the effective integration of both. Also, research describes expertise as knowing both the subject matter content (the “big ideas” of the disciplines) and the ways of inquiring into new questions—and it makes the case for teaching both.

Q

How can students do a science investigation before they have learned the vocabulary words with which to describe the results?

A

Scientific investigations, whether conducted by students or scientists, begin with observations of something interesting or perplexing, which lead to scientific questions, and then to reflections on what the person already knows about the question. It may seem that students need some concepts and vocabulary to begin, but investigations can be designed and carried out without knowing all the specific terms and definitions involved. In fact, the observations, data collection, and analysis involved in an investigation generally provide the context for developing operational definitions, science concepts, inquiry abilities, and an understanding of scientific inquiry, which can later be associated with names or “vocabulary.”

Knowing vocabulary does not necessarily help students develop or understand explanations. Rather, once students begin to build and understand explanations for their observations, the proper names and definitions associated with those events become useful and meaningful. In essence, words become symbols for their understanding of the phenomena. As a result, definitions based on direct experience more often result in understanding than just memorizing words.

The issue of vocabulary development is particularly relevant to working with students who are English-language learners. Teachers of these students need to pay special attention to whether assessment of students’ science knowledge is confounded by their use of the language, and to how student learning is supported when their language skills are just developing. As noted in research synthesized by Fradd and Lee (1999), when formulating their teaching strategies, teachers need to consider how students of diverse cultures and languages think about science, the experiences they have had in learning science, and, ultimately, how to structure new science learning experiences to optimize students’ opportunities to learn important science concepts and inquiry abilities. The degree of structure given to lessons and the amount of direct "teaching" of inquiry skills need to depend on teachers' keen assessment of students' language development, current science knowledge, skills, and beliefs, and cultural orientations (Fradd and Lee, 1999).

Q *Why did the Standards choose to leave out the science process skills such as observing, classifying, predicting, and hypothesizing?*

A The "process skills" emphasized in earlier science education reforms may appear to be missing from the *Standards*, but they are not. Rather, they are integrated into the broader abilities of scientific inquiry. As the *Standards* point out, "The standards on inquiry highlight the abilities of inquiry and the development of an understanding about scientific inquiry. Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (National Research Council, 1996, p. 105). The *Standards* thus include the "processes of science" and require that students combine those processes and scientific knowledge to develop their understanding of science.

Q *Do the Standards imply that teachers should use inquiry in every lesson?*

A No. In fact, the *Standards* emphasize that many teaching approaches can serve the goal of learning science: "Although the *Standards* emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry" (National Research Council, 1996, p. 23).

Everyone knows that investigations often take longer than other ways of learning, and there are simply not enough hours or days in the school year to learn everything through inquiry. The challenge to the teacher is to make the most judicious choices about which learning goals can be best reached through inquiry (remembering that deep understanding is most likely to result from inquiry), and what the nature of that inquiry should be. Other teaching strategies can come into play for other learning goals.

Q *How can teachers cover everything in the curriculum if they use inquiry-oriented materials and teaching methods?*

A As noted in the previous question, the *Standards* do not suggest that all science should be learned through inquiry. However, investigations are important ways to promote deep understanding of science content and the only way to help students practice inquiry abilities. So there is still the issue of coverage vs. learning strategy to address.

Analysis of data collected in the Third International Mathematics and Science Study (TIMSS) reveals that the typical U.S. eighth-grade science textbook includes about 65 topics. A similarly large number of science topics appears yearly in state and local science standards and curriculum guides. Teachers, understandably, feel obligated to teach all of the topics called for in their local science curriculum. The result can be the "mile wide and inch deep" curriculum often decried in U.S. education. Furthermore, research shows that this "cover everything" approach provides few opportunities for students to acquire anything but surface knowledge on any topic (Schmidt et al., 1997).

There are several steps that teachers and administrators can take to deal with this problem. They can renegotiate the expectations embodied in the curriculum. They can carefully select a few areas to emphasize, spending more time teaching those areas through inquiry. They can carefully analyze the curriculum expectations and combine several learning outcomes in lessons and units. They can work with other grade-level teachers to eliminate the redundancies that often exist in a curriculum, but rarely deepen understanding. If they teach subjects other than science, they can integrate science outcomes into other subject areas (for example, presenting the findings of an investigation in a language arts lesson).

Teachers and administrators can be helped by district and state decision-makers who can reduce the number of topics that teachers are required to teach.

Q *How much structure and how much freedom should teachers provide in inquiry-oriented science lessons?*

A The type and amount of structure can vary depending on what is needed to keep students productively engaged in pursuit of a learning outcome. Students with little experience in conducting scientific inquiries will probably require more structure. For example, a teacher might want to select the question driving an investigation. She or he also might decide to provide a series of steps and procedures for the students guided by specific questions and group discussion. The instructional materials themselves often provide questions, suggestions, procedures, and data tables to guide student inquiry.

