Occasional Paper No. 121

MATTER AND MOLECULES
TEACHER'S GUIDE: SCIENCE BOOK

Glenn D. Berkheimer, Charles W. Anderson, Okhee Lee, and Theron D. Blakeslee
with the assistance of
David Eichinger and Karen Sands

Published by

The Institute for Research on Teaching
College of Education
Michigan State University
East Lansing, Michigan 48824-1034

August 1988

This work is sponsored in part by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded from a variety of federal, state, and private sources including the United States Department of Education and Michigan State University. This material is based upon work supported by the National Science Foundation under Grant No. MDR-855-0336. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the position, policy, or endorsement of the funding agencies. © All rights reserved by Michigan State University.
Institute for Research on Teaching

The Institute for Research on Teaching was founded in 1976 at Michigan State University and has been the recipient of major federal grants. Funding for IRT projects is currently received from the U.S. Department of Education, Michigan State University, and other agencies and foundations. IRT scholars have conducted major research projects aimed at improving classroom teaching, including studies of classroom management strategies, student socialization, the diagnosis and remediation of reading difficulties, and school policies. IRT researchers have also been examining the teaching of specific school subjects such as reading, writing, general mathematics, and science and are seeking to understand how factors inside as well as outside the classroom affect teachers. In addition to curriculum and instructional specialists in school subjects, researchers from such diverse disciplines as educational psychology, anthropology, sociology, history, economics, and philosophy cooperate in conducting IRT research. By focusing on how teachers respond to enduring problems of practice and by collaborating with practitioners, IRT researchers strive to produce new understandings to improve teaching and teacher education.

Currently, IRT researchers are engaged in a number of programmatic efforts in research on teaching that build on past work and extend the study of teaching in new directions such as the teaching of subject matter disciplines in elementary school, teaching in developing countries, and teaching special populations. New modes of teacher collaboration with schools and teachers' organizations are also being explored. The Center for the Learning and Teaching of Elementary Subjects, funded by the U.S. Department of Education's Office of Educational Research and Improvement from 1987-92, is one of the IRT's major endeavors and emphasizes higher level thinking and problem solving in elementary teaching of mathematics, science, social studies, literature, and the arts. The focus is on what content should be taught, how teachers concentrate their teaching to use their limited resources in the best way, and in what ways good teaching is subject-matter specific.

The IRT publishes research reports, occasional papers, conference proceedings, the Elementary Subjects Center Series, a newsletter for practitioners (IRT Communication Quarterly), and lists and catalogs of IRT publications. For more information, to receive a list or catalog, and/or to be placed on the IRT mailing list to receive the newsletter, please write to the Editor, Institute for Research on Teaching, 252 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

Co-directors: Jere E. Brophy and Penelope L. Peterson


Editor: Sandra Gross

Editorial Assistant: Diane Smith
Abstract

This is the teacher's guide for the science book of *Matter and Molecules*, a set of instructional materials about the kinetic molecular theory written at the middle school level. The complete *Matter and Molecules* materials include a science book, an activity book, 17 transparencies, three wall posters, and teachers' guides for both the science book and activity book (Occasional Paper No. 122).

The *Matter and Molecules* materials were used in a research and curriculum development study during 1986-1988. The project staff studied Grade 6 students' prior knowledge of the aspects of the kinetic molecular theory. This information was then combined with teaching strategies identified in earlier studies to design instructional materials particularly effective in promoting meaningful conceptual change learning. Such learning requires students to go beyond the memorization of terms and to use scientific conceptions to explain common phenomena. For students, this kind of learning in science often requires them to go through the difficult process of conceptual change, reshaping and abandoning ideas or misconceptions that they have developed from experience and have believed for a long time.

The first year of the project, the Lansing Grade 6 science teachers used *Models of Matter*, which is the third unit in the sixth-grade level of the Houghton Mifflin Science Program. The project staff conducted pre- and post- clinical interviews and tests and observed the classrooms of four collaborating teachers. Posttests only were given to the other Grade 6 science classes. This data informed the development of the *Matter and Molecules* materials.

The second year repeated all segments of the first year except all teachers used the *Matter and Molecules* instead of the *Models of Matter* materials. The *Matter and Molecules* materials were found to be helpful to the teachers, and the students using these materials were more successful in undergoing conceptual change than students who used the *Models of Matter* materials.
Written by

Glenn D. Berkheimer, Charles W. Anderson, Okhee Lee,
and Theron D. Blakeslee
with the assistance of
David Eichinger and Karen Sands

Illustrated by
Saundra L. Dunn

About the Authors

Glenn Berkheimer, coordinator of the Educational Systems to Increase Student Achievement Project, is a senior researcher with the Institute for Research on Teaching and professor of teacher education at Michigan State University. Charles Anderson, a member of the project, is also an IRT senior researcher and associate professor of teacher education at MSU. Theron Blakeslee, Okhee Lee, and David Eichinger are research assistants with the project. Karen Sands is an undergraduate majoring in elementary education working with the project. The illustrator Saundra Dunn is a graduate assistant in teacher education.
Staff of the
Educational Systems to Increase Student Achievement Project
funded by the
National Science Foundation

Principal Investigators:

Glenn D. Berkheimer
Charles W. Anderson
Steven T. Spees

Doctoral Graduate Students:

Theron Blakeslee
David Eichinger
Okhee Lee

Collaborating Teachers:

Paula Cronheim
Alan Donaldson
Donald Williams
William Woodland

Undergraduate Students:

Kristen Bruning
Donna Carter
Charlene DeWitt
Karen Sands
Gwen Muhling
Larissa Bien
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Transparencies</td>
<td>T-1</td>
</tr>
<tr>
<td>List of Charts and Posters, Videotape Contents</td>
<td>T-2</td>
</tr>
<tr>
<td>Introduction: Writing Descriptions and Explanations</td>
<td>T-3</td>
</tr>
<tr>
<td>Unit Introduction</td>
<td>T-10</td>
</tr>
<tr>
<td><strong>Lesson Clusters</strong></td>
<td></td>
</tr>
<tr>
<td>1. States of Water</td>
<td>T-11</td>
</tr>
<tr>
<td>2. Other Solids, Liquids, and Gases</td>
<td>T-26</td>
</tr>
<tr>
<td>3. The Air Around Us</td>
<td>T-36</td>
</tr>
<tr>
<td>4. Compressing and Expanding Air</td>
<td>T-48</td>
</tr>
<tr>
<td>5. Explaining Dissolving</td>
<td>T-59</td>
</tr>
<tr>
<td>6. Heating and Cooling, Expansion and Contraction</td>
<td>T-67</td>
</tr>
<tr>
<td>7. Explaining Melting and Solidifying</td>
<td>T-78</td>
</tr>
<tr>
<td>8. Explaining Evaporation and Boiling</td>
<td>T-87</td>
</tr>
<tr>
<td>9. Explaining Condensation</td>
<td>T-97</td>
</tr>
<tr>
<td>List of Materials by Lesson</td>
<td>T-111</td>
</tr>
<tr>
<td>Appendix: Transparencies for Copying</td>
<td>T-115</td>
</tr>
</tbody>
</table>

## ORGANIZATION OF PAGES IN THIS UNIT

![Diagram](image)

**Student Pages**

- Reproductions of Science Book Pages are always on the left side.

**Teachers' Pages**

- Pages with information for Teachers are on the right side.

Each Lesson Cluster in the Teacher's Guide is composed of the following parts:

**I. Cluster Introduction.**

*Please read the introduction first.* It contains essential information to help you understand and use the materials.

A. Lesson Cluster Goals and Lesson Objectives
B. Key Elements of a Good Description or Explanation
C. Students' Conceptual Learning
D. Conceptual Contrasts

**II. Student Text and Accompanying Comments to the Teacher.**
<table>
<thead>
<tr>
<th>Transparency</th>
<th>Lesson</th>
<th>Page (SBTG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How big is a speck of dust compared to a molecule?</td>
<td>1.3</td>
<td>T-19</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>T-43</td>
</tr>
<tr>
<td>2. Why can you change liquid water into ice but not alcohol?</td>
<td>2.1</td>
<td>T-30</td>
</tr>
<tr>
<td>3. What would ocean water look like?</td>
<td>2.2</td>
<td>T-32</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>T-66</td>
</tr>
<tr>
<td>4. How are molecules arranged and how do they move?</td>
<td>2.3</td>
<td>T-35</td>
</tr>
<tr>
<td>5. What do molecules of air look like?</td>
<td>3.2</td>
<td>T-43</td>
</tr>
<tr>
<td>6. What is the smell of baking cookies?</td>
<td>3.2</td>
<td>T-44</td>
</tr>
<tr>
<td></td>
<td>8.4</td>
<td>T-96</td>
</tr>
<tr>
<td>7. What happens to air molecules when the plunger is pushed in?</td>
<td>4.2</td>
<td>T-53</td>
</tr>
<tr>
<td>8. Where does the air go when you pump it into a tire?</td>
<td>4.4</td>
<td>T-58</td>
</tr>
<tr>
<td>9. What happens when sugar dissolves in water?</td>
<td>5.1</td>
<td>T-63</td>
</tr>
<tr>
<td>10. Why does the sugar dissolve faster in hot water?</td>
<td>6.1</td>
<td>T-71</td>
</tr>
<tr>
<td>11. Why does heating the metal ball make it expand?</td>
<td>6.2</td>
<td>T-72</td>
</tr>
<tr>
<td>12. Why does liquid water change into ice when it gets cold?</td>
<td>7.1</td>
<td>T-82</td>
</tr>
<tr>
<td>13. Where does the water go when clothes dry?</td>
<td>8.1</td>
<td>T-92</td>
</tr>
<tr>
<td>14. What's inside the bubbles of boiling water?</td>
<td>8.2</td>
<td>T-95</td>
</tr>
<tr>
<td>15. What is the steam above boiling water?</td>
<td>9.1</td>
<td>T-102</td>
</tr>
<tr>
<td>16. Where did the water come from on the outside of the cold glass?</td>
<td>9.3</td>
<td>T-104</td>
</tr>
<tr>
<td>17. What do all forms of precipitation have in common?</td>
<td>9.5</td>
<td>T-106</td>
</tr>
</tbody>
</table>

*For Transparencies to Copy see Appendix*
LIST OF POSTERS

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To EXPLAIN things, ask TWO QUESTIONS</td>
<td>4.4</td>
</tr>
<tr>
<td>2. States of Matter</td>
<td>6.1</td>
</tr>
<tr>
<td>3. Changes of State</td>
<td>7.1</td>
</tr>
<tr>
<td>4. Explaining Changes in Matter</td>
<td>Inside back cover</td>
</tr>
</tbody>
</table>

VIDEOTAPE

"Voyage of the Mimi"--
episode "Making Dew"

9.3 T-104

To obtain, contact:

Sam Gibbon
Voyage of the Mimi
Bank Street College
610 W. 112th St.
New York, NY 10025
212/663-7200
INTRODUCTION

The Importance of Matter and Molecules

This unit is designed to teach middle school students about one of the most fundamental and important theories in physical science: the kinetic molecular theory. The essential idea of the kinetic molecular theory is a simple one: All matter is made of tiny particles, atoms and molecules, and those particles are constantly in motion.

Although this idea is simply stated, the ramifications have proved rich and complex. All of modern chemistry is devoted to developing our understanding of these particles and their interactions. The kinetic molecular theory also plays a fundamental role in physics, in biology, in geology, and in meteorology. In other words, it is impossible to understand most of modern science without a good understanding of the kinetic molecular theory.

Unfortunately, many middle and high school students do not have a good understanding of the kinetic molecular theory, and their understanding of all branches of science suffers as a result. In our previous research, we have investigated college students' or adults' understanding of a variety of scientific topics. Over and over, we have found that these older students encounter fundamental difficulties because they do not have an adequate understanding of the kinetic molecular theory. Our scientific understanding of heat and temperature, for instance, or respiration and photosynthesis, or ecology, or weather, is based on the kinetic molecular theory. Many students never develop an adequate understanding of the kinetic molecular theory.

Thus this unit is designed to address an important deficiency in our middle school science curriculum. Because many students do not acquire an adequate understanding of kinetic molecular theory in middle school, they are not adequately prepared for science courses in high school and beyond. With the help of this unit, we feel that is possible to improve this situation.

Students' Learning About Matter and Molecules

In preparing this unit we have done a great deal of research. We have interviewed and tested many students to see how they understood matter and molecules, and we have carefully analyzed how a previous version of the unit (the "Models of Matter" unit in the Houghton Mifflin Science textbook series) was helping and was failing to help these students improve their understanding.

This research has helped us to understand why the kinetic molecular theory is so difficult for many students. Our research shows that most students do not enter middle school devoid of ideas about matter and molecules. In fact, they have developed a great many theories about the "stuff" that the world is made of, and what its properties are, and how it changes. These ideas are based on the students' personal experiences, so they make sense to the students and are often strongly held. Unfortunately, students' theories are generally different from the kinetic molecular theory, and sometimes incompatible with scientists' understanding of the world.
The presence of students' alternate ways of thinking makes learning science a far more difficult and complex process than you might normally imagine. Understanding the kinetic molecular theory requires students to do far more than absorb new information; instead, they must reassess and change their common sense, everyday understandings of the world. Sometimes they must abandon misconceptions or habits of thought that have served them well all their lives in favor of new and unfamiliar ideas. This complex learning process is one that we and other researchers have labeled a process of conceptual change.

Through our research we have tried to develop a detailed understanding of the conceptual changes that students must go through to understand the kinetic molecular theory. Relevant parts of this detailed list of conceptual changes are presented and discussed at the beginning of each lesson cluster in this Teacher's Guide, and we used this list to guide the development of all the materials that make up this unit. Most of the conceptual changes on our detailed list can be grouped around four main themes, or big ideas that the students must master in order to understand the kinetic molecular theory. These four main themes and the conceptual changes associated with each are discussed below.

1. Understanding the nature and properties of matter. The kinetic molecular theory is a theory about matter; we do not believe that non-material things such as love, or light, or temperature are made of molecules. Thus students must be able to separate matter from non-matter in order to know when the kinetic molecular theory is applicable.

   There is a standard definition that is supposed to help students do this: "Matter is anything that has weight and takes up space." Unfortunately, this definition doesn't help most students very much. Many students believe that gases such as air and helium are weightless. On the other hand, they commonly believe that forms of energy such as heat and light take up space. Thus most middle school students cannot reliably separate matter from non-matter.

   There are other problems, too. Many students are familiar with the terms, atoms and molecules, and with the idea that matter is made of tiny particles. There are a great many ideas, however, that they are unclear about. Just how tiny are molecules? Is a molecule smaller than a speck of dust--smaller than a cell? Is there air between air molecules? Are all molecules moving, even in solids like ice and rocks? Is there just one kind of molecule or are there many different kinds? How many different kinds of molecules make up pure water? sea water? air? The list of possible questions goes on and on, and middle school students have developed beliefs about many of these questions, often beliefs that are in conflict with the kinetic molecular theory.

   One central goal of this unit, therefore, is to help students identify and describe matter in its various states (solid, liquid, and gas) and to understand the molecular composition of a variety of different kinds of matter.

2. Identifying and describing physical changes in matter. Although kinetic molecular theory plays an essential role in our understanding of chemical changes such as burning, respiration and photosynthesis, or growth and decay, chemical changes are not discussed in this unit. Rather than chemical changes, where molecules are created and destroyed, this unit focuses on
physical changes, where intact molecules are simply rearranged. Examples of such physical changes include thermal expansion and contraction, the compression and expansion of gases, dissolving, and changes of state such as melting and condensation.

We have found that many students do not fully understand even the non-molecular aspects of these physical changes in matter. Even students who correctly use words like "dissolved" and "evaporated," for example, may mean by those words that some bit of matter has entirely ceased to exist, rather than that it continues to exist in an invisible form. Students also have trouble distinguishing between similar physical changes such as melting and dissolving. Condensation is an especially difficult phenomenon for many students; they find it very difficult to understand where the water comes from that forms dew on the grass or fog in the air.

Therefore another essential goal of this unit is to help students recognize a variety of different physical changes in matter and describe what is happening to the substances that are changing.

3. Developing molecular explanations for observable properties and phenomena. The importance of kinetic molecular theory lies in its explanatory power. This theory enables us to develop detailed and convincing explanations of the physical and chemical properties of substances, as well as of many events or phenomena in the world around us that would otherwise be mysterious.

Many students assume that there is a fairly simple and straightforward relationship between the properties of a substance and the properties of its molecules. They may believe, for example, that ice is made of cold, hard molecules and that ice melts because the molecules become warmer and turn into liquid. The power of the kinetic molecular theory, however, lies in our understanding that the molecules themselves do not change during physical changes in substances such as melting. Physical changes involve changes in the arrangement and motion of the molecules, but not changes in the molecules themselves.

Therefore, a third goal, and perhaps the most important goal for the unit is to help students explain observable phenomena and observable properties of matter in terms of the arrangement and motion of molecules.

4. Describing and explaining the world around us. Our final goal involves our beliefs not just about kinetic molecular theory, but about science in general. We believe that both the interest and the power of science derive from the ability of scientific theories to help us describe, predict, explain, and ultimately to control our world. This implies that scientific knowledge should help students to describe and explain the real world, the world that they see around them every day.

Unfortunately, most students do not experience scientific knowledge in this way. They learn instead that science classes are places where they must learn bits and pieces of obscure information: Atomic symbols, or molecular formulas, or whatever. They learn that their own ideas and their own reasoning do not count. Instead, they must reproduce those bits and pieces of information on demand—rarely more than one word at a time! Understandably, this leaves many
students alienated from science, and unaware of the power and the beauty that scientific knowledge can hold.

Therefore, our final goal is to help students use scientific knowledge to develop their own personal descriptions and explanations of real-world phenomena, and thus to appreciate how interesting and useful scientific knowledge can be.

**Using this Unit to Teach about Matter and Molecules**

Achieving the goals described above is not easy. Students (and sometimes teachers) must work through a difficult process of conceptual change in order to achieve each goal. Because the process of conceptual change is so difficult and complex, there is no simple way that students can work their way through it. A variety of different, complementary approaches is necessary. Therefore, the **Matter and Molecules** unit includes several different components, each designed to help students in a different way. Each of these components, its purposes, and recommendations for teaching strategies that will help make it more effective are described below.

**The Science Book: Reading with understanding.** The first part of this unit is the Science Book, or student text. This text is written to explain the important ideas about matter and molecules discussed above in a way that will help students learn with understanding. Reading about the kinetic molecular theory with understanding, however, is a difficult task for most students. They can truly understand only if they successfully work through the process of conceptual change; that is, they must actively integrate the information in the Science Book with their own previous ideas, sometimes realizing that their previous ideas were incorrect and changing them accordingly.

Both our research and the work of other researchers indicates that no matter how well a textbook is written, many students normally fail to read it with understanding. The reason is that many students do not normally process the information in the text in an active way. Teachers can make a great deal of difference in how students read and process textbooks. By helping your students to ask the right questions and think actively about what they read, you can help them understand the Science Book much better than they otherwise would.

In particular, we recommend a set of teaching strategies based on the work of Annemarie Palincsar and Ann Brown, who have found that student comprehension can be greatly increased if students engage in the following activities as they read:

1. **Summarizing:** developing brief summaries of the passage that they just read.

2. **Generating questions:** suggesting questions that address important ideas (as opposed to minor details) in the passage they just read.

3. **Clarifying:** identifying statements or ideas that are unclear or confusing to them and asking questions that help them resolve their difficulties.
4. **Predicting:** making predictions about the contents of the next lesson or passage that they will read.

We would add to Palincsar and Brown's list a fifth activity, **applying**, or trying to figure out how the ideas in the text can be used to describe, or predict, or explain events or observations that the students make about the world around them.

There are a variety of strategies that you can use to help your students engage in these important activities. The simplest is just to use these activities as a guide to class discussions of the Science Book. After you and the class have finished reading each lesson, call on students in your class and ask them to **summarize**, **generate questions**, **clarify**, **make predictions**, and **apply** the ideas in the lessons that they just read.

There are also other ways that you can involve students in these activities. You might want to have students write summaries, questions, clarifications, predictions, or applications, then share what they have written with the class. You could also sometimes have the students working with each other in small groups, sharing summaries, questions, clarifications, predictions, and applications with each other. Regardless of how you do it, though, you can greatly enhance the effectiveness of the Science Book by helping your students to engage in these activities as they read it.

**The Activity Book: Writing descriptions and explanations.** This unit is based on a basic belief about the nature and purposes of scientific knowledge: We believe that science was developed for the purpose of describing and explaining natural phenomena. This means that an important part of teaching science consists of giving students the chance to practice their own descriptions and explanations. For that reason, this unit includes an Activity Book containing many questions that require students to write out descriptions or explanations.

Although this writing is essential for student learning, it is also a lot of work, for the students and for you. We would like to give you a few suggestions about how to make the work load manageable while still giving the students plenty of practice in developing descriptions and explanations.

You do not have to check every activity and question set yourself (though you certainly can if you want to). It is important for students to answer all of the questions, but there are a variety of ways that they can get practice and feedback in answering these questions without your having to read every student answer. For example:

1. Students can answer their questions individually, then meet in groups of three to compare their answers and develop a group consensus answer. The group consensus answers can then be compared in a class discussion.

2. Groups of students working together on a question set of a laboratory activity can develop a group consensus answer. The group consensus answers can then be compared in a class discussion.
3. Students can check each other’s papers. It is possible for students to learn a great deal from a class discussion that focuses on what qualities make an answer acceptable or unacceptable.

4. Student answers can be used as a basis for class discussion rather than individual checking. You can solicit a variety of answers from the students, and lead the class in a discussion of the merits of each answer.

You can probably think of a variety of other arrangements that will work equally well. What is important is that students keep writing and discussing their descriptions and explanations, with enough feedback from you or from each other to help them understand their mistakes and improve the quality of their descriptions and explanations.

Some questions are intended primarily for the purpose of eliciting students’ ideas about topics that they have not yet studied and may only partially understand. These questions should not be graded on a right-or-wrong basis; they should be used as a basis for discussion by small groups of students or by the whole class.

Lesson Cluster Review Questions and Tests: Monitoring and feedback. The last question set in each lesson cluster contains questions reviewing the content of the entire lesson cluster. If you grade those question sets, which are packaged separately so that they can be taken up or used as tests, you should be able to do an adequate job of monitoring the progress of individual students.

Your materials also include two tests, one covering Lesson Clusters 1-4, the second covering Lesson Clusters 5-9. Since each lesson cluster builds on ideas from previous lesson clusters, you should review or reteach ideas that your students are having trouble understanding, as revealed by their performance on the review question sets or the tests.

Overhead Transparencies: Discussing important questions. The unit also contains a set of overhead transparencies that are designed to help you develop class discussions about key ideas in the unit. These transparencies are listed immediately after the Table of Contents of this Teacher’s Guide. Each transparency is illustrated and discussed at the lesson where we feel that it could appropriately be introduced. (Although we encourage you to use transparencies whenever you feel appropriate, several times, if necessary.)

Each of the transparencies has two layers. The bottom layer poses a question about a situation. You should encourage students to express their ideas about that situation and the answer to the question. After your students have tried to answer the question and you are aware of how they think, you can flip down the overlay to give them a scientific answer to the question.

You will find that your students’ answers are sometimes very different from those in the science book. These differences are often the result of misconceptions that a surprisingly large number of students firmly believe. For the students to see the differences, it is essential for the students to have a chance to answer the questions and discuss the contrasts. Students must
see these contrasts explicitly so they understand the need for abandoning their naive ideas in favor of the more sophisticated scientific conceptions.

The transparencies will work most effectively if you encourage an atmosphere in your classroom where students feel safe in expressing ideas they are not sure of, and where students know that their ideas are valued even if they are not entirely correct.

**Activities and Demonstrations: Connecting Scientific Ideas With the Real World**

Every lesson cluster includes at least one hands-on activity for students to do or a demonstration for students to observe; most lesson clusters have more than one. The Activity Book contains questions for students to answer about each activity and demonstration. The materials and teaching suggestions for each activity and demonstration are listed in the section on that lesson in this Teacher’s Guide. A master list of materials for all lessons is included as an appendix at the end of this Teacher’s Guide.

These activities and demonstrations give students a chance to make careful observations of a variety of phenomena and to use the kinetic molecular theory to describe and explain those phenomena. Thus they play an essential role in helping students connect scientific ideas with the real world.

**Charts and Posters: Helping students remember and organize key ideas.** The unit also includes one chart (on the inside back cover of the Science Book and this Teacher’s Guide) and three posters (listed after the Table of Contents). These charts and posters present in tabular or graphic form some key ideas that your students will need to refer to over and over throughout the unit. We therefore recommend that you introduce each of these charts and posters as it becomes relevant, then refer to it whenever appropriate after that time.

**Videotape: Illustrating key ideas.** Some ideas, especially those involving molecular motion, are difficult to envision from still pictures. We therefore have selected a videotape that illustrates these ideas in a more active way.

The videotape is an episode entitled "Making Dew" taken from The Voyage of the Mimi television series. This segment shows how the crew of the Mimi designed and used solar stills when they were shipwrecked on an island that contained no fresh water. This section should be shown in connection with Lesson 9.3.

**Scheduling**

The length of this unit depends, of course, on how quickly or how thoroughly you teach. The lessons are generally designed to take about one 45-minute class period each. Since there are 35 lessons in the unit, you should probably allow at least 7 weeks to teach the entire unit. Tests, reteaching difficult ideas, and supplemental activities could make the unit last longer.
MATTER AND MOLECULES

Unit Introduction

For the next several weeks you will be studying matter and molecules. You will learn to explain what matter is made of and how it changes. Before you do that, though, let's talk about a basic question: What is matter, anyway?

Matter is all the "stuff" that the world around us is made of. All solids, liquids, and gases are forms of matter. Your body, trees, the oceans, air, and clouds are examples of matter. You will learn in this unit about many different substances. All are kinds of matter.

As you learn about the substances in the world around you, you will discover that this unit is different from most other science books. You will learn some new and interesting facts, but more importantly, you will use those facts to explain things in the world around you. This unit is designed to help you explain things, not just learn facts.

Sometimes we will ask you to explain things that you haven't studied yet. We do this because sometimes your own ideas are important, even if they are not scientifically correct. Many of you will have different answers to these questions because you have different ideas. To learn science well, it is important for you to think about how your answers to questions are the same or different from other students' answers and your teacher's ideas. Whenever this book asks you to write your ideas about something before you talk about it in class, write the best answer you can, then think about your answer and other peoples' ideas.

So let's begin now. We will start by looking at one of the most common (and one of the most important) of all the substances around us--WATER.
Unit Introduction

You may want to discuss with your students some things that are not matter. These may include the vacuum of outer space, forms of energy such as light and heat, or abstract concepts such as temperature, force, and love.

If some students are still confused, stress that any solid, liquid, or gas is matter. If something is not a solid, liquid, or gas, it is not matter.
INTRODUCTION TO LESSON CLUSTER 1
States of Water

A. Lesson Cluster 1 Goal and Lesson Objectives

Goal

Students should be able to describe the three states of water in terms of the arrangement and movement of water molecules.

Lesson Objectives

1.1. Describe ice (solid water) and liquid water as two different states of the same substance.

1.2. Describe ice (solid water), liquid water, and water vapor as three different states of the same substance.

1.3. Describe liquid water as composed of invisible water molecules.

1.4. Describe the differences among the three states of water in terms of the arrangement and movement of water molecules.

Describe the unique properties of water and how these properties affect our lives.

B. Key Elements of a Good Description

1. At the visible or macroscopic level, students should be able to state that ice, liquid water, and water vapor are the same substance. Liquid water changes into ice or water vapor by heating or cooling. During the changes of states, liquid water does not disappear or change weight.

2. Students should recognize that there is invisible water vapor in the air.

3. At the invisible molecular level, students should explain the observable properties of ice, liquid water, and water vapor in terms of the arrangement and motion of water molecules. Key points include the following:

   a. Ice, liquid water, and water vapor are all made of water molecules, H₂O.

   b. Water molecules are too small to be seen, even with a microscope, and they are always in motion.
c. Ice, liquid water, and water vapor differ in the arrangement and motion of water molecules:

- Ice: Water molecules are locked in a rigid pattern, and vibrate in their places.

- Liquid water: Water molecules slide and bump past each other.

- Water vapor: Water molecules move freely with much more space between them than in the liquid or solid state.

C. Conceptual Learning

This lesson cluster introduces the unit by focusing on water, a substance that is familiar to students in its solid (ice), and liquid (water) states. This substance is used to introduce many key ideas of the unit, ideas which will be applied repeatedly throughout the unit. Some of the ideas that may cause difficulty for your students are discussed below.

Lessons 1 and 2:

At the observable or macroscopic level, students must recognize the essential sameness of water in all three states of water. First, although most students understand that ice and liquid water are the same substance, a variety of subtle misconceptions are common:

a. Some students believe that when ice melts into water, it loses weight, because ice is solid or hard.

b. Some believe that when water evaporates, it loses its weight, or that when water evaporates, it disappears or becomes weightless.

Second, many students have difficulty with the idea of water vapor. The cause of the difficulty is that water vapor is invisible, whereas ice and liquid water are observable. Many students have the following common misconceptions:

a. Water does not change into gas, or water vapor.

b. "Foggy steam" from boiling water is the gaseous state of water. It is not; it is really tiny drops of liquid water.

c. There is no water vapor in the air. Students who believe this have difficulty understanding condensation in Lesson Cluster 9.

d. The bubbles in boiling water are air.
Lessons 3, 4 and 5:

At the invisible or molecular level, you will probably find that many of your students haven't heard of the word "molecules." Even if some students have heard of it, their understanding is likely to be substantially different from the ideas conveyed in this unit. Furthermore, although many students might have heard of the term atoms, their understanding may not be scientific. Their acquaintance with the term atoms may even interfere with the new term molecules.

The size of molecules is one characteristic that is difficult for students to understand because it lies outside the realm of their normal experience. Although students think of molecules as small, it is hard to convey just how small they are. Many students think of molecules as similar in size to other tiny objects that they are familiar with, such as specks of dust, bacteria, or cells. Even if they say that molecules are smaller than these objects, they may still think that they can see molecules with a microscope. In reality, a typical human cell contains perhaps 100 trillion molecules; a dust speck, even more. Thus, molecules are too small to be seen.

Students also have difficulty in understanding that molecules are constantly moving. Molecules are always moving, even in substances such as ice where no motion of the substance is visible. Many students think that molecules are moving in liquid water because liquid water is flowing, but molecules are not moving in ice because ice is not moving. The constant motion of molecules is difficult for students to believe, both because it seems to contradict the evidence of their senses and because they have never encountered objects that, like molecules, are so tiny that they are unaffected by friction and thus never come to a stop.

Students are confused between observable properties of a substance and properties of the molecules themselves. Many students may believe, for instance, that molecules of water become hard and cold when the water freezes, rather than simply becoming locked into a rigid arrangement and motion in their places. Some students may even think that when water changes into ice water, water molecules change into ice molecules.

Many students believe that there are molecules in substances rather than the substances are made of molecules. For example, they think that water contains molecules (like blueberries in a muffin) rather than consisting of molecules and nothing else (like grains of rice). Students may think there is "air" or "water" between water molecules. Thus, it needs to be strongly emphasized that water is made of only molecules and there is nothing between water molecules.
D. Conceptual Contrasts

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students’ Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of matter</td>
<td>Matter is conserved in all physical changes.</td>
<td>Matter not always conserved, especially in changes involving gases (e.g., water disappears when it is heated).</td>
</tr>
<tr>
<td>Water vapor in air</td>
<td>Air contains invisible water vapor.</td>
<td>Water in air is visible (e.g., fog, &quot;steam&quot;). There is no gaseous state of water.</td>
</tr>
<tr>
<td>Molecular constitution of matter</td>
<td>All matter is made of molecules.</td>
<td>Molecules are in substances (e.g., water has molecules in it, with water between the molecules).</td>
</tr>
<tr>
<td>Size of molecules</td>
<td>Molecules are too small to see, even with a microscope.</td>
<td>Molecules may be comparable in size to cells, dust specks, etc. Molecules can be seen with a microscope.</td>
</tr>
<tr>
<td>Constant motion</td>
<td>All molecules are constantly moving.</td>
<td>Molecules may sometimes be still, especially in solids.</td>
</tr>
<tr>
<td>Visibility of molecular motion</td>
<td>Molecular motion continues independently of observable movement.</td>
<td>Molecules simply share in observable movements of substances (e.g., molecules do not move in ice because ice is frozen).</td>
</tr>
<tr>
<td>Molecular explanation of states of matter</td>
<td>States of matter are due to different arrangements and motions of molecules: - solid: vibrate in rigid array. - liquid: random motion within limits. - gas: random motion, no limits.</td>
<td>States of matter described only in terms of observable properties of the state attributed to individual molecules (e.g., water molecules are hard in ice).</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 1
States of Water

Lesson 1.1: Solid Water and Liquid Water

You certainly know about liquid water. That’s what you drink and take showers in. But have you seen any solid water around recently? Of course you have, only you probably called it ice.

How do you know that ice is really solid water? Can you show it? You probably can, but there isn’t much time, so you’ll have to hurry!

* * * * * *
Do Activity 1.1 in your Activity Book
* * * * * *

Ice and liquid water look and feel different, but they are still the same substance: ice can change to water and water can change to ice. Scientists call these different forms of water STATES. The solid state of water is ice. The liquid state of water is water. Water also exists in a third state, a gas called water vapor. We will discuss water vapor in the next lesson. Since solid water (ice), liquid water, and gaseous water (water vapor) can be changed into each other by heating or cooling, that is a good reason to believe that they must be different states of the same substance.
Lesson 1.1: Solid Water and Liquid Water

Purpose:

To help students describe ice and liquid water as two different states of the same substance.

Advance Preparation:

For each group of 2-3 students you will need ice cubes and a ziplock plastic bag which will provide a water tight seal. If you choose to do the optional activity, you need a balance to weigh the ice cube-plastic bag system.

Materials List:

For each group of students: one ice cube and one ziplock plastic bag. For the class: one balance (optional).

Teaching Suggestions:

Have the students read the first two paragraphs of the student text. Elicit as many student responses as possible to the question "How do you know that ice is really solid water?" Discuss the student responses until students understand the problem for the activity.

When you begin to talk about gases, be alert to any student confusion between "gas" and gasoline. Although gasoline is a liquid some people shorten the word to "gas."
Lesson 1.2: Solid, Liquid, and Gas

In the last lesson you learned about solid water and liquid water. In this lesson you will learn about the other state of water, the gas called water vapor.

Have you ever seen water vapor? The answer is no. You have never seen water vapor, even though it is all around us and you have felt its effects. In order to learn more about water vapor, watch your teacher do Demonstration 1.2.

* * * * * * *

Do Question Set 1.2 in your Activity Book
* * * * * * *

As you can see from the demonstration, water vapor is an invisible gas. Liquid water changes to water vapor when it evaporates or boils. The gas inside the bubbles of boiling water is water vapor. Water vapor can change back into liquid water when it cools down.

Water vapor is always invisible. You might think that the "steam" you see rising from boiling water is water vapor, but it is not. The "steam" you see is really tiny drops of liquid water that form when the water vapor cools.

Water changes from liquid to gas in the flask, then back to liquid in the test tube
Lesson 1.2: Solid, Liquid, and Gas

**Purposes:**

To help students describe liquid water and water vapor as two states of the same substance. To have students infer that ice, liquid water, and water vapor are three states of the same substance.

**Advance Preparation:**

In order to demonstrate the distillation of water, you should collect the materials and assemble the apparatus before class. A drawing of the apparatus on p. 3 of the Science Book will help you visualize the setup. You should start heating the water about 10 minutes before class so it is operating during class without any drops of water in the connecting tube. By having the apparatus operating before the students observe it carefully, you can usually prevent some students thinking that drops of liquid water that are in the tube are water vapor.

**Materials List:**

One hot plate, one small Erlenmeyer flask with a one hole stopper, glass tubing including two right angles, one test tube, and one beaker.

**Teaching Suggestions:**

Before you do this activity, you should be aware of how we use "steam" in this unit. Technically, steam refers to hot water vapor, so both steam and water vapor are invisible. However, this is contrary to the way steam is used in everyday conversation. To most people, steam is the "fog" or "white cloud" above boiling kettles or coming off a hot shower. This usage is so common that it is confusing to confront grade 6 students with the scientific definition. Therefore, for the purposes of this unit, we use the technical definition of water vapor (that it is an invisible gas) and the nontechnical, or common, usage of steam (that it is a "white cloud" or "fog").

1. Have the students read the first portion of the student text and discuss it completely.

2. The students should answer question #1 in the Activity Book (Question Set 1.2) before they observe the distillation of water closely.

3. Do the demonstration, have the students complete the Question Set, and discuss their responses completely.

4. Continue with the Science Book. Stress that water vapor is always invisible and that there is always water vapor in the air. Also emphasize that ice, liquid water, and water vapor are three states of the same substance.
Because we cannot see it, we are not always aware of the water vapor around us, but it is always there. There is always water vapor in the air around us, and on humid days, the amount is especially high. Dew, and fog, and rain are all made of drops that formed when water vapor in the air changed back into liquid water.

Ice, liquid water, and water vapor are three different states of the same substance. They are water in its solid, liquid, and gas states. They are the same because they are all made of the same "stuff." In the next lesson, you will learn more about the makeup of the three states of water.
Lesson 1.3: Molecules, the Smallest Pieces of Water

In Lessons 1.1 and 1.2 we decided that liquid water, ice, and water vapor are all the same substance. What reasons did we give for that? They are all the same substance since they can change from one state to another by simply heating or cooling. Scientists have another reason for saying that they are the same substance. They are all made of the same tiny pieces or molecules.

What do we mean by that? Well, let’s try to answer by thinking of the following question: If you had a pair of magic eyeglasses that showed the tiniest parts of water, what would the water look like?

This question may seem strange to you. After all, water doesn’t look like it is made of anything except little drops of water. You know that water can be in little droplets, so maybe you said that water is made of little water droplets. Well, what is a water droplet made of?

We cannot tell what water is made of just by looking at it. But scientists say that water is made of water molecules. That is, if you divide a water droplet into smaller pieces until you can not divide it any more, then we have the tiniest pieces of water. We call these tiniest pieces, water molecules.

*Magic eyeglasses show molecules of water*
Lesson 1.3: Molecules, the Smallest Pieces of Water

Purposes:

To introduce the molecular theory of matter and to help students describe liquid water as composed of invisible molecules that are constantly moving.

Materials List:

1. Transparency 1: How big is a speck of dust compared to a molecule?

Teaching Suggestions:

You may want to re-read the section, Students’ Conceptual Learning, found in the Introduction at the beginning of Lesson Cluster 1. In re-reading this section, please note that most students have difficulty believing that water is made of molecules and nothing else. Some students come to think that there are molecules in the water rather than water consisting of molecules and only molecules. You should stress, therefore, that water is made of only water molecules and nothing else. Students also have difficulty believing that molecules are constantly moving, especially in a solid like ice. These two concepts are among the most important concepts in the entire unit as well as in this lesson.

The first paragraph gives you the opportunity to review the major concepts taught in lessons 1.1 and 1.2. You may also want to stress that when ice changes to liquid water, the water has exactly the same number of molecules as did the ice. Thus, there could not be a change in weight. The same is true for liquid water changing into water vapor.

Molecules of water are actually shaped somewhat like the way we have drawn them (see Science Book p. 6). This "Mickey Mouse" shape is easy for students to remember. Atoms of hydrogen and oxygen are not solid balls, as the drawing suggests; each atom actually consists of a "cloud" of electrons surrounding a nucleus made of protons and neutrons. But water molecules and other molecules often do act like small hard particles.
Some of you might have heard that water is called \( H_2O \). We call water \( H_2O \) because one water molecule is made of even tinier parts, called atoms. A single water molecule contains two hydrogen (H) atoms and one oxygen (O) atom. The oxygen atom is larger, and the hydrogen atoms are stuck to it in kind of a V-shape. All water molecules are the same. Each water molecule is \( H_2O \).

\[
\text{HYDROGEN} \quad \text{HYDROGEN} \\
\text{H} \quad \text{H} \\
\text{O} \quad \text{OXYGEN}
\]

* A molecule of water (\( H_2O \))

Every drop of liquid water—and every sliver of ice—is made of trillions of water molecules, and every water molecule contains three atoms (two hydrogen atoms and one oxygen atom).

Since we already said that water molecules are the tiniest pieces that make up water, you know that they are very small. But how small are they?

Let’s compare them with some other small things. There are some small things that you can barely see, like specks of dust. Water molecules are much, much smaller than that.

There are other small things that we can see only with a microscope, like germs or the cells our body is made of. Are water molecules smaller than cells or germs?

Yes, much smaller! In fact, a typical cell in your body might be made of 100 trillion \((100,000,000,000,000)\) molecules. (More than half of these are water molecules, but a cell contains many other kinds of molecules, too.)
This is a good place to use Transparency 1:

**HOW BIG IS A SPECK OF DUST COMPARED TO A MOLECULE?**

![Diagram showing the size comparison]

The speck of dust is really trillions of times bigger than any of the molecules in air.

---

**TRANSPARENCY 1: HOW BIG IS A SPECK OF DUST COMPARED TO A MOLECULE?**

**Bottom Layer**

Many students believe that molecules are about the same size as or perhaps a little smaller than a speck of dust, a cell, or a germ. Encourage students to express their answers to the question.

**Overlay**

Many students may have difficulty with understanding the relative size of molecules. Contrast students' incorrect ideas with the scientific notion that the speck of dust is really trillions of times bigger than the molecules of air. Reference to the comparison of a cell with water molecules (illustration: Science Book, p. 7) may help. [A trillion is equal to 1,000,000,000,000.]

All students have difficulty comprehending how incredibly small molecules are. Although it is not necessary for students to know exactly how small molecules are, they should definitely get the impression that they are very, very small, are constantly moving and never stop moving even in solids such as ice.
Suppose our magic eyeglasses could show us a single cell floating in a drop of water. What would it look like? Something like the picture below. (The picture can't show the whole cell because a cell is so much bigger than the water molecules.)

The molecules of liquid water are always moving. They are constantly sliding past and bumping into each other. They never stop. They are moving in all different directions. This movement goes on all the time, even when the water is just sitting in the cup.

The two important points we have talked about in this lesson are: liquid water is made of very tiny, tiny pieces called water molecules, and water molecules are always moving. In Lessons 1 and 2, we said that ice (solid water), liquid water, and water vapor (gaseous water) are the same substance.

Then in this lesson, you learned how all three states of water are the same. They are made of water molecules which are constantly moving. Now, can you guess what is different about the molecules in the three states of water? In Lesson 1.4, you will learn about how ice, liquid water, and water vapor are different. You will also learn how ice, liquid water, and water vapor are alike. First, though, try answering some questions about what you learned in this lesson.

* * * * * *

Do Question Set 1.3 in your Activity Book

* * * * * *
Lesson 14: Molecules and the Three States of Water

You have learned how ice, liquid water, and water vapor are the same. They are all made of water molecules, and those water molecules are always moving. Then, how are ice, liquid water, and water vapor different? Why do they look different? Why do they act different? How can we explain the differences in terms of molecules? You will learn about these topics in this lesson.

The differences among the three states of water are not in the molecules themselves. Water molecules are all the same. The differences are in the way the molecules are arranged and the way they move. Can you think of ways that water molecules might be arranged differently in the three states of water? If you can, discuss your ideas with your classmates.

Here is how scientists explain the differences among the three states of water. In solid water (ice), water molecules are close together, locked in a rigid pattern, and thus they are not moving past each other. They vibrate, but they stay in place. Remember, molecules are constantly moving and never stop, even in a solid.

In liquid water, water molecules are moving faster. They are still close together, but they are no longer stuck in a rigid pattern as they are in ice. Water molecules in liquid water are constantly sliding past and bumping into each other; they keep moving from one place to another.

The molecules of water in water vapor are far apart and moving freely. They have lots of empty space between them. They move rapidly through this empty space, hitting and bouncing off each other.

The pictures on the next page give a rough idea of how water molecules look in ice, liquid water, and water vapor. (Though you could never really see them--they’re much too small!)
Lesson 1.4: Molecules and the Three States of Water

Purpose:

To help students describe the differences among the three states of matter in terms of the arrangement and movement of water molecules.

Teaching Suggestions:

In using this lesson with students, stress that the difference in properties among ice, liquid water, and water vapor is due to the arrangement and movement of the molecules and not due to any change in the molecules themselves.

Also, stress that molecules are constantly moving and never stop, even in a solid.
Ice:

*Water molecules are locked in a rigid pattern, vibrate in their places.*

Liquid water:

*Water molecules slide and bump past each other*

Water vapor:

*Water molecules bounce around freely in space*
Stress that the differences among the three states of matter is the result of the arrangement and movement of the molecules and not due to changes in the molecules themselves.
For the last four lessons you have been learning about a single important substance, water. You have learned that water exists in three states: ice, liquid water, and invisible water vapor. You have learned that the three states are the same in that they are all made of very tiny water molecules that are always moving.

Finally, you have learned how the arrangement and motion of water molecules are different in the three states. In ice the molecules are stuck rigidly together and vibrate in place. In liquid water they slide and bump past one another. In water vapor they are much farther apart and they bounce around freely.

Water is not the only substance in the world, though. We can see thousands of other substances all around us. In Lesson Cluster 2 you will learn about some of those other substances and the molecules that they are made of.

Now we have some questions for you. Let's see if you can use these ideas to answer them.

* * * * * * * * * * *

Do Review Question Set 1.4 Now

* * * * * * * * * *
Supplemental Reading: The Miracle of Water

Water is the most abundant liquid on earth and is needed by all living things. Rivers, oceans and lakes cover about three fourths of the surface of the earth. Besides this, there are large amounts of underground water. In many places, you can tap into this underground water by drilling wells. A water well is a hole in the ground from which you can pump water. Many people get their drinking water from these wells. Your body is about 71% water. Fruits and vegetables contain about 90-95% water.

Water, this very common liquid that you use every day, has many uncommon properties. Many of these uncommon properties are essential to life on earth. One of water's properties is that it dissolves more solids, liquids, and gases than any other liquid. This uncommon property of water allows your blood to carry oxygen and food to every cell of your body and to carry carbon dioxide and waste materials from each cell of your body. This property also allows you to wash your face, wash your clothing, cook your food, and to stay alive. It is for these reasons that water is called the universal solvent. (A solvent is a liquid that dissolves other solids, liquids, and gases.)

Another uncommon property of water is that it takes a lot of heat to increase its temperature, and it gives off a lot of heat when it cools down. If it were not for this uncommon property, life as we know it would only exist near the equator. The sun heats the earth, including the water, near the equator and as the water moves north and south from the equator it keeps the earth warm enough to support the living things that you are aware of. This uncommon property also helps you maintain your body temperature. In other words, this helps you stay warm in the winter and cooler in the summer.

One of the most surprising uncommon properties of water is that it expands when it freezes. Almost all other liquids contract when they solidify or freeze and expand when they melt. When you cool down water it contracts just like any other liquid until it is 4 degrees Celsius. From 4°C to 0°C, the temperature at which water freezes, it expands. Ice, then, acts like any other solid and expands when heated and contracts when cooled.

This special property of water is truly a miracle because it makes possible life on earth. Because water expands when it freezes, ice is light enough to float on top of liquid water. Scientists predict that if water contracted instead of expanding when it freezes, the ice would build up from the bottom of the lakes until eventually the lakes were made of solid ice. This would mean that states like Michigan, Wisconsin, Indiana, Ohio, Pennsylvania and New York would be much colder in the summer time than they are now.
Supplemental Reading: The Miracle of Water

Purpose:

To help students describe the uncommon properties of water and how these properties affect their lives.

Teaching Suggestions:

We use water frequently in our science activities because it is available, familiar to students and inexpensive. Students need to know, however, that many properties of water are not typical of most substances.

You should use this lesson to emphasize these exceptional properties of water. The exceptional properties include:

1. Most living things contain more water than any other substance.

2. Water dissolves a greater number of other substances than any other substance.

3. Water has a great capacity to retain heat.

4. Most liquids contract when they freeze. Water expands between 4°C and 0°C.

5. Water changes from one state to another within a narrow temperature range. There is always water as a gas (water vapor) in the air, liquid water in the oceans, and solid water (ice) at the earth's poles.

Discuss these properties to help students describe the uncommon properties of water.
Because water expands when it freezes, it also helps to loosen the soil and break up rocks to make soil. Over thousands and thousands of years, this process has helped to make some of the richest farm lands in the world.

Another uncommon property of water is that it changes from one state to another within a relatively narrow temperature range. This enables us to have solid water in the freezer, liquid water to drink, and boiling water to cook our food.