As students mature and gain experience with inquiry, they will become adept at clarifying good questions, designing investigations to test ideas, interpreting data, and forming explanations based on data. With such students, the teacher still should monitor by observation, ask questions for clarification, and make suggestions when needed. Often teachers begin the school year providing considerable structure and then gradually provide more opportunities for student-centered investigations.

Many teachers in the primary grades have considerable success with whole-class projects. An example is a class experiment to answer the question: "What is the 'black stuff' on the bottom of the aquarium?" Guided by the teacher, the students can focus and clarify the question. They can ponder where the "black stuff" came from based on their prior knowledge of goldfish, snails, and plants. Using their prior knowledge, the students then can propose explanations and decide what they need to set up a fair test. How many aquariums will they need? What will be in each aquarium? What are they looking for? How will they know when they have answered the question? After a number of well-structured whole-class inquiries with ample time to discuss procedures and process as well as conclusions and explanations, students are more prepared to design and conduct their own inquiries.

Q *How can teachers use inquiry and maintain control of their students?*

A To have productive experiences, inquiry requires considerable planning and organization on the part of both teachers and tudents. Teachers need to create systems for organization and management of materials and guidelines for student use of materials and conversation. Students need to learn how to work with materials in an organized fashion, communicate their ideas with one another, listen to each other's ideas with respect, and accept responsibility for their own learning. In addition, it always is helpful when students know what is expected of them in terms of behavior and performance. As students become collaborators, they recognize the conditions for progress themselves and need less external control.

Q *How much do teachers need to know about inquiry and about science subject matter to teach science through inquiry?*

A The more teachers know about inquiry and about science subject matter, and the more they themselves are effective inquirers, the better equipped they are to engage their students in inquiries that will help them understand scientific concepts and inquiry. It generally does not work for teachers to stay one step ahead of the students when using an inquiry-oriented program.

However, to a certain extent, teachers can develop their own understanding through inquiry as they investigate with their students and participate in professional development programs. Teachers also can consult with other teachers to learn more about a topic, refer to science background material printed in teachers guides, participate in professional development, and invite into the classroom parents, scientists, and others who have expertise to help in learning about the topic. Like their students, teachers should view themselves as learners, being eager to try new ways of teaching and extend and sharpen their subject matter knowledge. And they should use their own teaching to inquire about how to improve it, so that their ability to teach through inquiry increases in each successive year.

Q

What can teachers do who are provided only traditional instructional materials?

A

Teachers who want their students to learn to inquire and to learn through inquiry are hampered if their materials are text-based and focus students on memorizing scientific laws and terminology. However, a teacher's curriculum is not defined by the materials alone, but more broadly by what students focus their attention on, how they learn, and how and on what they are assessed. Teachers can use the *Standards* to determine goals for their students and decide which pieces of their materials they can use to help students reach those goals. They can consider decreasing the "cookbook" nature of whatever "labs" or hands-on activities are included with their materials and resequencing them to come before the readings or lectures so students can explore in a concrete way *before* learning the concepts and terms. Teachers can emphasize learning the major concepts and downplay the vocabulary. They can reconstruct test items to assess major science concepts, inquiry abilities, and understandings about inquiry; they can create one full and open inquiry for students to conduct for several weeks of class. And they can supplement the materials they are given with other materials they receive in professional development or from colleagues, or locate on the Web. The important thing is to determine a set of learning goals for students that reflect the *Standards* and let those guide how and what students learn.

Q

Where can teachers get the equipment, materials, and supplies they need to teach through inquiry?

A

The National Science Foundation (NSF) has supported the development and field testing of a number of inquiry-oriented science curriculum programs. These science programs, complete with student and teacher guides and materials for student activities or laboratories, are now available through commercial publishers. [See *Selecting Instructional Materials: A Guide for K–12 Science* (NRC, 1999b).] Many districts that have adopted these programs operate a centralized district materials center and loan the materials to teachers. Some districts supply a certain number of kits per grade level that are housed at school sites, with consumable supplies being replenished as needed by the district.

Where districts have not adopted such programs, individual teachers and schools have developed a variety of mechanisms to provide needed materials and supplies. Some teachers develop a list of common household materials and supplies and have students collect them from home and bring them to school. Often a group of teachers at a school will collaborate on a project so they can share materials.

If inquiry is to be the norm rather than an exception, schools must realize that materials are an essential element of teaching and should devote adequate resources and organizational structures to purchase and support use of appropriate materials. Teachers should not be expected to supply the essential supplies of teaching.

Q

Where can teacher educators obtain inquiry-oriented programs to use in preparing teachers?

A

Many teacher educators use curriculum materials developed for use in K–12 classrooms to help prospective students experience and learn to use inquiry-based materials. In addition, there are materials that can be used by teacher educators, at both the preservice and inservice levels, that are designed to use for teacher learning.

Q

What barriers are encountered when implementing inquiry-oriented approaches?