The title of this section is "The Miracle of Water" because these uncommon properties of water make life possible on earth, make most portions of the earth warm enough for people to live, provide water in the form of rain far from lakes and rivers to help provide more food for people and help us have an abundance of a convenient liquid to wash our clothes, cook our food, and cool our drinks. As you study more about water, you will see that the combination of unique properties of water is truly a miracle.
D. **Conceptual Contrasts**

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular constitution of matter</td>
<td>All matter is made of molecules.</td>
<td>Molecules are in substances.</td>
</tr>
<tr>
<td>Size of molecules</td>
<td>Molecules are too small to see.</td>
<td>Molecules may be seen with a microscope.</td>
</tr>
<tr>
<td>Motion of molecules</td>
<td>All molecules are constantly moving.</td>
<td>Molecules may be still, especially in solids.</td>
</tr>
<tr>
<td>Visibility of molecular motion</td>
<td>Molecular motion continues independently of observable movement.</td>
<td>Molecules simply share in observable movements of substances.</td>
</tr>
<tr>
<td>Different kinds of molecules</td>
<td>Different substances are made of different kinds of molecules.</td>
<td>Substances are made of the same kind of molecules.</td>
</tr>
<tr>
<td>Pure substance vs. mixture</td>
<td>Pure substances are made of one kind of molecules; mixtures, two or more kinds of molecules.</td>
<td>Distinction based on observable properties, such as taste, color, etc.</td>
</tr>
<tr>
<td>Molecular explanation of states of matter</td>
<td>States of matter are due to different arrangements and motions of molecules.</td>
<td>States of matter described only in terms of observable properties of substance or properties of individual molecules.</td>
</tr>
</tbody>
</table>
INTRODUCTION TO LESSON CLUSTER 2  
Other Solids, Liquids, and Gases

A. Lesson Cluster 2 Goals and Lesson Objectives

Goals:

Students should be able to describe solids, liquids, and gases of a variety of substances in molecular terms.

Students should be able to contrast pure substances and mixtures in terms of their molecular composition.

Lesson Objectives:

Students should be able to:

2.1. Explain that different substances are made of different kinds of molecules.

2.2. Contrast pure substances with mixtures, substances that contain more than one kind of molecule.

2.3. Contrast solids, liquids, and gases of different substances in terms of motion and arrangement of their molecules.

B. Key Elements of a Good Description

Students should explain that different substances are made of different kinds of molecules and that pure substances contain only one kind of molecule, while mixtures contain two or more kinds of molecules. Students should contrast solids, liquids, and gases of all substances in terms of motion and arrangement of molecules:

- Solids: Molecules vibrate while locked in a fixed pattern.
- Liquids: Molecules move about while remaining close together, sliding past each other and constantly colliding.
- Gases: Molecules move freely about in space, sometimes colliding with each other or with objects.

C. Students’ Conceptual Learning

Much of this lesson cluster focuses on the application of ideas from Lesson Cluster 1 to substances other than water, particularly ideas about molecules’ small size and constant motion, and the motion and arrangement of molecules in different states of matter. Students should come to recognize that molecules are the basic components of all substances. Some students may still think that molecules are in substances, rather than substances are made of molecules.
LESSON CLUSTER 2
Other Solids, Liquids, and Gases

Lesson 2.1: Are Other Substances Made Of Molecules?

In Lesson Cluster 1 you studied ice, water, and water vapor. All three states of water are made of the same kind of molecules—H\textsubscript{2}O. Each state has molecules arranged differently, but the molecules are the same. Water molecules are the building blocks for ice, water and water vapor.

If you look around you, most of the substances you see are solids, liquids, or gases. Most substances can also change from one state to another. For example, lead is usually a solid, but if you heat it hot enough, it becomes a liquid. If you heat liquid lead very hot it becomes a gas. You can change the solid form of a substance into a liquid, or a liquid into a gas. It is possible to do this because all the states of a substance are made of the same kind of molecules.

You could never change ice into glass, though, or water into alcohol, or water vapor into oxygen gas. Even though these substances look similar and are in the same state, one cannot be changed into another? Do you know why?

The answer is that their molecules are different. Each substance is different from every other substance because each is made of its own kind of molecules. In the same way, we can classify all substances as either solid liquid, or gas, but that doesn’t mean that all liquids are exactly alike. Each substance is made of its own kind of molecules, with a certain size, shape, and weight.

Let’s look at some examples of different kinds of substances and their molecules. You have already studied one substance, water, and you have seen drawings of what a water molecule looks like. You learned that a water molecule can be drawn like the picture below.
If we were able to see the molecules in a drop of pure water, (that is, water that is not dirty, or polluted) we would notice that all of the molecules of water would look exactly the same. They would all have the same structure.

If we could see the molecules of another substance, for example, alcohol, would these molecules look the same as the water molecules we just studied? No, the alcohol molecules are different from the water molecules. That’s because each substance has its own kind of molecule, with a certain size, shape, and weight. The molecule of alcohol would look like this:

![Image of alcohol molecule](image)

**ALCOHOL: CH₃CH₂OH**

As you can see, an alcohol molecule looks very different from the molecules of water because it is made of different atoms. If we could use our magic eyeglasses to see the molecules in a drop of alcohol, we would see that all of the alcohol molecules have exactly the same shape, size, and weight.

The world is made of millions of different substances, and every substance is made of its own kinds of molecules! Some molecules, like water molecules, contain only a few atoms. Other molecules have hundreds or thousands of atoms. Even the largest molecules, though, are far too small to see.
Lesson 2.1: What Are Other Substances Made Of?

Purpose:

To help students explain that different substances are made of different kinds of molecules.

Materials List:

Transparency 2: Why can you change liquid water into ice but not alcohol?

Teaching Suggestions:

Some students may know that lead and solder are used by plumbers to seal pipes. Lead is an excellent substance for this because it melts at 327°C (620°F) and boils at 1620°C (2948°F). Solder is 2/3 lead and 1/3 tin and melts at 275°C (527°F). Because of its relatively low melting temperature solder is also used to connect or solder electrical wire.

After Lesson Cluster 1, some students may think that different substances are made of the same kind of molecules (for instance, that water, sugar, and alcohol all are made of the same kind of molecule). This lesson is designed to help students realize that different substances are different because they consist of different kinds of molecules.

To stress the impossibility of changing one substance to another, you might want to refer to Midas, a legendary Phrygian king who for a time was given the power of turning to gold everything he touched. The only way he could have done that was by substituting gold molecules for the molecules of the substance.
Sugar is another substance you probably know. A sugar molecule is made of many atoms. (The formula is $C_{12}H_{22}O_{11}$). This is too complex to draw here. So in this unit, we will make up a shape for a sugar molecule like this:

![SUGAR: C_{12}H_{22}O_{11}](image)

All substances are made of molecules, but that doesn’t mean that everything is made of molecules. Some things are not substances at all. Light, heat, and sound are not substances; they are forms of energy. Thoughts, love, and space are not substances either. Things that are not substances cannot be solids, liquids, or gases, and they are not made of molecules. There are no light molecules, or heat molecules, or sound molecules. There are no temperature molecules, or space molecules, or love molecules. Only matter exists as solids, liquids, and gases. Only matter is made of molecules.

Now try answering some questions about different substances and their molecules.

* * * * * * *

Do Question Set 2.1 in your Activity Book

* * * * * * *
Stress that water molecules are different than alcohol molecules. Each substance has molecules unlike any other substance.

Compare the drawing of the water molecule with the formula $H_2O$.

Compare the drawing of alcohol with water. You may want the students to describe how they are the same and how they are different.

At the grade 6 level we do not distinguish the various kinds of alcohol. If students ask, there are many kinds of alcohols such as methyl (wood alcohol), ethyl (grain alcohol), isopropol (rubbing alcohol), etc.

Another way to write the formula for alcohol is $C_2H_5OH$. 
Lesson 2.2: Pure Substances and Mixtures

You learned in the last lesson that different substances are made of different kinds of molecules. Molecules of each substance have their own size, shape, and weight, and they are different from the molecules of all other substances. We can use this idea to help us study the difference between a pure substance and a mixture. We can tell a pure substance from a mixture by thinking about molecules.

A pure substance has only one kind of molecule. Pure substances can be either solids, liquids, or gases. Pure sugar is an example of a pure substance. It is made only of sugar molecules. Lead, water, and alcohol are also pure substances. They each have only one kind of molecule.

A mixture has two or more different kinds of molecules mixed together. Mixtures can also be either solids, liquids, or gases. The Kool-Aid that you drink is an example of a mixture: It contains water molecules and other molecules mixed together. Sometimes you can tell that something is a mixture by looking at it, but not always! Try making some mixtures and see!

* * * * * *

Do Activity 2.2 in your Activity Book

* * * * * *

It is easy to tell that some things are mixtures because you can see the separate particles: salt and pepper, for example. Sometimes, though, the substances when mixed together break up into individual molecules: sugar and water, for example. You can no longer see the different substances, but their molecules are still there, all mixed together!

Most of the materials around us are mixtures, made of two or more different kinds of molecules. Very few substances are pure substances. Even substances that look pure may actually be mixtures.

For example, you might think that glass is a pure substance because it is clear, and you can see through it. But glass is actually a mixture of many different kinds of molecules. Milk is also a mixture, and ocean water. Your body is a mixture containing thousands of different kinds of molecules.
In discussing the drawings of molecules, stress that there are different combinations of atoms that make up various different molecules.

Use Transparency 2 here:

**WHY CAN YOU CHANGE LIQUID WATER INTO ICE BUT NOT INTO ALCOHOL?**

![Diagram of water and ice](image)

**WHY CAN YOU CHANGE LIQUID WATER INTO ICE BUT NOT INTO ALCOHOL?**

![Diagram of water and alcohol](image)

**TRANSPARENCY 2: WHY CAN YOU CHANGE LIQUID WATER INTO ICE BUT NOT INTO ALCOHOL?**

**Bottom Layer**

Many students will know that you cannot change water into alcohol, but will not be able to correctly explain why. They will be able to tell you on a macroscopic level that, "Water and alcohol are not the same stuff" but not how the two substances are, in molecular terms, different.

**Overlay**

It is important to point out through the overlay the scientific idea that water and alcohol cannot be changed into one another because their molecules are different. [In connection with this transparency it may also be useful to have students look at the illustrations on p. 15 of the Science Book.]
What about air and water? Are they pure substances or mixtures? Water is a pure substance, made of only water molecules. Air, on the other hand, is a mixture, made of many different kinds of molecules mixed together. You will study more about air in Lesson Cluster 3, but for now the important point to remember is that it is very hard to tell whether a substance is a pure substance or a mixture just by looking at it, tasting it, or smelling it.

All pure substances are either solids, liquids, or gases. But some mixtures such as muddy water are not easily classified as a solid, a liquid, or a gas. This is because mud contains solid particles of dirt mixed with liquid water. So mud is partly solid and partly liquid. Mud and many other mixtures contain two different states of matter.
Lesson 2.2: Pure Substances and Mixtures

**Purposes:**

To help students distinguish between pure substances and mixtures and to realize most common materials are mixtures not pure substances. To describe pure substances as being made of one kind of molecule, and mixtures as made of two or more different kinds of molecules.

**Advance Preparation:**

For each group of students you need to prepare six plastic cups, salt, pepper, sugar, oil, syrup, and dirt or soil. Because each group will need six plastic cups, you might want to assign each group member particular tasks.

**Materials list:**

For each group you will need:

1. six plastic cups
2. salt
3. pepper
4. sugar
5. syrup
6. dirt or soil
7. water

You will also need Transparency 3: What would ocean water look like?

**Teaching Suggestions:**

A majority of students may distinguish mixtures from pure substances based on observable properties, such as taste, color, texture, etc. Students need to recognize that even substances that appear "pure" may actually be mixtures of different kinds of molecules. There is often no way to tell a pure substance from a mixture by only observable properties.

1. After reading the definitions of pure substance and mixtures but before you do Activity 2.2, you may want to have the students list as many pure substances and mixtures as they can. Discuss their examples.

2. After the students discuss the remaining Science Book Lesson 2.2, emphasize that pure substances are made of only one kind of molecule while mixtures are made up of two or more different kinds of molecules.
Lesson 2.3: Molecules and States of Matter

In Lesson Cluster 1 you studied the three states of a single substance—water. In this lesson cluster you have studied several other substances: sugar, alcohol, oxygen, and so forth. Try using what you know about these substances to think about these questions:

How are all substances alike?
How are substances different from each other?

You might want to think about these questions for a minute before you read on.

* * * * * * *

There are many possible answers to the above questions. Substances are alike and different in many ways. Here are three correct answers that are very important:

1. All substances are alike in that they are all made of molecules.
2. Substances are alike in that they are found in three basic states: Solid, liquid, and gas.
3. Different substances are made of different molecules. (Pure substances like water and sugar are made of only one kind of molecule. Mixtures like air and wood contain different kinds of molecules mixed together.)

In this lesson you will be thinking about the molecules of solids, liquids, and gases. In what way are the molecules of all solids alike? In what ways are the molecules of different solids different? What about liquids and gases? You can think about these questions by discussing some substances that you are already familiar with.

Let's start with solids. Solids of different substances, like salt, steel, and sugar, are made of different kinds of molecules, but all solids are alike in the arrangement and motion of their molecules. All solids are made of molecules that are close together and locked into a rigid pattern. They move by vibrating in place and bumping into each other.
Use Transparency 3 here:

**WHAT WOULD OCEAN WATER LOOK LIKE?**

- How many different kinds of molecules would you see?

**WHAT WOULD OCEAN WATER LOOK LIKE?**

- How many different kinds of molecules would you see?
- You would see water molecules, salt molecules, and dozens of other kinds.

---

**TRANSPARENCY 3: WHAT WOULD OCEAN WATER LOOK LIKE?**

**Bottom Layer**

Often students make distinctions between mixtures and pure substances based on observable properties only; they believe that if something looks clear, then it is a pure substance. Thus, they will say that ocean water is pure because it looks clear. This would imply that ocean water has only one kind of molecule, even though most students will not answer in terms of molecules.

**Overlay**

Ocean water, even though it looks clear, has several different kinds of molecules, thus making it a mixture and not a pure substance. Emphasize this difference to your students. Although ocean water is a mixture of a number of different substances, only salt is shown in this transparency, as it is the most familiar to students.
The molecules of all solids are locked in a rigid pattern and vibrate in place

Similarly, different liquids such as water, alcohol, and gasoline are made of different kinds of molecules, but all liquids are alike in the motion and arrangement of their molecules. All liquids are made of molecules that move around freely but stay close together. The molecules of liquids slide past each other and are constantly bumping into other molecules.

The molecules of all liquids slide and bump past each other
Lesson 2.3: Molecules and States of Matter

Purpose:
To help students contrast solids, liquids, and gases in terms of motion and arrangement of molecules.

Materials List:
Transparency 4: How are molecules arranged and how do they move?
Different gases such as water vapor, oxygen, and carbon dioxide are made of different kinds of molecules, but all gases are also alike in the motion and arrangement of their molecules. All gases are made of molecules that are far apart from each other and moving freely through space. Sometimes gas molecules collide with other molecules or with objects.

\[ \text{The molecules of all gases are far apart and bounce around freely} \]

Now you have learned a lot about solids, liquids, and gases of different substances. You have learned that all solids, liquids, and gases are made of molecules. Different substances are made of different kinds of molecules, but the motion and arrangement of molecules is about the same in all solids. All liquids also have molecules that move and are arranged in similar ways. So do all gases.

You also know that some substances are pure substances; all their molecules are the same. Most substances, though, are mixtures, of different kinds of molecules. In the next lesson cluster you will study a gas that is a mixture of several different kinds of molecules. We can't see this gas, but it is very important to us. The gas is air.

\[ \text{*******} \]

Do Review Question Set 2.3 Now

\[ \text{*******} \]
Teaching Suggestions:

Solid: Some students may think that molecules in solids are not moving or that molecules themselves are hard. You should help these students distinguish observable properties of substances from invisible properties of molecules. Use the transparency to elicit the students' ideas about the arrangement and movement of molecules before you use the overlay. Then contrast the students' thinking with the overlay.

In discussing the molecules of a solid, you might want to use the analogy of students in their seats in your class. The students are in their chairs (fixed position) but they are constantly moving within this place. They do not move past each other.

Liquid: You might want to continue the analogy by comparing the movement of molecules of a liquid with the students moving around the room before or after class. Students are not in a definite array or pattern but moving past each other in a random manner.

Gas: The student analogy of a gas would be students moving very far apart after school is out. They move freely in all directions. (School buses are not a good analogy.)
How are molecules arranged and how do they move?

1. In grains of solid sugar?
2. In liquid alcohol?
3. In oxygen gas?

Solid sugar: Molecules are locked in a rigid pattern and vibrate in place.
Liquid alcohol: Molecules slide and bump past each other, but stay close together.
Oxygen gas: Molecules are far apart and move freely in space. They sometimes hit each other.

Transparency 4: How are molecules arranged and how do they move?

Bottom Layer
Even though students have learned about how molecules move and how molecules are arranged in water, they often cannot transfer these ideas to other substances. Also, many students still have difficulty with movement of molecules in solids.

Overlay
You should contrast students' naive thinking with the overlay, which gives a scientific view of molecules. Emphasize that even though the molecules of one substance (like sugar) may be different than the molecules of another substance (like ice), the molecules are still arranged and move in the same way in the solid state. This is what makes substances solids, liquids, or gases. Pay particular attention to movement of molecules in solids, as student have difficulty with this concept.

Supplemental Activities
1. Look up the molecular formulas of other pure substances, such as propane gas, ammonia, salt, baking soda, and make or draw models of a molecule of each.
2. You can show that milk (and other substances) are mixtures by freezing them. The water freezes before other substances in the mixture freeze.
INTRODUCTION TO LESSON CLUSTER 3
The Air Around Us

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to describe air in terms of both its macroscopic properties and its microscopic composition.

Lesson Objectives:

Students should be able to:

3.1. Describe air as a substance that takes up space.

3.2. Describe air as a mixture of molecules: nitrogen (N₂), oxygen (O₂), carbon dioxide (CO₂), water vapor (H₂O), and other gases.

Explain how a variety of other substances may be mixed in air. Also, explain how we are able to smell some substances.

3.3. Describe how breathing changes the composition of air by increasing or decreasing the amount of O₂, CO₂ and H₂O.

B. Key Elements of a Good Description

At the macroscopic level, students should describe air as a substance that takes up space. Air is a mixture of gases. The component gases vary in proportion from place to place and time to time.

At the molecular level, air is a mixture of different kinds of molecules, mostly N₂ and O₂ with small and sometimes variable amounts of other gases, such as CO₂, water vapor (H₂O), etc. Other substances may also be mixed in air, for instance, dust, germs, smell of substances, etc., but they are not a part of what we call air.

Also at the molecular level, students should explain that breathing changes the composition of air by increasing or decreasing the amount of CO₂, O₂, and H₂O.

C. Conceptual Learning

This lesson cluster provides opportunities for students to apply several ideas from previous lesson clusters, such as:

-- gas is a state of matter
-- like all matter, air is made of molecules, so tiny that they are invisible, and constantly in motion
-- air contains a mixture of different kinds of molecules
-- there is always water vapor present in air
There are other ways in which the contents of this lesson cluster are new and potentially difficult, however. Some of these problems have to do with ideas about air that are common in student thinking and in our language, but are not scientifically accurate. We speak of air as light, "airy," insubstantial, or even as nothing. Students must learn to see air and other gases as forms of matter like liquids and solids, with all the characteristics of matter in general:

-- air is made of molecules
-- air takes up space

The topic of air also causes difficulties for students because air is a complex mixture of gases that are generally colorless, odorless, and thus undetectable except by indirect means. Furthermore, the exact composition of air varies from time to time and from place to place. Many important phenomena, including respiration, photosynthesis, humidity, smells, pollution, and the water cycle, are associated with variations in the mixture of molecules in air. We cannot discuss all of these phenomena in this lesson cluster, or even in this unit. But a good understanding of the nature of air will prepare students for future learning about these phenomena.

**Lesson 3.1**

The question "Is air something or nothing?" may sound trivial, but some students think that air is nothing. Others who think that air is something still may have ideas that are not scientifically accurate. For instance, some may use air as a generic term for gases. Some may think that air has color or odor. This problem is caused by the fact that pure air is colorless and odorless, and thus not easily detected. Students should realize that air is "something," that it is a form of matter, and that it takes up space.

Matter is often defined as anything that occupies space and has weight. The definition is fine. We have emphasized the former and neglected the latter, because the concept of weight is often difficult for students to understand.

**Lesson 3.2**

A common student misconception about the composition of air is that molecules of air are substances that can be seen in the air. Some common examples of these misconceptions are as follows:

1. Air is made of dust particles, germs, bacteria, pollution, etc.
2. Dust particles or germs are comparable in size to that of molecules of air.
3. Air is made of some kind of "wavy" lines.

The teacher should take care to dispel these misconceptions by stressing that air is made of molecules. The teacher should also stress the size of a dust particle or other substances compared to the invisible size of molecules.
Another common student misconception about the composition of air is that air is a continuous medium that serves to hold things such as dust, dirt, and smells. The teacher should emphasize that air itself is composed of molecules and that particles of other substances such as dust and dirt can be mixed in air.

Students may also think that air is a single type of gas and thus that "pure air" contains only one type of molecule. The teacher should emphasize that even "pure" air is a mixture, consisting of different kinds of molecules of gases. (The relative amounts of these different kinds of molecules of gases vary from time to time or from place to place.)

Among the different kinds of molecules that make up air, the one students have most difficulty in understanding is the presence of water vapor in the air. The teacher should emphasize that air contains invisible water vapor (H₂O) as well as other kinds of gases, including oxygen (O₂), nitrogen (N₂), carbon dioxide (CO₂), and a few other gases.

The teacher should also help students understand that other substances may be mixed in the air, such as dust, dirt, germs, smells, etc. These substances are not part of the composition of pure or clean air. The gases that make up pure air are colorless and odorless, so what we see or smell is other substances mixed in air. You also should emphasize that air consists of only molecules and that there is nothing (that is, just empty space) between molecules of air.

Some students may be confused between observable movement of air and invisible molecular motion. For instance, students may think that molecules move in air because air is moving, and molecules stop moving when air is still. The teacher should stress that molecules of air always move and never stop. Since air is in the gaseous state, molecules are far apart and move freely.

Students may have difficulty in understanding the properties of smells of substances:

-- smell is matter
-- smell is gas
-- smell is made of molecules

Smells are substances mixed in air. We smell because the molecules move to our nose. Some common misconceptions are that (1) air carries smell, (2) smell travels through air, and (3) air molecules pick up smell.
Lesson 3.3

You should emphasize how breathing can change the composition of air by increasing the amount of CO₂ and H₂O and decreasing the amount of O₂. A common student misconception is that we breathe in oxygen and breathe out carbon dioxide. The teacher should help students understand by stressing that we breathe in and out air but the mixture of different kinds of molecules are different. That is, the air we breathe in and out contains the same kinds of molecules: nitrogen, oxygen, water, carbon dioxide, and a few others. The amounts of these substances, though, are different. The air that we breathe out has less oxygen, because some of it has been used by our body. It has more carbon dioxide and water vapor, because these are produced by our body.
### D. **Conceptual Contrasts**

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter vs. non-matter</td>
<td>Solids, liquids, and gases are matter, other things are not.</td>
<td>Gases often incorrectly classified as non-matter. Air is nothing.</td>
</tr>
<tr>
<td></td>
<td>Matter takes up space; non-matter does not.</td>
<td>Classification based on other properties (e.g., something you can see or feel)</td>
</tr>
<tr>
<td>Smell</td>
<td>Smells are gases and made of molecules.</td>
<td>Smells considered ephemeral, not really matter. Air carries smell or smell travels through air. Air molecules pick up smell.</td>
</tr>
<tr>
<td>Water vapor</td>
<td>Air contains invisible water vapor (humidity).</td>
<td>There is no gaseous state of water.</td>
</tr>
<tr>
<td>Molecular constitution of matter</td>
<td>All matter is made of molecules.</td>
<td>Substances not described as molecular.</td>
</tr>
<tr>
<td>Size of molecules</td>
<td>Molecules are too small to see, even with a microscope.</td>
<td>Molecules may be comparable in size to cells, dust specks, etc. Molecules can be seen with a microscope.</td>
</tr>
<tr>
<td>Motion of molecules</td>
<td>Molecules are constantly moving.</td>
<td>Molecules may sometimes be still (e.g., still air).</td>
</tr>
<tr>
<td>Visibility of molecular motion</td>
<td>Molecular motion continues independently of observable movement.</td>
<td>Molecules simply share in observable movements of substances (e.g., molecules move in air because air is moving).</td>
</tr>
<tr>
<td>Pure substance vs. mixture</td>
<td>Pure substances are made of one kind of molecules; mixtures, two or more kinds of molecules.</td>
<td>Distinction based on observable properties, such as taste, color, odor, etc.</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 3
The Air Around Us

Lesson 3.1: Is Air Nothing or Something?