A

In addition to the external barriers teachers face, their beliefs and values about students, teaching, and the purposes of education can impose obstacles to inquiry-oriented approaches. Research demonstrates many of the predicaments that teachers face when considering new approaches. In a cross-site analysis of schools that had successfully initiated new approaches to science and mathematics instruction, three kinds of problems were noted: technical, political, and cultural (Anderson, 1996). Technical problems included limited teaching abilities, prior commitments (for example, to a textbook), the challenges of assessment, difficulties of group work, the challenges of new teacher roles, the challenges of new student roles, and inadequate in-service education. Political problems included limited inservice education (i.e., not sustained for a sufficient number of years), parental resistance, resistance from principals and superintendents, unresolved conflicts among teachers, lack of resources, and differing judgments about justice and fairness. Cultural problems—possibly the most important because beliefs and values are central to them—included the textbook issue, views of assessment, and the “preparation ethic” (i.e., an overriding commitment to “coverage” because of a perceived need to prepare students for the next level of schooling). In addition to this study’s findings, barriers experienced currently include the widespread attitude that science is not a “basic” and the lack of appropriate instructional materials, both print and hands-on.

Q

How can teachers improve their use of inquiry in science teaching?

A

Research indicates that teachers have a fairly pragmatic approach to teaching. They tend to focus on what works to involve students or manage their classrooms, rather than on melding theory and practice (Blumenfeld, 1994). Teachers anchor their understanding in classroom events and base their actions on stories and narratives more than on theories and propositional knowledge (Krajcik et al., 1994). Thus, theory, beliefs, values, and understandings are important as teachers acquire an inquiry approach, but teachers should not be expected to address such mental constructs in isolation from their teaching context.

Collaboration can be an important catalyst of change. New understandings develop and new classroom practices emerge when teachers collaborate with peers and experts. Collaboration addresses not only the technical problems of reform but cultural issues as well. As Anderson (1996) says, “Collaborative working relationships among teachers provide a very important context for the re-assessment of educational values and beliefs. In this context—where the focus is the actual work of each teacher’s own students—one’s values and beliefs are encountered at every turn. It is a powerful influence. Crucial reform work takes place in this context.” Collaboration stimulates the reflection that is fundamental to changing beliefs, values, and understandings.

The appropriate professional development is a powerful way for teachers to improve their use of inquiry, as long as it is viewed as support for ongoing learning that is apt to take many years to change teaching practice significantly. Teachers can become wise consumers of professional development as they broaden their images and sources of learning.

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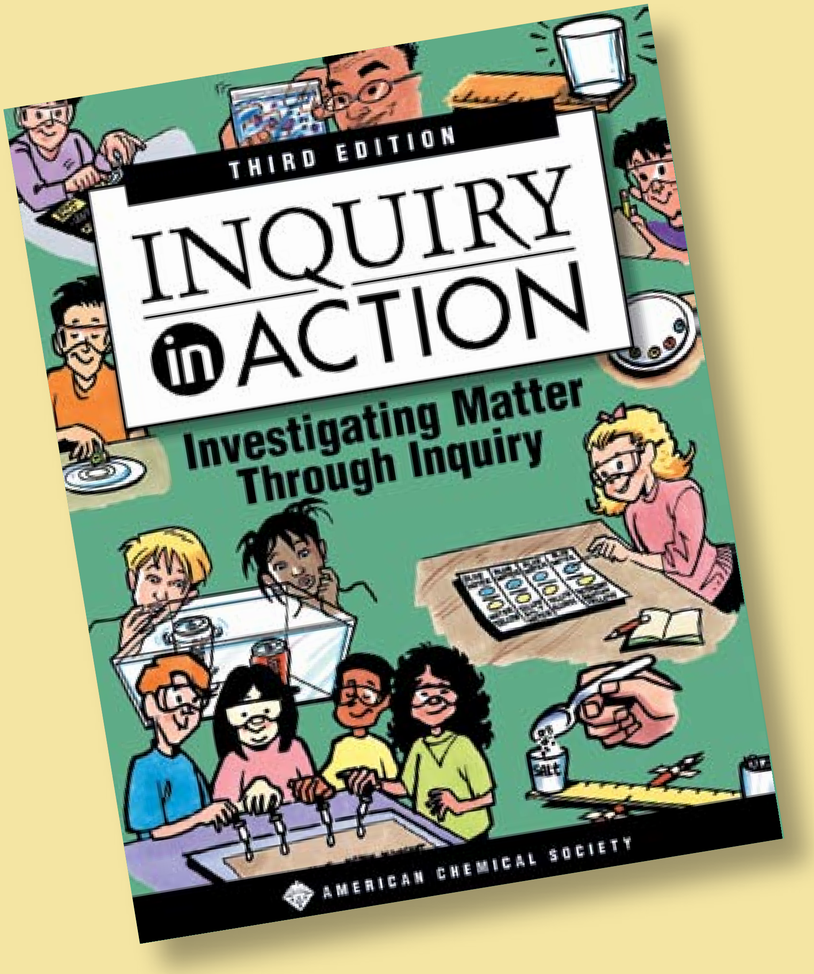

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