Air is all around us and all around the earth, but you can't see it. What is air?

Air is all around us

I asked one of my friends what would be left if you took all the furniture and rugs out of a room. She said "nothing." What about the air? Is air nothing? You can't see it, but there is something there. Try some activities where you work with the "something" that is air.

* * * * * * *
Do Activity 3.1 in your Activity Book now
* * * * * * *

When you hold a cup upside down under water, the cup does not fill up with water because air is really something. It is a gas that takes up space. Otherwise, we could easily fill up the cup with water.

When you sucked air out of the cup, did you notice that the level of water inside the cup went up? What happened when you blew air back in? You might have noticed that, this time, the water level went down. Air must be something, because it makes the water move up and down inside the cup.

In this lesson you learned that air is something that takes up space. The next lesson will help you find out what that "something" is.
Lesson 3.1: Is Air Nothing or Something?

Purpose:

To help students describe air as a form of matter that has certain definite properties, such as taking up space.

Advance Preparation:

This activity will require several large containers of water, preferably ones which are clear to better permit students to see the air levels in tumblers inverted in the water. Large beakers or other clear plastic containers would work well.

Materials List:

For each student group:

1. a small plastic bag
2. a plastic cup or small jar
3. a large container of water
4. a 2-ft length of plastic or rubber tubing
5. a grease pencil for marking water levels on cup

Teaching Suggestions:

This lesson is designed to show students that air really is "something", that it is a form of matter, and that it does take up space, as shown by the activities. Often students think that air is nothing, or not matter.

The major thrust of this lesson is Activity 3.1: Is the air in a cup a real substance?
Lesson 3.2: What is Air Made of?

Air is not a liquid or a solid. Air is a gas. Like all gases, air is made of molecules that are far apart. That is why you cannot see air.

All the molecules of air are moving all the time, even when there is no breeze. The molecules never stop moving. They are far apart so they move freely, but they bump into each other and into other things, bouncing back and forth.

Air is all around us, all the time. Even though you can’t feel them, molecules of air are always hitting you. You breathe in molecules of air and breathe them back out.

The air that is all around the earth is called the atmosphere. The atmosphere goes up past the clouds, higher than mountains. As you go higher in the air, the molecules of air get farther and farther apart, and the air gets thinner and harder to breathe. If you keep going up, you finally get to space, where there are no air molecules at all.

SPACE

ATMOSPHERE

EARTH

The atmosphere surrounds the earth

What are molecules of air like? First of all, let’s imagine clean air without any germs, bacteria, dirt, dust, smoke, or pollution in it. Clean air is a mixture of different kinds of molecules, including nitrogen molecules (N₂), oxygen molecules (O₂), carbon dioxide molecules (CO₂), and water molecules (H₂O). These molecules "look" something like the pictures on the next page, though they are really too small to see.
Lesson 3.2: What is Air Made of?

Purposes:

To help students describe air as a mixture of molecules: mostly nitrogen (N₂), and oxygen (O₂), but also including carbon dioxide (CO₂), water (H₂O), and other gases. To help students describe air as having other materials mixed in it, such as dust, dirt, and smells.

Materials List:

1. Transparencies: "What does the air look like?", "How big is a speck of dust compared to a molecule?", and "What is the smell of baking cookies?"

2. Perfume to be released in the classroom.

Teaching Suggestions:

Resulting from the preceding lesson the students should be starting to think about air as matter. This lesson will reinforce that concept. Remember: A common student misconception is that molecules of air are substances that can be seen in air, such as dust or pollution. Continue to talk about having magic glasses so that students remember how tiny molecules are.

Have the students read the Science Book out loud or silently, and discuss any problems they might have.
Air is made mostly of nitrogen, oxygen, water, and carbon dioxide

How are these molecules alike and how are they different? All the nitrogen molecules are alike, but they are different from the oxygen molecules. All the oxygen molecules are alike, but they are different from water molecules. These molecules move freely and mix together to make air. AIR IS MADE OF THESE MOLECULES.

How big or small do you think these molecules of air are? Different molecules have different sizes. Oxygen molecules are slightly bigger than nitrogen molecules. Nitrogen molecules are slightly bigger than water molecules. But how does the size of any kind of a molecule compare with a very, very small object you can see with your eyes, like a speck of dust? Which is bigger, a molecule or a speck of dust? How much bigger? If we compare the size of a molecule and that of a speck of dust, it would look like the picture below:

Air molecules and a speck of dust
Discuss the questions and the pictures thoroughly. Use Transparency 5 here:

**WHAT DO MOLECULES OF AIR LOOK LIKE?**

How many different kinds of molecules would you see in this jar of air?

**WHAT DO MOLECULES OF AIR LOOK LIKE?**

Air is made up of the following kinds of molecules:
- nitrogen (N₂)
- oxygen (O₂)
- water (H₂O)
- carbon dioxide (CO₂)

How many different kinds of molecules would you see in this jar of air?

**TRANSPARENCY 5: WHAT DO MOLECULES OF AIR LOOK LIKE?**

**Bottom Layer**

Students have a number of different conceptions about air. Some believe that air is nothing, or that there would be no molecules of air in the jar. Others believe that there is a generic kind of "air molecule." Some think that oxygen is the only thing of which air is made. Others believe that air is made up of pollution, germs, bacteria, smoke, dust, and other substances which can sometimes mix with air.

**Overlay**

It is extremely important to contrast these naive ideas with the scientific conceptions. Students should learn that air is not only something, but a number of different "somethings," namely, nitrogen, oxygen, water, carbon dioxide, and small amounts of other gases. You should also point out that, although oxygen is a part of the air, it is not the only thing air is made of, or even the most plentiful. Show them that there is much more nitrogen in the air-almost four times more.

Use Transparency 1 here:

**TRANSPARENCY 1: HOW BIG IS A SPECK OF DUST AS COMPARED TO A MOLECULE?**

Look for illustration and explanation of student misconceptions in Lesson 1.3.
As you see in the picture, a speck of dust which you can barely see with your eyes is much, much, bigger than a molecule (trillions of times bigger!). The speck of dust is made of trillions of molecules itself; it is a solid while air is a gas.

If you look at the air molecules in the picture, you will see that they are mostly nitrogen and oxygen molecules. Air is about 4/5 nitrogen and 1/5 oxygen. Water, carbon dioxide, and other gases make up only two or three percent of the molecules in the air. Can you think of any substances other than dust that mix in air? There are many, including dirt, germs, bacteria, smoke, and many other substances. Most substances that you can see in the air, like dust or smoke, are made of solid particles that contain trillions of molecules each. But sometimes substances that you can't see also mix with air.

What else is sometimes in the air? Did you think of smell?

Do Question Set 3.2 in your Activity Book

What is the smell of perfume? First of all, smell is a gas and made of molecules. When a bottle of perfume is opened, some molecules of the perfume leave the bottle, go into the air, and mix in the air. These molecules of perfume in the air are constantly moving, so they spread out. They spread out until the perfume molecules reach and affect your nose. Then you can smell them.

The same thing happens when you open a bottle of ammonia or you cut into a lemon. Molecules of the ammonia or lemon spread out in the air until they reach your nose. Ammonia, lemon, and perfume molecules are smelly because they affect your nose.

You smell ammonia when you breathe air with ammonia molecules in it

In this lesson you answered questions such as "What is air made of?", "What are smells?", and "How do smells travel?" In Lesson 3.3 you will study more about air and breathing.
Before doing the perfume activity, close the classroom windows and doors to avoid drafts.

Use Transparency 6 here:

**WHAT IS THE SMELL OF BAKING COOKIES?**

**WHAT IS THE SMELL OF BAKING COOKIES?**

The smell of baking cookies is a gas. Some of the molecules of the cookie move through the air.

\[
\text{\textbullet \textbullet \textbullet \textbullet \textbullet \textbullet } \text{air molecules} \\
\text{\textbullet \textbullet \textbullet \textbullet \textbullet \textbullet } \text{cookie smell molecule}
\]

**TRANSPARENCY 6: WHAT IS THE SMELL OF BAKING COOKIES?**

**Bottom Layer**

Many students do not fully understand smells. These students will say that the smell of baking cookies is "a fume" or "an odor" or "a scent." They usually cannot use what they know about molecules to explain smells.

**Overlay**

You should help students to see the scientific notion of smells, that all smells are gases and are made of molecules. Some of the molecules of the cookies break away from the cookie and then mix with and move through the air until the smell reaches your nose because of the constant motion of the air and smell molecules.
Lesson 3.3 Air and Breathing

Has anyone ever told you that you breathe in oxygen and breathe out carbon dioxide? Well, that isn’t really quite true. You breathe in air, which has oxygen molecules mixed in with molecules of nitrogen and other gases. What you breathe out is air, too, but the mixture of molecules is different! This lesson is about the changes that take place in air when you breathe it in and breathe it back out.

* * * * * *

Do Activity 3.3 in your Activity Book

* * * * * *

The air you breathe in is made mostly of nitrogen molecules, but your body has no use for them. You breathe them right back out. What your body needs from the air is the oxygen molecules that it contains. Oxygen molecules are used by your body; you get your energy by combining food and oxygen.

When your body uses food and oxygen, it produces two other substances, carbon dioxide and water vapor. How do you get rid of them? By putting them into the air that you breathe out!

The air that you breathe out, then, still contains the same kinds of molecules: nitrogen, oxygen, water, carbon dioxide, and a few others. The amounts of those substances, though, are different. The air that you breathe out has less oxygen, because some of it has been used by your body. It has more carbon dioxide and more water vapor, because these are produced by your body. The pictures on the next page illustrate these differences.
Lesson 3.3: Air and Breathing

Purpose:

To help the students explain that air breathed out contains more water vapor and carbon dioxide than normal air.

Background Information:

Bromthymol Blue (BTB) is an indicator that is blue in the presence of bases and yellow in the presence of acids. BTB turns yellow in this experiment because the interaction of carbon dioxide and water produces a weak acid, carbonic acid ($\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$).

Advance Preparation:

Prepare a BTB solution by adding about 35 drops of BTB to 3.5 liters (one gallon) of water. You may find it convenient to prepare more BTB solution to keep for later activities. Use approximately 10 drops of BTB per liter (quart) of water. The solution can be stored in plastic milk containers.

If the BTB solution is yellow when you prepare it, add a very small amount of household ammonia until the solution turns blue. Variations in the mineral content of the water can affect the color of the solution. Often the minerals will cause the BTB solution to turn green instead of yellow. However, this color change will still indicate the presence of carbon dioxide. Distilled or deionized water (available at grocery stores) have very low mineral contents.

Materials List:

For each student group:

1. a plastic cup
2. a soda straw
3. BTB solution

Teaching Suggestions:

1. Use the Science Book to introduce Activity 3.3: Breathing Out and Breathing In.

2. After you completed the activity use the Science Book to help students explain what happens to the air when they breathe.
In this lesson cluster you studied what air is made of and how breathing affects the make-up of air. In the next lesson cluster you will learn how to compress and expand air.

* * * * * *

Do Review Question Set 3.3 Now

* * * * * *
The observation that breath breathed out changes the color of the ETB solutions shows more CO₂ than in normal air, as you saw in the activity. Water vapor from breath condensing on a cool glass shows more H₂O than in normal air. These observations suggest these two components (CO₂ and H₂O) have variable composition in air. The relative amounts of N₂ and O₂ is quite constant throughout the world (78% N₂, 21% O₂, and about 1% other gases). The relative amounts of other gases are approximately: CO₂, 0.03%; H₂O, 0.3%.

Breathing at high altitudes is discussed in Lesson Cluster 5.3.

You might want to use Question Set 3.3: Cluster Review during the next class period. It can be used, if you wish, as an evaluatory tool.
INTRODUCTION TO LESSON CLUSTER 4
Compressing and Expanding Air

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain the expansion and compression of
gases (e.g., air) in molecular terms.

Lesson Objectives:

Students should be able to:

4.1. Explain that molecules are constantly moving and hitting each
other.

4.2. Explain why air in the syringe can be compressed, but water can
not.

4.3. Explain the various concentrations of air molecules at different
altitudes.

4.4. Understand how to make a good explanation, using the example of a
bicycle tire.

B. Key Elements of a Good Explanation

This is the first lesson cluster that focuses primarily on using the
kinetic molecular theory to explain observable phenomena. Such
explanation, however, will be the primary focus of all the remaining
lesson clusters. In general, all good explanations using the kinetic
molecular theory should do at least the following:

a. Substances:

Identify the substance that is responsible for the observable
phenomenon that is being explained and describe the macroscopic
changes that are taking place in that substance.

b. Molecules:

Describe the changes in molecules that are responsible for the
macroscopic substances.

For all of the phenomena in this lesson cluster, the key substances
are gases that are being compressed or are expanding. Students should
learn to explain both why air and other gases can be compressed and
why they "push back" harder when they are compressed. They can be
compressed because the molecules of gases are relatively far apart,
with lots of empty space between them. They push back harder when
they are compressed because when molecules are pushed closer together,
more of them hit the walls of the container, so the gas "pushes out"
harder.
C. **Conceptual Learning**

Constructing a complete molecular explanation for a phenomenon is a difficult process for many students. Some students do not even see why we would consider a discussion of molecules an "explanation," since students are used to explaining things by relating them to familiar ideas and events and the idea of molecules is not familiar or comfortable to them.

Even students who are trying to construct molecular explanations for phenomena often find it very difficult. They may have difficulty identifying the key substance that is responsible for the change, focusing, for instance, on the bicycle tire rather than the air inside it. They may not know what is happening to the substance, or to the molecules that it is composed of, or they may not be able to explain the relationship between molecular events and macroscopic phenomena. This unit contains many observable phenomena; the students will need all of these opportunities and lots of help to master this difficult task.

This lesson cluster builds in a variety of ways on ideas from earlier lesson clusters. In particular, students will need to use the ideas that all gases are substances made of molecules, and that those molecules are in constant motion, colliding with each other as well as with objects and the walls of whatever container holds a gas.

This lesson cluster also introduces several new and different ideas associated with the compressibility of substances. On the macroscopic level, many students have had little experience with the compressibility of gases or the relative incompressibility of solids and liquids.

D. **Conceptual Contrasts**

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of gases in space</td>
<td>Gases spread evenly through the spaces they occupy.</td>
<td>Distribution of gases is uneven before or after expansion or compression.</td>
</tr>
<tr>
<td>Compression of gases</td>
<td>Gases can be compressed.</td>
<td>Gases move from one region to another when compressed or expanded.</td>
</tr>
<tr>
<td>Constant motion</td>
<td>All molecules are constantly moving.</td>
<td>Molecules may sometimes be still, especially in solids.</td>
</tr>
<tr>
<td>Spaces between molecules</td>
<td>Gases consist of nothing except molecules with empty spaces between them.</td>
<td>Molecules have &quot;air&quot; or other things between them.</td>
</tr>
</tbody>
</table>
Lesson 4.1 and 4.2

To understand compression or expansion of gases, students should recognize that gases are evenly distributed through the spaces they occupy. Since air is invisible, however, students often postulate that air is distributed unevenly in order to explain a phenomenon. The most common student misconception is that gases (e.g., air) move from one place to another when compressed or expanded. For instance, when air is compressed in a syringe, air stays around the opening of the syringe because air is pushed forward. In contrast, when air expands in the syringe, air stays around the plunger because air is pushed backward. In fact, the constant motion of molecules and their freedom to move anywhere in the gaseous state assures that they will generally be distributed evenly (actually randomly) throughout the space occupied by a gas.

Compression of gases can be understood because of a molecular characteristic that most students are not aware of: Molecules of gases are relatively far apart and the spaces between them are empty. Some students may not think in terms of spaces between molecules. Furthermore, the teacher should emphasize that air consists only of molecules with empty spaces between these molecules.

In contrast to gases, solids and liquids can not be compressed by ordinary means. Molecules of liquids and solids are fairly closely packed and in constant contact with each other, so solids and liquids are much harder to compress. However, students may simply think in terms of observable properties of water vs. air, such as, water is hard or water has more "stuff" in it. At the microscopic level, some may think that molecules are larger or harder in water than in air. Thus, the teacher should emphasize that the difference between the compression of air and water is due to the relative distance between molecules. (Those solids that can be compressed are generally porous, like sponges. It is the air pockets that are easily compressed, not the solid itself.)

Lesson 4.3

The concentration of air varies at different altitudes. However, students may think that concentration of air is the same in a valley, at sea level, or in high mountains, and see no relationship to the compression or expansion of air in a syringe. The concentration of air, again, is due to relative spaces between molecules at different altitudes.

It is probably not important in this unit to talk about air pressure, or the weight of the atmosphere. We are only using the examples in this lesson as additional ways of talking about how molecules are arranged in gases. The teacher should stress how concentration of air is related to the amount of air that our body needs: We need to breath harder at higher altitudes, because we take in less air with each breath.
LESSON CLUSTER 4
Compressing and Expanding Air

Lesson 4.1: Explaining Things with Molecules

In the lessons that you have already studied, you have been learning quite a bit about molecules; what they are, how small they are, how they move, how they are arranged, and so on. These lessons have been helping you explain things in terms of molecules, not just in terms of what you see, hear, or feel.

In science, we often explain how things happen by giving molecular explanations. By using what we know about molecules in our explanations, we can better understand why something happens in a certain way.

For example, we have already learned that molecules are constantly moving. Because air molecules are constantly moving, they are always hitting objects in the air. This helps to explain why certain things happen. See if you can use the idea of air molecules hitting things to help you explain the demonstrations that your teacher will now do. Watch and discuss the demonstrations, then answer questions about these events in your activity book.

1) Hair dryer and ping pong ball.
2) Sitting on inflated ball, basketball or football.
3) Blowing on wind chimes (optional).

* * * * * * *

Do Question Set 4.1 in your Activity Book
* * * * * * *

In talking about the demonstrations you just watched, you might give explanations that mention the air but not air molecules. But a much better scientific explanation would also talk about what the molecules are doing and how they are involved in what is happening. Talking about molecules gives a better, more complete explanation of how things happen.

Look at the explanations that you wrote in your activity book. Did the explanations mention how the molecules of air were hitting the objects? If you did not, then see if you can change your explanations so that they talk about molecules.
Lesson 4.1: Explaining Things with Molecules

Purpose:

To help students explain that molecules are constantly moving and constantly hitting each other.

Advance Preparation

For this demonstration you will need a hair dryer, ping-pong ball, and an inflated ball. Wind-chimes are optional.

Materials List:

1. Ping-pong ball
2. Inflated ball
3. Hair dryer
4. Wind-chimes--optional

Teaching Suggestions:

1. Have the students read the first three paragraphs of the lesson and discuss them.

2. Do the demonstrations. You will need a hair dryer with a round nozzle and a ping-pong ball. When the hair dryer is pointed straight up it will support the ball in mid air.

3. Have the students answer the questions in the activity book and discuss them.
Lesson 4.2: Compressing Air

Can you push air closer together to get more air in a smaller space? This activity will help us answer that question.

* * * * * *

Do Activity 4.2 in your Activity Book

* * * * * *

A good explanation of why you can push the plunger partway in with air in the syringe, but not all the way, would go like this: Molecules of gases are far apart and have empty spaces between them. The molecules of air in the syringe are scattered all through the syringe. When the plunger is pushed in, the molecules of air are pushed closer together. When air molecules are pushed closer together, we say that the air is compressed.

Air and other gases can be easily compressed because their molecules are far apart. The molecules of solids and liquids, though, are already close together. This makes it almost impossible to compress solids or liquids such as water.

When you pushed the plunger in and then let it go, you should have seen the plunger move back out again. The plunger moves back out because air molecules are hitting it all the time, pushing on it, just like air molecules in the wind were pushing on the ping pong ball to hold it up. When you push in on the plunger, the air molecules are pushed closer together, and more of them hit the plunger. When you let go of the plunger, the air molecules push it back out.

The molecules that make up air and the molecules that make up water are always moving. Molecules of water are sliding past each other, moving all around. Molecules of air move quickly around inside the syringe, hitting each other and hitting off the inside of the syringe and plunger. This constant motion keeps the molecules spread evenly through the inside of the syringe.
Lesson 4.2: Compressing Air

Purpose:

To help explain that a gas has molecules that are very far apart with large empty spaces between the molecules. The gas molecules can be pushed together. Liquids can not be compressed because the molecules of liquids are already close together.

Materials List:

For each group of students:

1. Syringe
2. A plastic cup
3. Water

You will also need Transparency 7: What happens to air molecules when the plunger is pushed in?

Teaching Suggestions:

If you anticipate that the students will use the syringes for water fights do not distribute the water until it is needed.

1. Introduce the lesson with Activity 4.2.

2. You might want to review the arrangement and motion of molecules in liquids and gases before the students read the Science Book.
Use Transparency 7 here:

TRANSPARENCY 7: WHAT HAPPENS TO AIR MOLECULES WHEN THE PLUNGER IS PUSHED IN?

WHAT HAPPENS TO AIR MOLECULES WHEN THE PLUNGER IS PUSHED IN?

Bottom Layer

Many students believe that air molecules will escape or try to escape when the plunger of a syringe is pushed in. Some think all or most of the molecules are pushed to the opening of the syringe.

Overlay

Students hold the above misconceptions because they do not understand the idea of compressibility of air. You should point out to students that molecules of air have large, empty spaces between them. This means that when air is compressed, molecules merely move closer together. The molecules remain evenly distributed and are not all at one end of the syringe.
Lesson 4.3: Breathing Thick Air and Thin Air

You have just learned about how air can be compressed in a syringe when its molecules are pushed closer together. Now we'll look at other examples of air that are more or less compressed -- we'll call them thin air and thick air.

**Thin air.** One example of thin air is the air that is found in parts of the world where there are very high mountains. The air becomes much thinner high up in the atmosphere. When people climb really high mountains, they need to take extra oxygen with them in tanks. There is not enough air in every breath they take to let them climb the mountain without fainting.

![The air is thin up high in the mountains](image)

A similar thing happened to runners in the 1968 Olympic Games in Mexico City. Mexico City is very high up in the mountains. Runners had to breathe very hard because they took in less air with each breath. In order to prepare their bodies for this, many runners did their training in mountain areas all over the world so that they could get used to the "thin air."

**Thick air.** An example of thick air is the air found in a scuba tank. A scuba tank is a tank of air that a person can use to breathe **underwater** for about an hour.

![A scuba tank contains compressed air](image)
Lesson 4.3: Breathing Thick Air and Thin Air

Purpose:

To help students describe the various concentration of air molecules at different altitudes and to use the kinetic molecular theory to explain compression of gases.

Advance Preparation:

You may want to demonstrate compressed gas by using aerosol cans or a CO₂ fire extinguisher.

You may be able to find pictures of scuba divers or mountain climbers.

Materials List:

Aerosol cans or CO₂ fire extinguisher (optional)

Teaching Suggestions:

You can use aerosol cans to demonstrate the force with which compressed gas comes out of the can. Pictures of mountain climbers or deep sea divers using compressed air tanks may be useful in stimulating student interest and discussion.

1. Have the students read the Science Book and discuss the major ideas.

2. Then have the students do the Question Set 4.3.

3. Other Examples of Thick Air and Thin Air:

   a. Commercial airline flights. Some students probably have flown on commercial airline flights; above 10,000 feet the air is too thin to breathe easily. The entire crew and passenger compartments are pressurized to provide people sufficient air to breathe. Federal regulations require that emergency oxygen masks be provided on commercial airliners that fly above 10,000 feet.

   b. Deep-sea divers
The tank itself is not that big. In order to breathe from it for an hour, a lot of air has to be pushed into it. In fact a whole room full of air is compressed into the tank.

All of the air molecules in the room are forced into the tank

Do Question Set 4.3 in your Activity Book

Why is it harder to breathe up in the mountains than down in the valleys? We have already said that mountain climbers and runners in the mountains take in less air with each breath they take. How can we use what we know about molecules to help us understand that?

Air is made of molecules. These molecules are always moving, and they are very far apart. Up in the mountains, air molecules are farther apart than down in the valleys.
This is a good time to review what students have learned in this lesson and draw out any remaining misconceptions.
Each breath we take in the mountains has fewer molecules in it because the molecules are farther apart. Our bodies need the same amount of air, so we have to breathe harder, or else we will not get enough oxygen. That is why mountain climbers need to take the oxygen tanks with them.

What happens when we release air from a scuba tank? The air molecules have been pushed very close together in a full tank. When the tank valve is opened, the air rushes out—you can hear it making a rushing noise. Because the molecules inside the tank are pressed close together, they escape from the tank very quickly. As they escape, they move farther apart from each other. The air from the tank expands, or spreads out, as it escapes into the room.
You may have students try to explain, after having heard this explanation, how other phenomena work, such as the commercial airliners discussed at the beginning of this lesson.
Lesson 4.4: Bicycle Tires

Up to this point in this cluster, you have seen that air can be compressed. We explained air compression by saying that air molecules are normally very far apart, with lots of empty space between them, and they can be pushed closer together.

You have also learned something about scientific explanations. To make a good explanation, you often need to talk about molecules. You need to talk about the way molecules move and the way they are arranged in solids, liquids, and gases. You also need to know what kind of molecules you are talking about. You need to identify the substance that is changing and tell how it is changing.

In other words, a good explanation answers at least two questions:
1. A question about substances: What substance is changing and how is it changing?
2. A question about molecules: What is happening to the molecules of the substance?

Let's think about the explanation of air escaping from an air tank and see if it answers those questions. We said that air (substance) comes out of the tank and expands into the room because the molecules of air inside the tank are pressed very close together, and they move farther apart. That explanation answers both the question about substances and the question about molecules.

Now let's try to explain something else: What happens when you fill a bicycle tire with air? This is a little more complicated than the scuba tank or the syringe, but it will help you learn more about air molecules and how to make good explanations.

What happens when you fill a bicycle tire with air?
Lesson 4.4: Bicycle Tires

Purpose:

The primary purpose of this lesson is to introduce students to a simple way of checking the quality of their explanations. A good explanation discusses both the substances that are changing and what is happening to the molecules of those substances. Students apply this rule to one situation: Pumping air into the bicycle tire. The rule will be used regularly throughout the rest of the unit.

Advance Preparation (optional):

You may want to pump up a bicycle tire as a demonstration.

Materials

1. Bicycle pump and tire (or entire bicycle)
2. Transparency 8: Where does the air go when you pump it into a tire?
3. Poster 1: To EXPLAIN things, ask TWO QUESTIONS

Teaching Suggestions:

1. Have students explain what happens when air goes into and out of the bicycle tire.

2. You should model applying the rule to check the quality of the explanations.

3. Discuss other situations with students applying the rule themselves.

Use Poster 1 here:

To EXPLAIN things, ask TWO QUESTIONS

ONE about SUBSTANCES: What substance is changing and how is it changing?
and

ONE about MOLECULES: What is happening to the molecules of the substance?
Here is one explanation that answers both the question about substances and the question about molecules: As the tire is pumped up, air (substance) in the tire is being pushed into the tire and compressed. The molecules of the air are being pushed closer and closer together.

Notice that the air is the substance that is making the important changes, not the bicycle tire. The tire is getting a little bit bigger, but not a lot bigger. For a lot of air to fit into a bike tire, the molecules have to move closer together. The air has to be compressed.

The air in a bike tire will be evenly distributed inside the tire. As the molecules of air are pumped into the tire, the molecules spread out evenly, so there will not be more molecules near the valve.

If you let the air out of a tire, the molecules that were pressed very close together will now spread far apart. When this happens, the spaces between the molecules get bigger, and the air expands.

In this lesson cluster, you have learned many things about air molecules. You have learned that air molecules are constantly moving and hitting things. You have learned that air molecules can be pushed closer together; that is, air can be compressed. Air molecules can also spread farther apart. When this happens, we say that the air expands. You have also learned that air molecules are evenly distributed—this means that they spread out evenly and that they don't bunch up together in one place more than another place.

Finally, you learned what the two parts are to a good explanation. To make good explanations, you need to answer two questions:
1. A question about substances: What substance is changing and how is it changing?
2. A question about molecules: What is happening to the molecules of the substance?
WHERE DOES THE AIR GO WHEN YOU PUMP IT INTO A TIRE?

THE AIR MOLECULES SPREAD EVENLY THROUGH THE TIRE.

TRANSPARENCY 8: WHERE DOES THE AIR GO WHEN YOU PUMP IT INTO A TIRE?

Bottom Layer

Many students feel that when you pump air into a tire, the air molecules stay right next to the valve stem. They feel air simply goes "into the tire," and do not offer any further explanation.

Overlay

Students' naive ideas should be countered with the overlay. When air is pumped into a tire, the air molecules spread out until they are relatively evenly spaced. Thus, students should understand that the air "goes all over" or spreads evenly throughout the tire.

Suggestions for additional activities

1. Air pressure at sea level is about 15 pounds per square inch, and, the pressure of a gas is inversely proportional to its volume (i.e., doubling the pressure, halves the volume). Have students figure out what the pressure the of the gas in a syringe is when the volume is reduced from 5 ml to 2.5 ml, to 1 ml, to 0.5 ml.
INTRODUCTION TO LESSON CLUSTER 5
Explaining Dissolving

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain dissolving of solids in liquids in terms of molecules.

Lesson Objectives:

Students should be able to:

5-1. Explain how sugar dissolves in water.

5-2. Explain why stirring causes solids to dissolve faster than not stirring.

5-3. Understand that most solutions are complex, that is, have several solids dissolved in water.

B. Key Elements of a Good Explanation

As already introduced in Lesson Cluster 4, to make a good explanation, students need to answer two questions:

a. What substance is changing and how is it changing?

b. What is happening to molecules of the substance that accounts for the change?

For various phenomena of dissolving in this lesson cluster, the key substances are solids that are dissolving in liquids. It is the solids that are changing, but liquids also have important functions in the change. Thus, students should recognize how solids are changing and how liquids cause this change.

At the molecular level, students should understand two major components involved in dissolving:

a. Molecules of liquids hit the grains of solids.

b. Molecules of solids break away and spread out evenly in liquids.

Unless students integrate all three components in their explanation, their understanding of dissolving is not complete. Furthermore, students should realize that it is the molecular part of the explanation that provides a reason and accounts for the change in substances.
C. Conceptual Learning

Students are familiar with dissolving in daily life and, apparently, it seems easy to explain at a macroscopic level (that sugar, for instance, breaks up into pieces too small to be seen). The process of dissolving, however, is complicated at the molecular level. To develop adequate understanding, students should integrate several major components involved in dissolving. Due to this complication of explanation, dissolving may be a difficult task for some students.

Lesson 5.1

When sugar dissolves in water, the amount of sugar is conserved (does not increase or decrease). Some students may not understand conservation of matter. Students may think that, because sugar disappears, it no longer exists. They may mean this when they say that sugar evaporates or dissolves. Students should recognize that even though they can not see sugar in water, it is still there.

Water has a critical role in dissolving: Water molecules hit the sugar molecules and cause them to break away from sugar crystals. However, many students may think that water has nothing to do with what is happening with sugar. For instance, they may think that sugar crystals in a tea bag placed in water (Activity 5.2) get out because the holes in the tea bag get bigger in water, or they may think that the sugar "melts." (Melting is caused by heat and does not require water.)

Some students who remember the conception of empty space between molecules may erroneously think that small holes in the tea bag are actually empty spaces between molecules of the tea bag.

Some students may be confused between sugar molecules and the crystals of sugar. They may think that crystals are actually sugar molecules. The teacher should emphasize that crystals consist of trillions of sugar molecules.

Students may be confused between properties of molecules and observable properties of substances in dissolving. For instance, students may think sugar molecules themselves dissolve in water. Some may also think that after sugar dissolves in water, sugar will go down to the bottom of water and stay there, so it will taste sweeter at the bottom of water than at the top. In fact, sugar molecules are constantly moving and spread out evenly in water.

Lesson 5.2

The speed of dissolving can vary by the method used to speed it up, for instance, by stirring. The teacher needs to note to students that we can make substances dissolve either faster or slower in various ways.
Lesson 5.3

Students who distinguish pure substances from mixtures based on observable properties of substances may have difficulty understanding solutions. Based on color, taste, or other observable properties, some students may think that the water we get from a faucet is a pure substance. Students should recognize that regardless of how a substance appears, the molecules that make the substance determine whether it is pure or a mixture.

D. Conceptual Contrasts

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goals Conceptions</th>
<th>Student Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of matter</td>
<td>Matter is conserved in changes.</td>
<td>Matter not always conserved. The word &quot;dissolve&quot; sometimes used as a synonym for &quot;disappear.&quot;</td>
</tr>
<tr>
<td>Size of molecules</td>
<td>Molecules are too small to see.</td>
<td>Molecules are visible (e.g., crystals or &quot;wavy lines&quot; of sugar as sugar molecules).</td>
</tr>
<tr>
<td>Constant motion</td>
<td>All molecules are constantly moving.</td>
<td>Molecules may sometimes be still (e.g., sugar molecules go down and stay at the bottom of water).</td>
</tr>
<tr>
<td>Different kinds of molecules</td>
<td>Molecules of one substance are different from molecules of a different substance.</td>
<td>All molecules are alike.</td>
</tr>
<tr>
<td>Pure substance vs. mixture</td>
<td>Pure substances are made of one kind of molecule; mixtures, two or more kinds of molecules.</td>
<td>Distinction based on observable properties of substances, such as color, taste, texture, etc.</td>
</tr>
<tr>
<td>Molecular explanation of dissolving</td>
<td>Molecules of solute break away and mix with molecules of solvent.</td>
<td>Focus on observable substances or molecules themselves &quot;dissolve.&quot;</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 5
Explaining Dissolving

Lesson 5.1: How Did the Sugar Get Out?

A long time ago, in Lesson Cluster 2, you studied pure substances and mixtures. Do you remember the difference? Pure substances, like pure water and pure oxygen, are made of only one kind of molecule. Mixtures, like salt water and air, contain several different kinds of molecules.

This is a lesson cluster about mixtures. One kind of mixture is formed by dissolving a solid in a liquid. When a solid dissolves in a liquid, the molecules of the liquid hit the solid, breaking apart the solid into invisible molecules. These molecules spread evenly throughout the liquid.

In this lesson cluster you will dissolve several solids in water, you will find out how to make solids dissolve faster or slower, and you will learn to explain what happens to the molecules of both the liquid and solid in dissolving. The first step, though, is to watch something dissolve and describe what you see. So let’s get started!

* * * * * *

Do Activity 5.1 in your Activity Book

* * * * * *

Did you say that you could see wavy lines under the tea bag and taste the sugar in the water? That is true. We cannot see the tiny molecules of sugar or the tiny molecules of water; but we can taste the sugar in the water. The sugar did not disappear forever, but the sugar grains broke into separate, tiny molecules, so that we could no longer see the sugar. Just because we cannot see the sugar does not mean it is not there. The water tastes sweet, so it must still be there.

How did the sugar get out the tea bag? You can answer this question if you think about the size of sugar molecules. The holes in the tea bag are much smaller than a grain of sugar, but much larger than a molecule of sugar. As the water molecules hit the solid sugar, the molecules of sugar break away rapidly and mix with the water molecules. The tiny molecules easily pass through the holes in the tea bag. The wavy lines under
Lesson 5.1: How Did The Sugar Get Out?

Purpose:

To help students develop an explanation of how sugar dissolves in water. To make this explanation, they have to recognize that sugar grains have to break apart into much smaller sugar molecules.

Materials List:

For each student or each group of 2-3 students:

1. magnifying glass
2. sugar
3. empty tea bag
4. plastic cup
5. water

You will also need Transparency 9: What happens when sugar dissolves in water?

Teaching Suggestions:

This lesson begins with a brief introduction and goes right into the activity. Students answer a number of questions as they do the activity. You may want to discuss each question after students have done the activity, or have the class read in the textbook which explains dissolving. The last section of this lesson reviews the explanation and helps students see how the "explanation guide" heuristic applies to this explanation.

Some students do not recognize that water has to go into the tea bag to dissolve the sugar. They may have written in the activity that the sugar gets out because the tea bag holes get bigger in water.
the tea bag were caused by trillions of sugar molecules streaming from the solid sugar and mixing with the water molecules. As the sugar mixes more completely and spreads throughout the water, the wavy lines disappear.

Sugar molecules break out of their rigid pattern and mix with water molecules

Now let's try to organize these ideas into an explanation. Remember the parts of an explanation you were introduced to in Lesson Cluster 4? We'll use those to organize our explanation.

**Question**: How did the sugar get out of the tea bag?

**Substance**: The water went into the tea bag and dissolved the sugar. Sugar-water came out of the tea bag and mixed with the rest of the water. (The wavy lines were made by the sugar-water coming out of the tea bag.)

**Molecules**: The water molecules went through the holes in the tea bag, hit the grains of sugar, and broke off sugar molecules. The mixture of sugar molecules and water molecules went back out through the holes in the tea bag.
Some students think that sugar crystals are actually molecules. Crystals of sugar are cube-shaped because of the rigid array of (trillions of) molecules in solid sugar.

Use Transparency 9 here:

<table>
<thead>
<tr>
<th>WHAT HAPPENS WHEN SUGAR DISSOLVES IN WATER?</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram of sugar dissolving in water]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WHAT HAPPENS WHEN SUGAR DISSOLVES IN WATER?</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram of sugar molecules dispersed]</td>
</tr>
</tbody>
</table>

TRANSPARENCY 9: WHAT HAPPENS WHEN SUGAR DISSOLVES IN WATER?

Bottom Layer

Many students feel that, when sugar dissolves in water, the sugar "disappears" or "melts." Most students will not answer this question in terms of molecules.

Overlay

Students should be challenged to see that just because the sugar is no longer visible does not mean that it is gone forever. On a macroscopic level, the sugar mixes with the water. On the molecular level, water molecules hit the large grains of sugar, knocking off individual molecules. These sugar molecules eventually become evenly dispersed throughout the water. Since we cannot see individual molecules, the sugar seems to have disappeared. We know it is still there, however, because the water tastes sweet.

Remember that the word "substance" is supposed to remind students to ask two questions: What substance is changing? and How is it changing? The word "molecules" is supposed to remind students to write about what is happening to molecules during the change.

It is the molecular part of the explanation that provides a reason and accounts for the change. We want to help students get to the point of explaining the phenomena in this lesson cluster and the following clusters in terms of molecules.
Lesson 5.2: Dissolving Fast and Slow

In the first lesson, you dissolved sugar in water. The sweet mixture of water molecules and sugar molecules is called a solution. Many different substances dissolve in water (or other liquids), so you can make many different solutions. Can you make substances dissolve faster or slower? How? Activity 5.2 will help you answer those questions.

* * * * * * *

Do Activity 5.2 in your Activity Book

* * * * * * *

My friend found a way of making the salt dissolve faster. She stirred one cup. The salt dissolved much faster in the cup that she stirred than in the other one.

Let's try explaining why her method worked, using our guide for explanations.

**Question:** Why did stirring cause the salt to dissolve faster?

**Substances:** She stirred the mixture and water rushed around the grains of salt.

**Molecules:** Stirring caused more molecules of water to hit the salt grains, so the molecules of salt were broken off from the grains faster.

How did my friend's method compare with your method? Look at the explanation above and compare it with the explanation you wrote in your activity book. Do you see any ways that you could make your explanation better?
Lesson 5.2: Dissolving Fast and Slow

Purposes:

To help students find that stirring causes solids to dissolve faster than not stirring. To help students explain this finding in terms of molecular motion.

Materials List:

For each group of students:

1. two tumblers
2. two spoonfuls of Kosher or canning salt. (Table salt is sprayed with cornstarch which results in a cloudy solution.)
3. two plastic cups
4. a coffee stirrer

If you do the optional activity suggested in question 7 of the Activity Book, you will need a large pan or container to allow the salt solution to evaporate.

Teaching Suggestions:

You may want to list the student responses to the question "How can you make substances dissolve faster or slower?" on the chalkboard. If the students suggest that heating will make substances dissolve faster, inform them that they will investigate this in Lesson Cluster 6.

After the students do the activity, go over the explanation carefully and discuss the major points with the students.
Lesson 5.3: Complex Solutions

In Activity 5.2 you made a solution by dissolving both salt and sugar in water. We call solutions like that complex solutions; they contain more than one dissolved substance.

There are many complex solutions. For example, grape Kool-Aid drink has sugar, purple color, and grape flavoring all dissolved in water. Ocean water is another example. It contains not only salt, but many other substances dissolved in it. If you took ocean water, filtered out all the dirt, placed it in a pan, and let the water evaporate, you would get many salt crystals, but you would also get a variety of other kinds of crystals. Each kind of crystal indicates a different kind of substance.

You have also seen many other complex solutions, though you might not have known what they were. Honey is a complex solution. It consists mostly of water molecules and sugar molecules. That's why it is sweet. But the special flavor of honey comes from many other kinds of molecules that are mixed with the water and sugar. Syrup and ginger ale are also complex solutions. They both have water and sugar, plus other substances that give them their special flavors.

A store is full of complex solutions. Sometimes the labels even tell you what substances have been mixed together to make them. You might try looking at the labels on bottles of mouthwash, or soda, or shampoo. They tell you what substances have been dissolved in water to make them.

Even our drinking water has a number of substances dissolved in it. If your city gets drinking water from a well, the water has come into contact with a variety of rocks containing various minerals. Most of these minerals dissolve in water to some extent. If your drinking water comes from a spring, a lake, or a river, the same is true. Most of the water that you see, therefore, has a number of solids dissolved in it. So the water we get from a faucet is not really pure; it is really a complex solution.

Now try answering some questions about complex solutions—and the other things you have studied in this lesson cluster.
Lesson 5.3: Complex Solutions

Purpose:

To help students understand that most common solutions are complex; that is, have several solids dissolved in water.

Advance Preparation:

Teachers may want to have little cups or bottles of various complex solutions in the room for students to view.

Materials List:

Select 3 or 4 of items such as:

- Soda
- Mouthwash
- Catsup
- Honey
- Syrup
- Kool-aid
- Clear shampoo
- Apple juice
- Liquid dish detergent
- Hair color dye
- Dish water

You will also need Transparency 3: What would ocean water look like?

Teaching Suggestions:

Have students collect labels from different complex solutions they may find at home. Discuss why these items are complex solutions. Note: Some items you find in your kitchen or bathroom are not complex solutions, i.e., ammonia (without soap or detergent), bleach (without soap or detergent), hydrogen peroxide, and alcohol. Each of these solutions contains only water and one other compound.

Remember that the word "substance" is supposed to remind students to ask two questions: What substance is changing? and How is it changing? The word "molecules" is supposed to remind students to write about what is happening to molecules during the change.

It is the molecular part of the explanation that provides a reason and accounts for the change. We want to help students get to the point of explaining the phenomena in this lesson cluster and the following clusters in terms of molecules.
This lesson cluster is just about over. Let's end it with a summary of some of the most important ideas. See how much of this summary is like the one you wrote in your answer to the last question.

Lesson 1 was about dissolving sugar. You learned that when sugar dissolves it breaks up into individual molecules. You also learned how dissolving takes place. The water molecules break molecules of sugar off the grains. The water molecules and the sugar molecules intermingle until the sugar molecules are spread evenly through the water.

In Lesson 2 you learned that you can make things dissolve faster by stirring, and you learned that stirring speeds up dissolving because it makes more molecules of water hit the sugar grains and break off sugar molecules faster.

In Lesson 3 you learned that many of the liquids around you are solutions, usually complex solutions that have several different substances in them.

Can you think of a way to make a solid dissolve faster in water \textit{without} stirring? Without even touching the cup? That is one thing you will learn about in Lesson Cluster 6.
Suggestions for additional activities

1. Crystal growing

An interesting way to extend this lesson cluster is to have students grow two or more different types of crystals. The first step in growing crystals is to prepare a saturated solution. This can be done by dissolving as much of the solid as possible in a hot water solution. Pour this solution in a jar, and cover the jar with cheese cloth to prevent dust from getting into the solution. Allow the solution to cool overnight and crystals should form on the bottom of the jar. Pour the liquid from the crystals into a second jar, take one of the nicest crystals, tie it on a piece of thread, and suspend it in the solution of the second jar. Allow it to stand as the crystals grow.

If crystals start forming on the bottom or sides of the jar, repeat the procedure just described by pouring the solution into a clean jar and again suspending a seed crystal on a piece of thread.

There are a number of salts that make interesting crystals. Some are: alum, Rochelle salt, photographer's hypo or sodium thiosulfate, and cupric sulfate. Alum is aluminum sulfate and Rochelle salt is potassium sodium tartrate.

Growing crystals is tedious and requires a lot of patience. Perhaps you would want to start growing crystals several weeks before you intend to use them.


2. Finding complex solutions

Students bring in solutions from stores and study the labels. (Remember that only clear liquids are true solutions.)
INTRODUCTION TO LESSON CLUSTER 6
Heating and Cooling, Expansion and Contraction

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain why solids dissolve faster in hot water, and why substances expand when heated.

Lesson Objectives:

Students should be able to:

6.1 Explain why hard candy dissolves faster in hot water than in cold water.

6.2 Explain the expansion and contraction of solids.

6.3 Explain the expansion and contraction of liquids.

6.4 Explain the expansion and contraction of gases.

B. Key Elements of a Good Explanation

Both the rate of dissolving and thermal expansion can be explained by using the principle that molecules of a substance move faster when the substance is heated. In dissolving, molecules of hot water are moving faster than molecules of cold water, and hence break off molecules of candy faster. The molecules of candy that are knocked loose then mix in with the water molecules.

In thermal expansion, molecules of solids, liquids, and gases move farther apart when they move faster. When the molecules move farther apart, the solids, liquids, and gases get bigger.

C. Conceptual Learning

Several tasks in this lesson cluster deal with the conception of thermal expansion in three different states of matter. A principle applies to explain all the tasks: heating a substance makes the molecules of the substance move faster, and therefore they move farther apart. This makes the substance expand. In contrast, when a substance is cooled, things happen in the opposite way. Many students have difficulty understanding and applying this rule to explain phenomena.
First, the explanation of thermal expansion requires knowledge about molecules. Unless students understand this principle in molecular terms, their explanations may be inconsistent across different situations. For instance, the same student may think that a ball will shrink when heated, the column of mercury in a thermometer will rise because of heat pressure, and the dime on a bottle will rattle because hot air rises. They should understand that even though things "appear" different, the scientific conception of thermal expansion applies in all these situations.

Second, students may be confused between observable properties of substances and properties of molecules themselves. For instance, students may think that molecules become hot or cold, or that molecules themselves expand causing substances to expand. Students should realize that molecules do not get hot or cold and that the only change is to the motion and arrangement of molecules when a substance is heated or cooled.

Finally, students may have difficulty recognizing the cause/effect relationship. Students should understand that when molecules move faster, this causes the molecules to move farther apart. Then, students should associate what is happening to molecules with the change in the substance: When molecules move farther apart, this causes the substance to expand.

Lesson 6.1: Another Way to Make Something Dissolve Faster

This lesson explains why sugar dissolves faster in hot water: Molecules of hot water move faster and hit the molecules of sugar more often. Some students may think that "hot" molecules in hot water move faster than "cold" molecules in cold water. The teacher should stress that there is no change in individual molecules, but only in the motion of molecules.

Lesson 6.2: Heating Solids

This lesson explains the thermal expansion of solids. At the macroscopic level, some students may predict that solids "shrink up" or shrink when heated. They should realize that solids actually expand when heated. At the molecular level, common students' misconceptions are:

a. Molecules themselves expand or contract.

b. Molecules do not move in solids (e.g., the metal) and begin to move when solids are heated.

c. Heat is made of "heat molecules."

Lesson 6.3: The Thermometer

This lesson explains thermal expansion of liquids, using the liquid in a thermometer as an example. At the macroscopic level, many students may think that the liquid comes out of the bulb and moves up (that is, the liquid changes places from the bottom toward the top) or that "heat pressure" of the hot water causes the liquid to go up. The teacher should emphasize that the liquid expands, not moves from place to place.
Lesson 6.4: Gases and the Dancing Dime

The expansion of air is illustrated by "The Dancing Dime" on top of a cold pop bottle. The explanation of the "dancing" is sometimes difficult for students. At the macroscopic level, some students may focus their attention on the bottle, the dime, heat, etc. They should first recognize what substance to focus on: the air in the bottle. Even then, many students may think using the idea of "heat" or "hot air": Hot air rises, heat rises, air pushes up, hot air pushes out the cold air, etc. All these ideas suggest that air moves from one place to another place within the bottle, rather than that air expands.

At the molecular level, some students may be confused between observable properties of substances and properties of molecules. For instance, they may think that molecules of air are cold and do not move when the bottle is frozen and that they begin to move when the bottle is heated.

D. Conceptual Contrasts

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal expansion</td>
<td>Substances expand when heated.</td>
<td>Substances may &quot;shrivel up&quot; when heated; expansion of gases explained in terms of movement of air.</td>
</tr>
<tr>
<td>Constant motion</td>
<td>Molecules are constantly moving.</td>
<td>Molecules may sometimes be still, especially in solids.</td>
</tr>
<tr>
<td>Effect of heat on molecular motion</td>
<td>Molecules of hot substances move faster.</td>
<td>Molecules themselves can be hot or cold.</td>
</tr>
<tr>
<td>Molecular explanation of thermal expansion</td>
<td>Increased motion moves molecules farther apart.</td>
<td>Molecules themselves expand.</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 6
Heating and Cooling, Expansion and Contraction

Lesson 6.1: Another Way to Make Something Dissolve Faster

In the last lesson you learned one way to make things dissolve faster: you can stir the water. There is another way to make something dissolve faster, though. This way involves no stirring and no moving the cup. Do you know what it is? You can try this way in Activity 6.1.

* * * * * *
Do Activity 6.1 in your Activity Book
* * * * * *

Did you know that when you say that something is "hot" or "cold," you are actually saying something about the molecules of that substance? Words like "hot" and "cold" describe how fast or slow the molecules of a substance are moving. Hot substances have fast-moving molecules. Cold substances have slower-moving molecules.

Heating any substance makes the molecules of that substance move faster. In hot solids, the molecules vibrate faster in their places. In hot liquids, the molecules move faster as they slide and bump past each other. In hot gases, the molecules move faster through space.

Cooling any substance makes the molecules of that substance move slower. In cold solids, the molecules vibrate more slowly in their places. In cold liquids, the molecules move more slowly as they slide and bump past each other. In cold gases, the molecules move more slowly through space. These differences between hot and cold substances are illustrated on the following page.
Lesson 6.1: Another Way to Make Something Dissolve Faster

Purposes:

To help students explain that hard candy in hot water will dissolve faster than in cold water because the molecules of hot water are moving faster and hit the candy more often than in cold water. That makes the water molecules knock the molecules off the piece of candy faster. To help students describe objects in which the molecules are moving fast as hot objects and objects in which the molecules are moving slow as cold objects.

Background Information:

Many of the concepts related to temperature and the speed of the molecules are too complicated for grade 6 students. We have therefore attempted to teach only a portion of the relationship between temperature and molecular motion. For example, temperature is a measure of the average kinetic energy of molecules, not just the velocity or speed of molecules. Since K.E. = 1/2 mv^2, the kinetic energy depends upon both the mass (m) of the molecules and their velocity (v) or speed. We have decided not to discuss the mass of the molecules because it is too difficult for grade 6 students. We resolved this issue by stressing that any given substance that has fast moving molecules is at a higher temperature than the same substance with slower moving molecules. What we have presented is correct. We simply chose not to present all the relationships.

Materials List:

1. Two plastic cups
2. Two pieces of hard candy
3. Hot and cold water
4. Transparency 10: Why does the sugar dissolve faster in hot water?
5. Poster 2: States of Matter

Teaching Suggestions:

1. After students do activity 6.1, have the students read the remainder of the lesson. Stop frequently to discuss the important parts.
1. **Cold solids:** Molecules vibrate slowly in place

2. **Hot solids:** Molecules vibrate quickly in place

3. **Cold liquids:** Molecules slide and bump slowly past each other

4. **Hot liquids:** Molecules move fast as they slide and bump past each other

5. **Cold gases:** Molecules move slowly through space

6. **Hot gases:** Molecules move fast through space
**WHY DOES THE SUGAR DISSOLVE FASTER IN HOT WATER?**

The water molecules move faster, so they break off sugar molecules faster.

**Bottom Layer**

Students often answer this question by saying, "heat causes faster dissolving" or "molecules get hotter and so they move faster and dissolve faster." These are elements of the explanation but not an adequate explanation.

**Overlay**

Heating a system does make the process of dissolving speed up, but that is not really an answer to the question. The important part of the question is that dissolving is faster in hot water. It is not because molecules heat up (molecules are neither hot or cold), but because they move faster, and are thus able to break off sugar molecules faster.
Now let's try using these ideas to explain why the candy dissolved faster in hot water. We will talk about the cold water, then the hot water. We will answer the question about substances and the question about molecules for each temperature of water.

In the cold water the candy (substances) dissolved slowly because the water molecules were moving slowly as they knocked off molecules from the pieces of candy.

In the hot water the candy dissolved faster because the water molecules were moving faster and hit the candy more often. That made them knock the molecules off the pieces of candy more quickly.

Did the explanation about hot water answer both the question about substances and the question about molecules? Find the parts of the explanation that answer each question.

When molecules are moving faster they make substances dissolve faster. Fast-moving molecules cause other effects, too. You will learn about one of those other effects in the next three lessons.
Why does heating the metal ball make it expand?

Heating makes the molecules move faster and push each other farther apart.

TRANSPARENCY 11: WHY DOES HEATING THE METAL BALL MAKE IT EXPAND?

Bottom Layer
Most students are amazed when the heated ball will not go through the ring, and are not able to explain this phenomenon. This is because they believe that, until the solid melts, heating will have no effect.

Overlay
Use the overlay to counter these naive conceptions. Just like in liquids and gases, when a solid is heated, the molecules move faster. They do not move fast enough to break out of the rigid pattern (melting), but they do push each other a little further apart, causing the metal ball to expand (expansion caused by heating).
Lesson 6.2: Heating Solids

Heating a solid, such as a metal ball, makes the molecules vibrate faster. This fast vibration makes the ball feel hot when you touch it. The fast vibration of the molecules has another effect, too, one that is harder to see or feel. When the molecules vibrate faster they actually push each other a little farther apart.

So what happens when all the molecules of a solid push each other a little farther apart? The solid gets a little bigger, or expands. So heating solid objects makes the objects expand. This process is called thermal expansion ("thermal" means "with heat").

Let's try using these ideas to explain why a metal ball that barely fits through a ring won't go through the ring after it is heated. In this explanation we will talk about molecules first, then substances. As long as an explanation answers both questions, though, it is still a good explanation.

Heating the ball made the molecules of the metal vibrate faster, so they pushed each other farther apart. This made the metal ball expand (substance), so it would no longer fit through the ring.

Metal balls are not the only things that expand when heated. All solids expand when they are heated (unless heating causes some of the molecules to break up or makes the solid lose molecules). Concrete, rocks, metal objects, glass, and other solids all expand when they are heated. They all expand for the same reason, too. Their molecules move faster and push each other farther apart.

When solids cool, the molecules slow down. This allows the molecules to move closer together, so the solids contract. Solids expand when they are heated. They also contract when they are cooled; this process is called thermal contraction.

It is hard to see solids expand and contract because the molecules move only slightly farther apart or closer together. We have to measure the solids very carefully to tell that their size has changed.

Now try using what you know about thermal expansion and contraction to answer some questions about other situations where solids are heated or cooled.

* * * * * *

Do Question Set 6.2 in your Activity Book

* * * * * *
Lesson 6.2: Heating Solids

Purpose:

To help students use the kinetic molecular theory to explain the expansion and contraction of solids.

Advance Preparation:

For this lesson you will need the ball and ring demonstration and the Transparency 11: Why did heating the metal ball make it expand?

Materials List:

For this demonstration you will need:

1. A ball and ring apparatus
2. A heat source such as a propane burner or candle
3. Transparency 11: Why does heating the metal ball make it expand?

Teaching Suggestions:

Some students believe that when you heat a solid it gets larger or expands because the molecules themselves get larger. Stress that the molecules themselves do not get larger or expand. When a solid is heated the molecules move faster, hit each other more frequently which causes them to move farther apart. The molecules moving farther apart causes the solid to expand.

1. Begin with Activity 6.2 Heating and Cooling Solids--The Ball and Ring Demonstration.

2. Use Transparency 11:

3. Continue the lesson in the Science Book.

4. Students may be confused by apparent contradiction of objects such as leaves drying in the sun (water molecules escape), meat cooking (water and fat molecules escape), melting styrofoam (air molecules escape), or burning paper (molecules are broken down into simpler molecules).
Lesson 6.3: The Thermometer

In the last two lessons you have learned that the molecules of all substances move faster when the substances are heated, and that solids expand when they are heated and contract when they are cooled. What about liquids? Do you think that they expand and contract the way solids do? Try Activity 6.3 and find out!

* * * * * *
Do Activity 6.3 in your Activity Book
* * * * * *

Could you explain why the column of the liquid in the thermometer rose and then fell? You know from Lesson 6.1 that the molecules of liquids move faster when the liquid is heated. That is one way that liquids and solids are alike.

Liquids and solids are also alike in another way. When the molecules move faster, they bump into each other harder and push each other farther apart. So just like solids, liquids expand when they are heated.

Liquids also contract when they are cooled. When the molecules of a liquid slow down, they move closer together. So liquids go through thermal expansion and thermal contraction just as solids do.

Heating makes the molecules of a liquid move faster and push each other farther apart.
Lesson 6.3: The Thermometer

Purpose:

To help students use the kinetic molecular theory to explain the expansion and contraction of liquids.

Background Information:

Some students will correctly explain that glass expands when heated as well as the liquid. Although this is true, the glass expands much less than the liquid in a thermometer. Hence, the volume of the thermometer tube remains nearly unchanged while the volume of the liquid increases significantly when heated. This is why the column of liquid changes.

Materials List:

For each group of students:

1. One thermometer
2. Two plastic cups
3. Hot and cold water

Teaching Suggestions:

Some students may think that the liquid goes up the thermometer tube when the bulb gets warmer because "heat rises." To confront this misconception, encourage students to read the thermometer on its side and upside-down to see if it changes.

Discuss each part of the lesson fully to help students explain the changes in the thermometer.
Cooling slows down the molecules of a liquid and they move closer together

Now we can explain how the thermometer works. Compare the explanations below to the ones you wrote in your Activity Book. Did you answer the questions about substances and the questions about molecules in the same way as the explanations below?

When you place the bulb of the thermometer in hot water, the molecules of the colored liquid move faster and push each other farther apart. This causes the colored liquid to get larger or expand. The colored liquid expands up through the thermometer tube which gives a higher temperature reading.

When you place the bulb of the thermometer in cold water, the molecules of the colored liquid move slower and come closer together. This causes the colored liquid to get smaller or contract. The contraction makes the column of colored liquid move down toward the bulb. This gives a lower temperature reading.
After you have finished reading in the Science Book, you may want to have students go back to questions in the Activity Book and change their answers to make them more complete.
Lesson 6.4: Gases and the Dancing Dime

Solids expand when they are heated and contract when they are cooled. So do liquids. It probably won’t surprise you that gases act the same way. Gases also expand when they are heated and contract when they are cooled.

The molecules of a hot gas move faster than the molecules of a cold gas, so they hit each other harder and bounce harder off the sides of a container. This makes the molecules move farther apart and push the sides of a container outward.

Cooling is just the opposite. The molecules slow down, so they don’t hit each other or the walls of a container as hard, and they move closer together.

Hot gases have fast-moving molecules that bounce farther apart

Cold gases have slow-moving molecules that stay closer together
Lesson 6.4: Gases and the Dancing Dime

Purpose:

To help students use the kinetic molecular theory to explain the expansion and contraction of gases.

Advance Preparation:

Collect one large glass soda bottle that has a pry-off cap for each student group. Bottles with screw-tops tend to have necks too large to hold dimes on top. The bottles should be cold at the beginning of the activity. You can store them in the school refrigerator or in a styrofoam chest with ice.

Materials List:

1. One large soda bottle, cold
2. One dime
3. One balloon for optional activity

Teaching Suggestions:

The expansion of gases is often confused with convection currents, especially in the activities we use that seem to show hot air rising. Watch out for this conceptual confusion. Students are very familiar with the phrase "hot air rises," and it seems difficult to picture gases (or solids, for that matter) expanding. The activity in this lesson will help students get a visual image of air expanding, especially if the class talks specifically about the difference between "hot air rising" and air expanding (see Activity Book, Lesson 6.4, question 4, especially part c).
Do you remember when you studied expansion and compression of gases in Lesson Cluster 4? Now you know two ways of moving the molecules of a gas closer together or farther apart!

In Lesson Cluster 4 you moved the molecules of gases closer together by pushing them together with pressure from something like a syringe or a bicycle pump. Another way to move the molecules closer together is to cool off the gas. Then the molecules slow down and move closer together even without an extra "push."

In Lesson Cluster 4 you moved the molecules of gases farther apart by releasing pressure, like when you released the plunger of the syringe or let the air out of the bicycle tire. Another way to move the molecules farther apart is to heat the gas. Then the molecules move faster and push each other farther apart.

Let's try that other way of getting gases to expand. The dancing dime will help you see it happen!

* * * * * * *
Do Activity 6.4 in your Activity Book
* * * * * * *

This lesson cluster is almost over. You knew before this lesson cluster that all substances are made of tiny particles called molecules. You knew that molecules are always moving.

In this lesson cluster you learned another important idea. The temperature of a substance tells you something about how fast the molecules are moving. Heating a substance makes the molecules move faster. Cooling a substance makes molecules move slower.

The motion of the molecules explains why solids dissolve faster in hot water, as well as thermal expansion and contraction. In Lesson Cluster 7 you will use these ideas about molecular motion to explain melting and freezing.

* * * * * * *
Do Review Question Set 6.4 Now
* * * * * *
There is an Activity 6.4 and a Question Set 6.4.

Students should complete Activity 6.4: The Dancing Dime, at this time.

You may want to use Question Set 6.4: Lesson Cluster Review, as an assessment of student progress.
INTRODUCTION TO LESSON CLUSTER 7
Explaining Melting and Solidifying

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain melting and solidifying, by
reference to the molecular structure of solids and liquids, and the
motion of molecules in each state.

Lesson Objectives:

Students should be able to:

7.1 Explain melting and freezing of water.

7.2 Explain melting and solidifying of other substances.

7.3 Explain that different substances have unique melting and
solidifying temperatures.

B. Key Elements of a Good Explanation

There are three key principles involved in explanations of melting and
solidifying:

1. Molecules of a substance move faster when the substance is
   heated, and slower when it is cooled.

2. The molecules of a solid are close together, arranged in a rigid
   array, vibrating back and forth. The molecules of a liquid are
   also close together, but move freely past each other.

3. There is a force of attraction between molecules of the same
   substance. This force of attraction is strong enough in solids
   to keep molecules tightly packed together.

When a solid is heated, its molecules begin to move faster and faster,
until their motion overcomes the force of attraction between them.
They move too quickly to be held in a rigid array—but not quickly
enough to evaporate, or change into a gas, by escaping the attraction
altogether.

When a liquid is cooled, its molecules move more slowly. At its
freezing temperature, the force of attraction binds them together in a
rigid array.
C. Conceptual Learning

In Lesson Clusters 1 and 2, students learned differences among solids, liquids, and gases of substances in terms of the arrangements and motions of their molecules. The contents in Lesson Clusters 7, 8, and 9 are about how or why a substance changes from one state to another. In Lesson Cluster 6, students have learned that heating or cooling makes molecules move faster or slower. Thus, the students need to integrate scientific ideas they have already learned in understanding and explaining various changes of state in these last three lesson clusters. The specific example used is water in its three states, and the same explanation applies to other substances.

One additional conception that you should stress in the next three lesson clusters is that molecules attract each other. In solidifying and condensing, molecules slow down enough so that their attraction for each other "locks" them together in the solid or liquid state arrangement. In melting and evaporating, the increased motion of molecules allows them to overcome their mutual attractions, and change their molecular arrangement (from solid to liquid, or liquid to gas).

Lesson 7.1: Melting Ice and Freezing Water

At the macroscopic level, emphasize that matter is conserved when a substance changes from the solid state to liquid state. For instance, to many students, the solid state of water may appear to be heavier or have more "stuff" than the liquid state. However, water is conserved in all physical changes of state because the molecules of water remain the same from ice to liquid water, or vice versa.

Students may still be confused between observable properties of substances and properties of molecules themselves. Some common students' misconceptions are:

a. When ice melts, molecules themselves melt.
b. Molecules are different in ice and liquid water.
c. Molecules are hard or frozen in ice and begin to move when ice melts.

There is no change in individual molecules, but only in the arrangements and motions of molecules during changes of state.

Lesson 7.2: Melting and Solidifying of Other Substances

After learning how water melts and freezes, students should be able to explain how other substances melt and solidify. Most students are familiar with melting and freezing of water. But it is not always clear to students that wax, for instance, "freezes" or solidifies. They may say that it hardens or dries out, and not be able to account for the change in terms of molecules, even though they did for water.
Lesson 7.3: Adventure into the Hot Zone and the Cold Zone

This lesson takes students on an imaginary voyage into very hot and very cold regions. Combining scientific ideas presented in the last two lessons, it describes how melting and solidifying of different substances occur at different temperatures.

D. Conceptual Contrasts

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goals Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of matter</td>
<td>Matter is conserved in all physical changes.</td>
<td>Matter is not always conserved (e.g., ice weighs more than water).</td>
</tr>
<tr>
<td>Constant motion</td>
<td>All molecules are constantly moving.</td>
<td>Molecules may sometimes be still, especially in solids (e.g., molecules do not move in ice).</td>
</tr>
<tr>
<td>Visibility of molecular motion</td>
<td>Molecular motion continues independently of observable movement.</td>
<td>Molecules simply share in observable movements of substances (e.g., molecules begin to move when ice melts).</td>
</tr>
<tr>
<td>Same molecules in different states of same substance</td>
<td>Solid, liquid, and gas forms of the same substance are all made of the same type of molecules.</td>
<td>Molecules of the same substance are different in its different states (e.g., ice molecules).</td>
</tr>
<tr>
<td>Effects of heat on molecular motion</td>
<td>Molecules of hot substances move faster.</td>
<td>Molecules themselves can be hot or cold.</td>
</tr>
<tr>
<td>Molecular explanation of states of matter</td>
<td>States of matter are due to different arrangements and motions of molecules.</td>
<td>States of matter described only in terms of observable properties, or properties of state attributed to individual molecules (e.g., molecules are hard in ice).</td>
</tr>
<tr>
<td>Attraction of molecules</td>
<td>Molecules of one substance attract each other.</td>
<td>Molecules bounce around like billiard balls and do not attract each other.</td>
</tr>
<tr>
<td>Molecular explanation of changes of state</td>
<td>Heating and cooling cause changes of state by making molecules move faster or slower.</td>
<td>Heating and cooling make molecules &quot;melt&quot; or molecules begin to move when heated.</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 7
Explaining Melting and Solidifying

Lesson 7.1: Melting Ice and Freezing Water

Do you remember the first experiment you did in this unit? It was an ice melting race. You learned then about the states of water: ice, liquid water, and water vapor. You also learned how water molecules are arranged and how they move in each state. What you did not learn in the first lesson cluster was how or why water changes from one state to another.

This lesson cluster, as well as Lesson Clusters 8 and 9, is about changes of state in water and other substances. You have seen changes of state many times, and you probably know most of the words that we use to describe them. When a solid changes into a liquid, we call it melting. When a liquid changes into a solid we call it freezing or solidifying. Changes from the liquid state to the gas state are called evaporation or boiling. Changes from the gas state to the liquid state are called condensation. This drawing summarizes all the different changes of state:

Now let's go back to melting ice. When ice melts, one substance (water) is going through a change of state (melting). Can you explain how and why it happened? You already know how molecules are arranged and how they move in solids and liquids. You also know something else important: Molecules move faster when a substance is heated. Let's try putting these ideas together in an explanation of how ice melts.
Lesson 7.1: Melting Ice and Freezing Water

Purpose:

To help students use the kinetic molecular theory to explain melting and solidifying of water.

Materials List:

1. Transparency 12: Why does liquid water change into ice when it gets cold?
2. Poster 3: Changes of state

Teaching Suggestions:

Introduce this lesson by having the students read the first two paragraphs of the Science Book and discuss Activity 1.1: Changing Solid Water to Liquid Water--Fast. You might want to ask students to try to explain melting before you continue to read this lesson. Some of them may be able to bring together what they know about the motions and arrangements of molecules in solids and liquids with the idea that molecules move faster when they are heated. Most students will probably not be able to do this yet. The rest of this lesson discusses the explanation of melting ice.

Use the diagram and poster to stress the relationships among condensation, solidifying, melting, and evaporation (boiling).

Many students believe that when water freezes, the molecules freeze or change into ice molecules. Emphasize that this is not true. When water changes state, the molecules remain the same. The only change is in the movement and position of the molecules.

This idea that the attraction between water molecules causes them to form into the rigid pattern of a solid is important for explaining freezing. Attraction is not so important for explaining melting: One can simply say that when molecules move faster, they break out of the rigid pattern of a solid.

Some students want to bring into the explanations of melting the idea that when molecules move faster, they move farther apart, and therefore break out of their pattern. But this is not universally true. Molecules of water actually move a little closer together when ice melts. Since the explanation of melting is difficult enough as it is, "moving farther apart" should be left out of it.

The same is true with the explanation for freezing: some students want to say that when a substance is cooled, the molecules slow down, move closer together, and (therefore) the attraction between them becomes greater and they form a rigid pattern. This type of explanation is confusing, because the molecules are already very close together and the attraction between them always exists. What is important here is that the molecules slow down enough so that the attractive force can cause them to coalesce into a rigid pattern.
When ice is warmed it melts into liquid water. The water molecules in ice are locked into a rigid pattern, but as they vibrate faster they break out of that rigid pattern and begin sliding and bumping past each other. Solid ice has melted into liquid water!

(Did the explanation above answer both the question about substances and the question about molecules? Check it and see!)

*Ice melts when the water molecules vibrate fast enough to break out of their rigid pattern*

Water freezes when it is cooled down and the water molecules move slower. To completely explain how water freezes there is one other thing you need to know about molecules. Water molecules are attracted to each other. This attraction makes the molecules stick together in a rigid pattern if nothing breaks them apart.

But the attraction between molecules keeps them stuck in a rigid pattern only if the molecules are moving slowly. When water molecules are moving fast, their motion keeps them from sticking together. They jiggle apart rather than settling into a rigid pattern. When water gets cold, though, the molecules slow down. Then the attraction between them makes them stick together in a pattern. Liquid water has changed into ice!

Water is not the only substance that melts and solidifies. You will learn about some other substances in the next lesson. First, though, try answering some questions about what you have learned.

* * * * * * *

Do Question Set 7.1 in your Activity Book

* * * * * * *
Why does liquid water change into ice when it gets cold?

The attraction among the molecules makes them stick together in a rigid pattern.

Transparency 12: Why does liquid water change into ice when it gets cold?

Bottom Layer

Many students will answer this question by saying, "the water freezes" and will not go any further in their thinking.

Overlay

"The water freezes" is a correct answer at the macroscopic level, but it is important to get students to think in terms of molecules. When water molecules are in a liquid state, they are moving past each other and bumping into each other. As the water gets cold, the molecules begin to slow down, and the attraction among the molecules become stronger, making them stick together in a rigid pattern. This is ice.

Use Poster 3 here:

Melting
Solid
Freezing or Solidifying

Evaporation or Boiling
Liquid
Condensation

Gas

Poster 3: States of Matter
Lesson 7.2: Melting and Solidifying of Other Substances

If you can explain how water melts and freezes, then you can also explain how other substances melt and solidify. Different substances are made of different molecules, so they melt at different temperatures. But the processes of melting and solidifying are about the same for all substances.

Whenever any substance melts, its molecules are moving fast enough to break out of their rigid pattern. Whenever any substance solidifies, its molecules have slowed down enough so that they start sticking together in a rigid pattern.

Can you explain how melting is different from dissolving? In some ways melting and dissolving are alike. Both involve the molecules of a solid breaking out of their rigid array. But the causes of melting and dissolving are very different. Melting is caused by heat: When the molecules of a solid move fast enough, they break out of their rigid pattern. Dissolving, on the other hand, occurs when the molecules of a liquid knock the molecules of a solid apart and carry them away.

Melting is also different from thermal expansion. Both are caused by heat, but in the case of thermal expansion the motion of the molecules just moves them farther apart. Their pattern stays the same. Melting occurs when the motion of the molecules makes them break out of their rigid pattern.

(There are some materials that do not melt and solidify because their molecules break apart when they are heated. This is especially true of substances made from living things, like wood or cloth or paper or meat. When wood is heated, for example, its molecules break apart into smaller molecules. The wood burns if there is oxygen around it. If there is no oxygen, the wood is changed into new substances made of smaller molecules, including charcoal, water, and other liquids.)

One place where you often see materials melt and solidify is in your kitchen. Have you ever melted butter? What about cheese? Chocolate? Caramel? Sugar? Try some activities with kitchen materials that you can melt and solidify.

* * * * * * *

Do Activity 7.2 in your Activity Book

* * * * * * *
Lesson 7.2: Melting and Solidifying of Other Substances

Purpose:

To help students infer that almost all substances can be in either the solid or liquid state.

Advance Preparation:

For this demonstration you will need to set up a hot plate so you can heat water. You will also need ice so you can cool the four substances, which you can keep in the school refrigerator or in a styrofoam chest. You will also need the materials listed below.

Materials List:

1. one hot plate
2. two beakers
3. olive oil, shortening, chocolate, and paraffin
4. four test tubes
5. test tube rack
6. ice

Teaching Suggestions:

Read and discuss the lesson in the text with your class. Stress that almost all pure substances can be in the solid or liquid state by melting or freezing them, but some mixtures, as noted in the text, do not melt when heated.

Use this opportunity to review the differences between a pure substance and a mixture. Emphasize that a mixture is made of two or more pure substances. A pure substance has only one kind of molecule, but a mixture has two or more kinds of molecules.

It is important for students to realize the connections between the kinetic molecular theory and real life; therefore, you may want to discuss melting and freezing in the kitchen. Ask students about their experiences or those of their parents in the kitchen.
Lesson 7.3: Adventure into the Hot Zone and the Cold Zone

You can see some substances going through changes of state, like water and other things in the kitchen. Other substances, though, always seem to be the same state. Oxygen and nitrogen, for example, always seem to be gases. Steel and rocks always seem to be solids. Can those substances melt and solidify? In order to find out you will have to venture into the hot zone and the cold zone. Get ready!

As you explore the valleys between the highest Himalayan mountains you stumble across two large caves. One is in the north side of the valley, the other in the south. Each cave is marked by a rock column and a message in Hanzi. After conferring with your guide you understand that the column to the north says "The Cold Zone" and the column to the south "The Hot Zone." The guide further explains that the deeper you go into the tunnel on the north side the colder it gets and the further you go into the tunnel on the south side the hotter it gets.

![Diagram of Hot Zone and Cold Zone]

You decide to go into the south tunnel first. As you step inside the tunnel there are two rock columns with weird looking clothing suspended between them. After the guide reads the message in Hanzi on the stone pillars, he informs you that unless you wear the special clothing you cannot survive in the tunnel.

After carefully dressing in the special clothing you proceed into the tunnel. You proceed slowly because you can tell that it is quite hot at the end of the tunnel, but just beyond the pillars you recognize a large rock of ice slowly dripping water on your clothing. A little distance beyond the ice rock there is a rock of sugar that is also melting. Beyond that there are a number of familiar metals. First is solder (similar to what plumbers or electricians use). Beyond that is a huge chunk of aluminum that is melting. It glistens like silver, but it is not quite the same as silver. You can tell because just beyond the aluminum is silver and then pure gold. The silver and gold have melted and resolidified so that there are beautiful configurations on the walls and on the bottom of the cave. Beyond this you can see sandstone and a variety of rocks melting.
Lesson 7.3: Adventures into the Hot Zone and the Cold Zone

Purposes:

To help students infer that each substance has its own unique freezing or melting temperature. To help students be cognizant of the wide range of temperatures in which substances melt or freeze.

Teaching Suggestions:

This lesson is an imaginary flight into the heights and depths of temperature. Feel free to add visual aids by drawing pictures on the blackboard or on transparencies.

Encourage students to tell what they think the story is attempting to teach them (see Purpose above). The main point to get across to your students is that all substances can be solids at their unique freezing or solidifying points, and all substances can become liquids at their unique melting points.
As you keep going, more and more substances melt. There aren't any solids left! By the time you reach 2700 degrees Celsius, all metals are liquids, and so are all rocks. You are swimming now in your magic suit! You put on your magic eyeglasses and see that the molecules are really moving fast. No wonder they won't stay in a pattern! You look forward and the cave back goes on and on into higher and higher temperatures. Some of the liquids are turning into gases and forming bubbles, boiling up out of sight. But it is time to turn back before your suit loses its magic and you become a bunch of liquids and gases!

You come out of that cave and look across the valley toward the north. The cold zone seems very inviting because you are still very hot. As you step inside the cold zone cave, you again see two pillars with very different clothing than you had in the hot zone. It takes you a long time to put this clothing on and it is so heavy that it is difficult to walk. There is also a special light that you will need in the cold zone.

After you make sure that your clothing is adjusted properly and you figure out how to operate the special light, you proceed into the cold zone. And immediately you find a very familiar rock—ice. But just beyond this ice rock, there is something that you hardly believe. It is solid antifreeze. You had thought that antifreeze would not freeze. But it does, and it makes up a beautiful rock. When you get beyond the antifreeze you see another rock that looks like silver. It is hard like silver, too, but it is mercury. Now, mercury is normally a liquid at room temperature, but it is a solid in the cold zone. Deeper in the cave you find solid carbon dioxide or dry ice. You've seen this before, but not nearly as much as in the cold zone.

By the time you reach -219°C, there is no more air to breathe. You look around you and see why: Oxygen and nitrogen have turned into liquids, and now they are solids. The last gas, helium, becomes a liquid at -272°C. It is the only liquid left. Every other substance has solidified!

You look up and see that the cave stops at -273°C. It doesn't go on and on like the hot zone. Your magic eyeglasses show you why. The molecules have almost stopped moving. You have reached absolute zero, the point at which molecules can go no slower. It is time to turn around and go back. You slowly make your way to the two stone columns again. You take off the clothing from the cold zone, hang it on the two pillars, and are eager to get out into the warm sun light between the two Himalayan mountains.
While resting with your guide you express surprise that gases like nitrogen, oxygen and hydrogen could be solids. He assures you that all substances can be solid if they are cold enough. As you breathe the fresh mountain air, you have more appreciation for the nitrogen, oxygen, and carbon dioxide in the air, because for the first time in your life, you have seen them. You have seen them as solids. The hot zone was not nearly as surprising as the cold zone, because you had seen pictures of volcanoes spewing out liquid rock on television. But the trip to the cold zone was something you will never forget.

* * * * * *

Do Review Question Set 7.3 Now

* * * * * *
Question Set 7.3 can be used as an evaluation tool if you want, or you may use it to review the major concepts of this lesson cluster.

Possible Extension Activities

1. Making ice cream illustrates freezing.

2. Making candles illustrates both melting and solidifying.

3. You may want to bring some dry ice to class (it is available at a convenience store). Dry ice is solid carbon dioxide. It changes directly to gaseous carbon dioxide at -78.5°C (or at higher temperatures). It can only exist as a liquid if it is in a container under pressure. The process of changing directly from a solid to a gas is called sublimation.
INTRODUCTION TO LESSON CLUSTER 8
Explaining Evaporation and Boiling

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain evaporation and boiling, both in macroscopic terms and in molecular terms.

Lesson Objectives:

Students should be able to:

8.1 Use the kinetic molecular theory to explain evaporation and boiling.

8.2 Use the concept of evaporation to explain the origin of water vapor in the air.

8.3 Use the kinetic molecular theory to explain rapid evaporation and boiling.

8.4 Use the kinetic molecular theory to explain smells and how smells travel.

B. Key Elements of a Good Explanation

Evaporation and boiling are both examples of liquids changing into gases. In boiling, the liquid changes into a gas at the bottom of the container, where the liquid is being heated, and forms bubbles of the substance in the gaseous state.

The change from liquid to gas is similar to the change from solid to liquid. In boiling, a substance is heated, molecules move more quickly and eventually move fast enough to change from a liquid to a gas. In evaporation, the substance is not being heated, but some molecules are moving fast enough to escape the surface of the liquid and mix with the air.

Smell is due to evaporation. A container of alcohol smells, for example, because some of its molecules are moving quickly enough to escape the liquid, mix with the air, and travel to our noses.
C. Conceptual Learning

At the macroscopic level, students should recognize two important ideas: when liquid water evaporates, it changes from the liquid state to the gas state (water vapor), and then this water vapor mixes with the air and stays there. Even though these two ideas have already been introduced in Lesson Clusters 1 and 3, many students may have difficulty putting them together. Some common students' misconceptions are:

a. When liquid water evaporates, it changes from liquid to air.
b. When liquid water evaporates, water molecules change into air molecules.
c. When liquid water evaporates, it disappears and is gone.
d. When liquid water evaporates, it goes to clouds or forms clouds (but not necessarily stays in the air).

Each of these misconceptions stem from the difficulty of understanding that there can be (and is!) invisible water vapor in the air.

At the molecular level, students should be able to explain how or why evaporation occurs. That is, molecules in the liquid state are constantly moving, but at different speeds. Faster-moving molecules at the surface of a liquid break away from the attraction of the other molecules, and escape into the air. Furthermore, heating makes liquids evaporate faster because there are more fast-moving molecules and therefore more molecules can escape.

Lesson 8.1: Where Did the Water Go?

To explain why the air is humid or dry, students should realize that there is water vapor in air and that the amount of water vapor varies in dry versus humid air. Many students, however, may simply think that humidity has to do with temperature, that is, air is humid in hot weather like summer and dry in cold weather like winter. The teacher should help students realize that there is water vapor in air and that there is more water vapor in humid air than in dry air.

At the molecular level, students should know by now that molecules are constantly moving. Individual molecules are moving at slightly different speeds. Unless students understand that individual molecules in a liquid move at different speeds, they may wonder why some molecules escape from water but others do not; they may think that water needs to be heated to evaporate. Instead, heating simply speeds up evaporation by making molecules move faster.
Although the Science Book does not go farther in its explanation, there is more: As faster moving water molecules escape from a cup of water, the temperature of the water in the cup will decrease, and fewer molecules will have sufficient energy to escape, slowing down evaporation. However, this will happen only in a cup of water that is insulated from the rest of the environment. The external environment (i.e., the air, the cup itself, the desk the cup is on, etc.) will continuously provide enough heat to keep the water at a steady temperature and evaporation will continue.

Lesson 8.2: Where Does the Water in the Air Come From?

Students should understand that the process of water evaporating into the air does not just happen from cups of water or humidifiers. A very large proportion of water vapor evaporates from the oceans, lakes, streams, animals, and plants.

Students should be able to explain that water molecules are always escaping from any surface with water in it. One reason why plants and animals need to drink so much water is to replace water lost through evaporation.

Lesson 8.3: Fast Evaporation and Boiling

The teacher should help students distinguish between evaporation without heating, with heating, and boiling:

a. Evaporation occurs (without heating) when individual fast-moving molecules escape from the surface of a container.

b. Heating speeds up evaporation by causing more molecules to move faster and more molecules to escape from the surface of a container.

c. Boiling occurs when molecules move faster and faster at the bottom of a heated container, and they eventually move fast enough to change to a gas at the bottom. Trillions of molecules of water vapor collect to form bubbles that rise to the top of the container.

Students also have difficulty with the notion of bubbles. Many students think that there is "air" in bubbles. Some students may think that heat from the hot plate goes through the container into the water and changes into bubbles. The teacher should emphasize that bubbles are a collection of molecules of water vapor. The teacher should also emphasize that heating is the cause of bubbles, but not the "source" of bubbles.

Lesson 8.4: Evaporation and Smells

Students have already learned about smells in Lesson Cluster 3: Smells are made of molecules of the substance that have escaped and mixed in with the air. This is a form of evaporation. Not all molecules that evaporate from substances are smelly, though.

Some students attribute smell to a "scent" that leaves the substance, but don't recognize that the amount of substance decreases as the "scent" leaves it. They most likely do not understand that the "scent" is actually molecules of the substance.
D. **Conceptual Contrasts**

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation</td>
<td>Matter is conserved in all physical changes.</td>
<td>Matter is not always conserved, especially in changes involving gases (e.g., water molecules change into air).</td>
</tr>
<tr>
<td>of matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water vapor in air</td>
<td>Air contains invisible water vapor (humidity).</td>
<td>There is no gaseous state of water in air.</td>
</tr>
<tr>
<td>Same molecules in different states of same substance</td>
<td>Solid, liquid, and gas forms of the same substance are all made of the same type of molecule.</td>
<td>Molecules in different states of the same substance are different.</td>
</tr>
<tr>
<td>Effects of heat on molecular motion</td>
<td>Molecules of hot substance move faster.</td>
<td>Molecules themselves can be hot or cold.</td>
</tr>
<tr>
<td>Molecular explanation of changes of state</td>
<td>Heating and cooling cause changes of state by making molecules move faster or slower.</td>
<td>Heating and cooling make molecules &quot;evaporate.&quot;</td>
</tr>
<tr>
<td>Molecular explanation of evaporation</td>
<td>Evaporation is caused by fast-moving molecules escaping from liquid.</td>
<td>Molecules &quot;evaporate&quot; or disappear.</td>
</tr>
<tr>
<td>Molecular explanation of boiling</td>
<td>Boiling occurs when molecules of a liquid move fast enough to change to a gas at the bottom of the container. Trillions of molecules of the gas collect to form bubbles that rise to the top of the liquid.</td>
<td>Boiling occurs when a liquid changes to air. The air carries some of the liquid out of the container.</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 8
Explaining Evaporation and Boiling

Lesson 8.1: Where Did the Water Go?

You see things drying out around you all the time; puddles dry up; clothes dry on a clothes line or in a dryer; your hair dries out after a shower; towels dry when they are hung up. Have you ever wondered what happens to the water when something dries up? It takes trillions of water molecules to make something wet. Where do they go when something dries out?

You probably already know the answer to this question. The water does not just disappear; things dry out when water changes from liquid water to water vapor. This is called evaporation. The liquid water changes to water vapor that mixes with the air.

You probably also know that clothes and towels dry out more slowly when the air is humid. Sometimes you feel sticky because sweat evaporates from your skin more slowly. What do we mean when we say that the air is humid?

The air is humid when there is a lot of water vapor in the air. You may remember from Lesson Cluster 3 that there is always some water vapor in the air. After a summer rain, you may say that it is hot and humid. That means that the temperature is high and the amount of water vapor in the air is also high. Sometimes, there is so much water vapor in the air that our homes become uncomfortable. We may use a device called a dehumidifier, which takes some of the water vapor out of the air.

*Humid air has many water molecules in it*
Lesson 8.1: Where Did the Water Go?

Purpose:

To help students use the kinetic molecular theory to explain evaporation and humidity.

Materials List:

1. Paper towels and water
2. Transparency 13: Where does the water go when clothes dry?

Teaching Suggestions:

Begin this lesson by placing a spot of water on a paper towel and on the chalkboard. Discuss with your students the two questions at the start of Lesson 8.1. Students should easily recognize that the molecules on the paper towel are water molecules. Elicit as many responses to the question, "What happens to the molecules" as you can. Some students may say that the water molecules "turn into air" or "just disappear." These are naive conceptions and are not adequate explanations.

You may want to discuss with your students the question, "What do we mean when we say the air is humid?" when you come to it in the text. Many students are familiar with the term "humid", but they do not really understand what it means. They do not associate water vapor in the air with humidity. Most students will talk about the effects of humidity, that is, "we feel uncomfortable" or "we sweat a lot." Encourage students to explain why they may feel uncomfortable or sweat more. Have them use the model of a good explanation presented in Lesson Cluster 4.
In the wintertime, there is usually less water vapor in the air, and we may become uncomfortable because water is evaporating too fast from our skin, causing our skin to feel dry. To become more comfortable, we may add water vapor to the air. That is why many furnaces have a humidifier, which adds water vapor to the air when the air is very dry. This makes us feel more comfortable.

How does evaporation happen? Let's try explaining it in terms of molecules. You know that the molecules in liquid water are constantly moving. In a liquid, though, the attractive forces between molecules keep them close together. What you might not know is that the molecules in a liquid move at different speeds. Some molecules are moving very fast, while other molecules are moving more slowly.

What do you think would happen if a fast-moving molecule reached the surface of a drop of water? Yes, it would escape! It would break away from the strong attraction of the other water molecules and become a molecule of water vapor in the air. If all the water molecules escape in this way, we say that something has "dried out." The liquid water has turned into water vapor in the air, and the water vapor makes the air more humid.

Evaporation occurs when fast-moving molecules of liquid water escape into the air

Do Question Set 8.1 in your Activity Book
Unless students understand that individual molecules in a liquid move at different speeds, they may wonder why some molecules escape from water but others do not; they may think that water needs to be heated to evaporate. Instead, heating simply speeds up evaporation by making molecules move faster.

Although the Science Book does not go farther in its explanation, there is more: As faster moving water molecules escape from a cup of water, the temperature of the water in the cup will decrease, and fewer molecules will have sufficient energy to escape, slowing down evaporation. However, this will happen only in a cup of water that is insulated from the rest of environment. The external environment (i.e., the air, the cup itself, the desk the cup is on, etc.) will continuously provide enough heat to keep the water at a steady temperature and evaporation will continue.

Use Transparency 13 here:

**WHERE DOES THE WATER GO WHEN CLOTHES DRY?**

**WHERE DOES THE WATER GO WHEN CLOTHES DRY?**

The water evaporates.
The water molecules mix with other molecules in the air.

**TRANSPARENCY 13: WHERE DOES THE WATER GO WHEN CLOTHES DRY?**

**Bottom Layer**

Students have a variety of conceptions concerning this phenomenon. Some students will say that the water "just disappeared." Others will say that "it soaks into the clothes." Still others say "it evaporated."

**Overlay**

Of all the above conceptions, only the last is correct. The water does evaporate but this is not specific enough. Students should also understand what is happening in terms of molecules. Some of the water molecules in the drying clothes are moving fast enough to escape the surface of the clothes. These molecules mix with the molecules of the air and become part of the air.
Lesson 8.2 Where Does the Water in the Air Come From?

You learned in the last lesson that when things dry out, the water goes into the air. When you dry your hair, when clothes dry, or when puddles of water dry up all the water eventually goes into the air.

Sometimes the air is humid, though, even if there is no liquid water nearby. In fact, there is some water vapor in all air, even air in a desert that is far away from any liquid water. Where does all that water vapor come from?

To answer this question you have to think of the entire earth, not just of what you see around you. There is lots of liquid water on the earth. In fact, most of the world is covered with liquid water. Three-fourths of the earth is covered with oceans, rivers, and lakes and only one-fourth with land.

Think of the hardest rain you can remember. Sometimes it rains for several days, and rains very hard. Millions of gallons of water are falling around you, and most of them evaporated from the oceans, rivers, and lakes far away. Moving air or wind moves the water vapor from one place to another. For example, water molecules are constantly escaping from the surface of the ocean and moving into the air. The moving air sometimes carries these water molecules high into the atmosphere, where they may be carried thousands of miles. In this way the water vapor can move from oceans over the land. Some of this water vapor is always in the air.

Water is always evaporating from the land, too, from trees and other plants. Plants, like all living things, are mainly water. Some of the water molecules from the plants are moving fast enough to escape the surface of the leaves and other parts of the plant. If you've ever been in the middle of a deep forest or in a cornfield where the corn plants are higher than your head, you might have noticed that the air was unusually humid. In other words, the air has a lot of water vapor in it. Most of this water vapor comes from the evaporation of water from plants.

Even you are a source of water vapor in the air. When you sweat, the liquid water on your skin evaporates and becomes water vapor in the air. You add water vapor to the air in another way, too. Every breath that you breathe out contains water vapor from your lungs. A little bit of the liquid water from your lungs evaporates and leaves your body with each breath.
Lesson 8.2: Where Does the Water in the Air Come From?

Purpose:

To help students use the kinetic molecular theory to explain evaporation as the source of water vapor in the air.

Advance Preparation:

You may want to have a world map or a globe to discuss the relationships of the amount of water and land on the earth.

Teaching Suggestions:

It seems to be very difficult for many students to believe that there is invisible water vapor in the air at all times. Even those who understand that water goes into the air when it evaporates from puddles or drying clothes seem to have difficulty with this idea of "humidity" when no source of water vapor is near by. This is an especially important conception, though, for the explanation of condensation given in the Lesson Cluster.
So there are always water molecules in the air, molecules that have escaped from liquid water in the oceans, in lakes and rivers, in plants, and even from liquid water in your blood. After you have answered some questions about the many ways that water can evaporate, you will get to try making another liquid evaporate: alcohol.

---

Do Activity 8.2 in your Activity Book

---

*Sources of water vapor in the air*
Lesson 8.3: Fast Evaporation and Boiling

Suppose you want to make water—or some other liquid—evaporate faster. How could you do it? You discussed one way in Lesson 8.1: Water evaporates faster in dry air than in humid air. There are other ways, though. See if you can figure some of them out.

* * * * * * * *

Do Activity 8.3 in your Activity Book
* * * * * * * *

You probably thought of a lot of different ways to make the alcohol evaporate faster. Some of these ways help more air move by the alcohol. You might blow on the alcohol, for example, or swirl it around, or pour it out and spread it around.

Another thing you might have done is to figure out ways of warming the alcohol. You might have used your hands to make it warmer, for example. Can you explain why heating a liquid makes it evaporate faster?

It makes sense if you think about it. When you heat a liquid, there are more fast-moving molecules, so more molecules can break away from the attractive forces and escape.

Some appliances, like clothes dryers and hair dryers, use both heat and blowing to speed up evaporation. For example, a clothes dryer heats up the clothes so that more molecules are moving fast enough to escape from the surface of the clothes. The large drum inside the dryer tumbles the clothes through the air so that the hot air comes in contact with all the pieces of clothing. If the clothes were not tumbled, only the ones on the top would dry. The water molecules could not escape from the clothes on the bottom.

Now let's think about what happens if the molecules of a liquid start moving really fast. If you continue to heat a beaker of alcohol (or any other liquid), the molecules at the bottom move faster and faster until the attractive forces can no longer hold them together and they fly apart. The alcohol changes to alcohol vapor down at the bottom of the beaker! This alcohol vapor forms bubbles that rise to the surface of the alcohol. This process is called boiling.

So evaporation and boiling are both changes of state from liquid to gas, but they don't work in quite the same way. Let's compare the two processes.
Lesson 8.3: Fast Evaporation and Boiling

Purposes:

To help students use the kinetic molecular theory to explain rapid evaporation and boiling. To describe what is inside the bubbles of a boiling liquid.

Advance Preparation:

For the activity, you will need to measure 2-ml portions of alcohol.

Materials List:

1. For each student, 2 ml of alcohol

2. Transparency 14: What's inside the bubbles of boiling water?

Teaching Suggestions:

Begin this lesson by discussing the first paragraph in the Science Book. Ask students if they know of any good ways to make the process of evaporation go faster. When you have gathered a list of possible responses, proceed to the activity.

After you have given ample time to the activity, discuss what happened with your students and read the next four paragraphs aloud. Take a moment to talk about the clothes dryer example. This is an everyday application of the kinetic molecular theory, and it is important for students to see the connection between science and real life.

It is important for students to understand that the bubbles in boiling water are water vapor. If you were to boil alcohol, the bubbles in boiling alcohol are gaseous alcohol. They are not made of air or anything else. The bubbles are not individual molecules. You should draw out these misconceptions through discussion and confront them directly.
1. When molecules escape from a liquid's surface and mix with the molecules of air, it is called **evaporation**. In evaporation, individual molecules escape from the liquid.

2. When molecules of a liquid move faster and faster at the bottom of a heated container, they eventually move fast enough to overcome the attractive forces between them and fly apart. The liquid changes to a gas at the bottom. The gas forms bubbles that rise to the top of the liquid. This is **boiling**.

The gas inside the bubbles of a boiling liquid is invisible. It looks like air, but it is not air. Air is a mixture of different kinds of molecules: nitrogen, oxygen, and so forth. The bubbles in boiling water contain only water molecules; the bubbles in boiling alcohol contain only alcohol molecules.
Finally, make sure students understand the difference between evaporation and boiling. You can select individual students from the class to explain the difference in their own words, or you may want them to write the differences and similarities down.

Use Transparency 14 here:

**Transparency 14: What's Inside the Bubble of Boiling Water?**

**Bottom Layer**

Although students will come up with a variety of answers to this question, their most common answer will probably be that there is air inside the bubbles.

**Overlay**

The bubbles do not contain air. This is an important misconception to counter. They contain invisible water vapor. Under each bubble which forms at the bottom of the container are molecules that are moving fast enough to move very far apart [so that the liquid changes] directly to a gas. These molecules have clustered together to form these bubbles which then rise to the surface and pop, releasing water vapor into the air.
Lesson 8.4: Evaporation and Smells

You know a lot, now, about evaporation and boiling. Let's try using what you know to explain something else that is all around you: smells. Do you remember studying smells in Lesson Cluster 3? We said that you smell something when your nose detects molecules that are mixed in with the other molecules in the air.

That explains how you smell gases, but lots of the things we smell are solids like cookies or liquids like perfume. How do you smell them? For an example, let's think about something really smelly. How about a skunk?

Skunks make their scent by spraying out a liquid that contains many different kinds of molecules. The liquid that skunks spray out begins to evaporate. Some of its molecules escape from the liquid and mix with the air, then they move around with the breeze. Our noses are very sensitive to these molecules so we can smell a skunk even if there are only a few of its smell molecules mixed with the air. It takes a long time for all the liquid to evaporate, so if you are sprayed by a skunk, people will know it for a long time!

Many other substances are made of molecules that our noses can detect. What did the room smell like during the alcohol evaporation race? Can you explain why?

Many of the things we smell are actually complex mixtures that only allow some of their molecules to escape. Cookies, for example, contain many different kinds of molecules. When cookies are baked, some of the substances in them remain solids, but other substances melt and start to evaporate. Then the molecules of those substances reach our noses. Aaaaah!

When molecules of a substance mix with air, they bounce around and move through space just like air molecules. One way to see how much the molecules are moving, even in "still" air, is to see how smells spread through a room. Perhaps you can try it.

So when you smell a solid or a liquid, it isn't really the solid or liquid that you smell. You smell molecules that escape from the solid or liquid and come to your nose by bouncing through space like the other gas molecules in the air. Our noses wouldn't have much to smell if it weren't for evaporation!

* * * * * *

Do Review Question Set 8.4 Now

* * * * *
Lesson 8.4: Evaporation and Smells

Purpose:

To help students use the kinetic molecular theory to explain smells and how smells travel.

Advance Preparation:

You will need Transparency 6: What is the smell of baking cookies? Optional demonstration: If you choose to do the demonstration, you will need a bottle of perfume, vinegar, or ammonia. Optional activity: You may wish to borrow a copy of "Bartholomew and the Oobleck," by Dr. Seuss, for use with Question Set 8.3 in the Activity Book.

Teaching Suggestions:

Begin by having students read the first two paragraphs of the Science Book aloud. Remind students that they studied smells in Lesson Cluster 3. See if students can think of answers to the question, "How do we smell a skunk?"

Discuss other scents. Read the passages in the book and also feel free to have students choose smells and explain how our noses detect them.

Optional demonstration:

You may want to release a small amount of perfume, ammonia, or vinegar in the front of the room and have students raise their hands as they begin to smell it. This helps students see how smells travel.

Use Transparency 6 here. See Lesson 3.2 for its description.

When most students understand smells, let them do Question Set 8.4. This is a cluster review, so you may choose to use it as an evaluation tool.
INTRODUCTION TO LESSON CLUSTER 9
Explaining Condensation

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain condensation of water vapor on cold objects, and how condensation fits into the water cycle.

Lesson Objectives:

Students should be able to:

9.1 Explain condensation as part of distillation, or when liquids boil in open containers.

9.2 Explain condensation from evaporation.

9.3 Continue explanation of condensation from evaporation.

9.4 Explain condensation when the source of water is not evident (in the open air, and as part of the water cycle).

9.5 Explain various forms of precipitation.

9.6 Describe how water is recycled over and over again through evaporation and condensation in the water cycle.

B. Key Elements of a Good Explanation

The explanation of condensation is similar to that of solidifying or freezing. When air is cooled, (by coming into contact with a cold surface, for instance), molecules of water vapor slow down. If they slow enough, the attractive forces between them hold them together when they collide, and they coalesce into tiny droplets.

The distinction between the molecular structures of liquids and gases is important for this explanation. In gases, molecules are far apart and move freely. When they collide, they are moving fast enough so that the intermolecular forces cannot hold them together—they bounce off each other. In liquids, molecules are held closely together, but they are moving fast enough so that they slide past each other, moving from one place to another.

C. Conceptual Learning

At the macroscopic level, students should recognize two important ideas in order to understand condensation of water: There is water vapor in air, and water vapor changes into liquid water on a cold object. First, the teacher should help students remember the presence of water vapor in the air. By now, most students would not have
difficulty with this. Then, the teacher should stress how cooling affects water vapor to change into liquid. The teacher should also stress how condensation is related to boiling or evaporation: they are reverse processes. This will help students recognize how the processes of evaporation and condensation continue over and over again.

At the molecular level, the teacher should stress that when molecules of water vapor hit something cold, they slow down and move closer together. The closer the molecules become, the more they attract each other, and they cluster together to form a liquid.

Finally, some students may not recognize that cooling is necessary for condensation. The teacher should emphasize that condensation occurs only when water vapor is cooled by hitting something cold. That is why students use cold containers in the experiments. Related to this, the teacher should make the distinction for students between the cause (i.e., coldness) and the source (i.e., water vapor) of condensation.

Lesson 9.1: Boiling and Condensing

This lesson uses the distillation apparatus again to illustrate condensation. Some common misconceptions are:

a. Bubbles in the boiling water are air, and air changes back to liquid.
b. Condensation occurs when hydrogen and oxygen in the air combine to form water.

The teacher should stress that water does not change into air, and vice versa. Instead, the bubbles contain water vapor and water vapor mixes in the air. The teacher should also stress that the chemical reaction of \(2H_2 + O_2 \rightarrow 2H_2O\) does not occur in the air because there is virtually no \(H_2\) in the atmosphere.

Many students also have difficulty with the identity of water vapor and the word "steam." They may think that the visible "steam" above boiling water is water vapor. Some students may think that "steam" is hot air or heat rising off water. The teacher should help students with their learning difficulties by emphasizing the scientific idea that water vapor produced by boiling is invisible. The visible "steam" is droplets of water which have already condensed from water vapor. (Scientists use the word "steam" to indicate the invisible water vapor produced by boiling. We put the word in quotation marks to indicate colloquial rather than scientific usage.)

Lesson 9.2: Purifying Water Without Boiling

The evaporation-condensation cycle occurs when water evaporates as well as when it boils. Evaporation—from oceans, lakes, etc.—is the process that puts most of the water vapor into the air around us. Evaporation of salt water produces pure water when it condenses. This lesson demonstrates and explains the purification of water as a result of evaporation.
A three-stage process of evaporation, spreading of water vapor, and condensation, explains the movement of water in the purification process.

Lesson 9.3: Evaporating and Condensing

This lesson continues the discussion of how distillation occurs through evaporation and condensation. It begins with viewing the "solar still" episode of "Voyage of the Mimi."

The teacher should remind students of the difference between boiling and evaporation from Lesson Cluster 8. As in the last lesson, the teacher should stress how evaporated gases mix with and stay in the air and how they condense on cold objects in molecular terms.

Lesson 9.4: Condensing in the Open Air

In the last two lessons, students could see water vapor condense into liquid water in containers (i.e., closed systems). In this lesson, condensation on a cup of cold water sitting in the open air is explained. Students should realize that there is always water vapor in the air. Students who do not recognize the presence of water vapor in the air may have difficulty understanding where the liquid water on the outside of the glass comes from. Some students' misconceptions are:

a. Air outside the glass changes into liquid water.
b. Water inside the glass seeps through to the outside of the glass.
c. Coldness comes through the glass.

Since there is no visible source of liquid water, students may wonder where water vapor in the air comes from. The teacher should help students recognize various sources of water vapor, such as oceans, lakes, tree leaves, etc.

Lesson 9.5: Condensation and Precipitation

In the last lesson, different forms of precipitation were explained as various processes of condensation in the open air. This lesson focuses on the three-step process of 1) Evaporation, 2) Spreading, and 3) Condensation as a detailed explanation of all forms of precipitation.

Students may have problems in explaining the seemingly unrelated phenomena of fog, dew, rain, snow, or hail until they can see how each is a result of the same processes (evaporation and condensation) but under slightly different circumstances.

Lesson 9.6: You Drank the Water that George Washington Used to Wash His Boots

This lesson uses a catchy example to illustrate the water cycle. The important idea in the water cycle is that water that is on the earth remains almost the same, and is only recycled over and over again through evaporation and condensation.
D. **Conceptual Contrasts**

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Goal Conceptions</th>
<th>Students' Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of matter</td>
<td>Matter is conserved in all physical changes.</td>
<td>Matter not always conserved, especially in changes involving gases (e.g., water outside a glass comes from nowhere, or is hot air or heat).</td>
</tr>
<tr>
<td>Water vapor in air</td>
<td>Air contains invisible water vapor (humidity).</td>
<td>Water vapor is visible (e.g., in &quot;steam&quot; or fog as water vapor).</td>
</tr>
<tr>
<td>Condensation</td>
<td>Water vapor in air condenses on cold objects.</td>
<td>Condensation is &quot;fog&quot;; is formed by a reaction between heat and cold; or no concept about cooling.</td>
</tr>
<tr>
<td>Same molecules in different states of same substance</td>
<td>Solid, liquid, and gas forms of the same substance are all made of the same type of molecule.</td>
<td>Molecules of liquids are different from molecules of gases.</td>
</tr>
<tr>
<td>Effects of heat on molecular motion</td>
<td>Molecules of hot substances move faster.</td>
<td>Molecules themselves can be hot or cold.</td>
</tr>
<tr>
<td>Molecular explanation of states of matter</td>
<td>States of matter are due to different arrangements and motions of molecules.</td>
<td>States of matter described only in terms of observable properties; or properties of state attributed to individual molecules (e.g., molecules are in drops).</td>
</tr>
<tr>
<td>Attraction of molecules</td>
<td>Molecules of one substance attract each other.</td>
<td>No concept about how cooling causes attraction of molecules.</td>
</tr>
<tr>
<td>Molecular explanation of changes of state</td>
<td>Heating and cooling cause changes of state by making molecules move faster or slower.</td>
<td>Heating and cooling make molecules evaporate or condense.</td>
</tr>
<tr>
<td>Molecular explanation of evaporation</td>
<td>Fast-moving molecules escape from liquid.</td>
<td>Molecules evaporate or disappear.</td>
</tr>
</tbody>
</table>
LESSON CLUSTER 9
Explaining Condensation and the Water Cycle

Lesson 9.1: Boiling and Condensing

You have been studying changes of state for quite a while now. You have studied melting, freezing or solidifying, evaporation, and boiling. That means there is only one change of state left to study: condensation.

You know that if a liquid is heated enough, it turns into a gas. The molecules of the liquid move fast enough to escape from the attractive forces that hold them together and begin moving freely through space.

What do you suppose happens if we slow down the molecules of a gas by cooling the gas? The slow-moving molecules begin to stick to each other and form clumps. Clumps with lots of molecules make up drops of liquid. This process, where a gas turns back into a liquid, is called condensation.

Sometimes it is possible to use boiling and condensation to purify dirty liquids. Your teacher will show you how.

* * * * * *

Do Demonstration 9.1 in your Activity Book

* * * * * *

Let's explain what happened.

When you heat the flask, the liquid water changes to water vapor at the bottom of the flask and rises to the surface as bubbles. This, of course, is called boiling. The hot water vapor goes through the tube into the bottom of the cold test tube. When the water vapor hits the cold test tube, the molecules slow down and move closer together. When the molecules slow down enough, the attraction among them makes them stay close together. They cluster together to form a liquid.

The dye and other substances in the flasks are made of molecules that do not boil as easily as water. When the water boils and goes through the glass tubing, the dye and other substances stay behind in the flask.
Lesson 9.1: Boiling and Condensing:

Purpose:

To help students use the kinetic molecular theory to explain the processes of condensation and distillation.

Advance Preparation:

For Demonstration 9.1 in the Activity Book you need a distillation apparatus set-up as pictured in the activity book. The "dirty water" is a mixture of water, salt, and food color.

Materials List:

You will need the distillation apparatus, which consists of:

1. hot plate
2. Erlenmeyer flask
3. glass tubing
4. test tube
5. water, food coloring or dye, and salt

You will also need Transparency 15: What is the steam above boiling water?

Teaching Suggestions:

Be sure to start heating the distillation apparatus before you come to the demonstration so that you have enough time.

When you get to the demonstration, describe the contents in the Erlenmeyer flask (a mixture of water, salt and food color). Tell them you are going to separate the water from the other substances.
The process of boiling or evaporating a liquid and then condensing it again is called distillation. It is possible to separate very complex mixtures by this process. For example, we can get pure water from salt water by distillation. To do this, we would boil off the pure water, leaving the salt and other materials behind in the flask. In a similar way, we distill gasoline and many other useful substances from petroleum. Petroleum is a very black, complex mixture containing thousands of different substances. By distillation we can separate out those substances that make up gasoline.

You don’t need a test tube to see water boil and then condense. You can actually see water condense whenever you boil water, or soup, or any other liquid. The water vapor produced by boiling is invisible. But when the water vapor cools off it condenses to form the tiny droplets of water that we see and call "steam." As these droplets rise a little higher, they evaporate and change into invisible water vapor once again!
It is important for students to note that they can see examples of condensation in their everyday life. Read the paragraph about what we often call "steam" and put up the transparency "What is the "steam" above boiling water?" Be sure to remind students that we cannot really see steam, and show them that what we call "steam" is really tiny drops of water.

Another everyday example of condensation is the "fog" that forms when we breathe out on a very cold day. Water vapor in our breath turns to tiny droplets of water when it is cooled by very cold air.

Use Transparency 15 here:

**WHAT IS THE "STEAM" ABOVE BOILING WATER?**

![Diagram of boiling water](image)

**WHAT IS THE "STEAM" ABOVE BOILING WATER?**

![Diagram of condensation](image)

The water vapor condenses into tiny droplets.

**TRANSPARENCY 15: WHAT IS THE STEAM ABOVE BOILING WATER?**

**Bottom Layer**

Many students believe that the visible "steam" above boiling water is a gas. They will probably say that it is a "fog" or a "white cloud."

**Overlay**

Be sure to elicit students' ideas about the state that the steam is in. Although students will often say that the "steam" is a "fog" or "cloud", which is correct, they often believe that the fog or cloud is a gas, which is incorrect. Actually, the invisible water vapor, which has escaped from the boiling water, cools rapidly and condenses into tiny droplets of liquid water. This is what we see as the fog or "steam."
Lesson 9.2: Purifying Water Without Boiling

In the last lesson your teacher demonstrated one way of purifying water. When water boils, the liquid water turns to vapor, but other substances are left behind. Then the water vapor can condense into pure water.

There are other ways of purifying water that do not involve boiling. Your teacher will show you one now.

* * * * * *

Do Demonstration 9.2 in your Activity Book

* * * * *

Did you figure out how the demonstration worked? It worked by a three-stage process:

1. Evaporation. The water in the tumbler evaporated. Molecules were escaping from its surface. The heat from the overhead projector made the water evaporate faster by making its molecules move faster. When the water evaporated, the salt and food coloring were left behind.

2. Spreading of water vapor. The evaporation made the air inside the aquarium very humid; it contained lots of water molecules. This humid air spread throughout the container.

3. Cooling and condensation. This humid air cooled down when it came near the cool plastic wrap at the top of the aquarium. When the air cooled down, the water molecules in the air moved more slowly, and the attraction between them made them clump together to form drops of water. The tiny drops of water collected into larger drops that fell into the cup.

There are many ways that this demonstration and the distillation of boiling water (Demonstration 9.1) are alike. In both demonstrations, the water changed from a liquid to a gas, then condensed back into a liquid again. In both cases, the water was purified because the salt and food coloring did not change into gases.

In one way, though, the two demonstrations were different. In Demonstration 9.1, the water was changed from a liquid to a gas by boiling. In Demonstration 9.2, the water changed to a gas by evaporation. Boiling is not the only way to produce water vapor that can later condense. Evaporation works more slowly but just as well. By using evaporation it is possible to distill liquids without boiling them.
Lesson 9.2: Purifying Water Without Boiling

Purpose

To help students use the kinetic molecular theory to explain condensation after water evaporates from a nearby container.

Advance Preparation

Follow the illustration in the Activity Book (Demonstration 9.2, Page 51) to set up the apparatus.

Materials List

1. overhead projector
2. two gallon aquarium/terrarium
3. two cups
4. "dirty" water—water, salt, food color
5. clear plastic wrap
6. rubber band
7. weight (coin)

Teaching Suggestions

Begin the demonstration early in the morning, and let it run continuously.

Students should be able to follow the path of water molecules through the three-stage process of evaporation, spreading of water vapor, and cooling and condensation. The three-stage process describes what is happening on the visible or macroscopic level. When students can trace the path of water molecules through this process, they are explaining the process at the molecular level.
Lesson 9.3: A Solar Still

In Lessons 9.1 and 9.2 you saw examples of stills. Stills are devices that purify liquids by boiling or evaporating them, then condensing the gases back into liquids. Stills can be very useful. Suppose, for example, you were trapped on an island with no pure water to drink. You will die if you drink a large amount of ocean water; it has too much salt in it. What could you do?

The crew of the Mimi found themselves with a problem like this. They were shipwrecked, and they could find no fresh water. They solved their problem by constructing solar stills.

Let's try explaining how the solar still works. It is a three-stage process:

1. **Evaporation.** The water down at the bottom, which is dirty or salty, is heated by the sun. Its water molecules move faster and more of them escape from the surface. The water evaporates, leaving salt and dirt behind.

2. **Spreading of water vapor.** The water molecules mix with the other gases in the air and move all through the container. The air becomes very humid.

3. **Cooling and condensation.** The plastic at the top is cooler than the air inside the still. The molecules slow down when they come close to it. The attraction between the water molecules pulls them together, and they form drops. Pure water—without any salt—condenses on the plastic.

This three stage process—evaporation, spreading, condensation—occurs whenever there is water inside a closed room or container. Try answering some questions about other situations where it occurs.

* * * * * * *

Do Question Set 9.3 in your Activity Book

* * * * * * *
Lesson 9.3: A Solar Still

Purposes:

To help students use the kinetic molecular theory to explain evaporation and condensation.

Advance Preparation:

You will need the videotape episode entitled "Making Dew" from the series "The Voyage of the Mimi" from Bank Street College of Education. (See p. T-2 for address.)

Teaching Suggestions:

Begin this lesson by showing the Solar Still Episode of "The Voyage of the Mimi." The "Voyage of the Mimi" is a series from PBS. This fifteen minute episode is titled "Making Dew." The crew needs drinking water to survive on an uninhabited island. They set up a solar still to separate pure water from salt water. The still illustrates, in miniature, the water cycle: evaporation, spreading, and cooling and condensation.

TRANSPARENCY 16 (to be used in Lesson 9.4):

![Diagram showing water molecule movement](image)

**Bottom layer:** Students often respond to this question by saying that the water on the inside of the glass can somehow seep through to the outside of the glass. Even students who know about condensation may say that the water evaporated from the glass, not recognizing that there is always water vapor in the air.

**Overlay:** It is important to contrast these ideas with the more scientific idea. Students should know that there is always water vapor in the air. The water vapor in the air cools when it comes in contact with the cold glass. This makes the molecules of water vapor slow down and cluster together to form water drops on the glass.
Lesson 9.4: Condensing in the Open Air

It is easy to see where the water vapor that condenses in a solar still comes from. It evaporated from the water at the bottom of the still. What if there is no liquid water in a room, though? Can water vapor still condense?

The answer, of course, is yes. There is always water vapor in the air. This water vapor comes from oceans, lakes, rivers--and from you. If the air is cooled, the water molecules slow down, and the attraction between them causes them to cling together. The water vapor condenses.

The water molecules that slow down and stick together on a cold glass probably evaporated at many different times and places. Some molecules escaped from the ocean, others from lakes or rivers. Some molecules escaped from the leaves of trees or other plants. Some came from your breath. The motion of those water molecules mixed them with the other molecules of the air and brought them into the room. Water condenses on a cold glass because the glass cools the humid air around it and causes water vapor in the air to condense.

A little bit of water condenses on cold drinks but there is lots of water vapor in the air. Enough to make billions of gallons of water. Most of the water in the air condenses to form various kinds of precipitation: rain, snow, fog, sleet, hail, or dew.

All precipitation occurs when humid air cools off, the water vapor in the air condenses. Rain, for example, starts when humid air rises high up, where the air is cold. The water molecules in this cooling air slow down and clump together to form... raindrops!

Every day the sun shines on the oceans and billions of gallons of water evaporate. Those water molecules travel all over the world, then condense and come down as rain (and other forms of precipitation). The salty oceans produce salt-free rain; the whole world is like a giant solar still!

Rain water collects into lakes and rivers, the rivers run into the oceans, and the whole process can start over again. This is how all the precipitation on earth originates. The same water goes through the process over and over again, evaporating, spreading, condensing, and evaporating again. The whole process is called the water cycle.

* * * * * *

Do Question Set 9.4 in your Activity Book

* * * * * *
Lesson 9.4: Condensing in the Open Air:

Purpose:

To help students use the kinetic molecular theory to explain the process of condensation when the source of water is not visible or nearby, and to explain the water cycle.

Materials List:

1. Transparency 16: Where did the water come from on the outside of the cold glass?
2. Glass and ice water

Advance Preparation:

Before class, you should prepare a glass of ice water and set it where the students can see it.

Teaching Suggestions:

Begin the class by showing the glass of ice water you have prepared. There should be water on the outside of the glass; make sure all your students get a chance to view it closely.

Then use transparency 16: "Where did the water come from?" (illustrated on the preceding page). Elicit student responses to this question before letting the students view the overlay. There will probably be a variety of ideas from students about where the water comes from. Many will say that it evaporated from the glass, moved around the side, and then condensed. You can ask them what they think might happen if the glass was covered with a lid. Since there is always water vapor in the air, water would still condense on the cup.
Lesson 9.5: Condensation and Precipitation

We said in the last lesson that all forms of precipitation (rain, fog, dew, snow, sleet, hail) are caused by condensing water vapor. In this lesson we will discuss in more detail how different kinds of precipitation are formed. As you read, remember that all kinds of precipitation form in the same basic steps; the differences are only in the details. The steps you already know about:

1. Evaporation: Water evaporates from oceans, lakes and rivers, plants and animals.
2. Spreading: Water vapor is carried around by winds.
3. Cooling and condensation. The air cools off, and the water molecules clump together to form drops (or, if it is cold enough, crystals of ice).

When we see those drops or ice crystals high up in the air above us, we call them clouds. When they come close to the earth, we call them precipitation: rain, fog, snow, sleet, or whatever. Now let's talk about how some specific types of precipitation are formed.

Clouds and rain. You should have some idea how rain is formed from the previous lesson. The first step is evaporation. As air moves over bodies of water or plants and animals, some of the molecules of water are moving fast enough to escape and move freely in the air. As more and more molecules move from the liquid to the air, the air becomes humid. That means that the air has a lot of water vapor in it.

Next comes spreading. Sometimes this humid air travels high above the earth.

4. Precipitation: Drops fall from clouds to ground: RAIN.

Sequence of events leading to forms of precipitation: CLOUDS and RAIN
Lesson 9.5: Condensation and Precipitation

Purpose:
To help students be able to explain in more detail the everyday phenomena of different kinds of precipitation--rain, fog, dew, and snow--in terms of the processes of evaporation, spreading, and condensation.

Materials:
Transparency 17: What do all forms of precipitation have in common?

Teaching Suggestions:
You may want to begin the lesson by first eliciting from the students all of the different kinds of precipitation they have experienced recently and listing them on the board. Then begin reading the lesson.

Before discussing what clouds are, you may want to challenge student thinking by asking why it doesn't rain on sunny days. What is missing when the sun shines: (clouds) What do clouds have to do with rain?

As students read the rest of the lesson, take time to discuss each kind of precipitation (rain, snow, sleet, hail, dew, fog) in terms of evaporation, spreading, cooling and condensation.

Use Transparency 17 here:

**WHAT DO ALL FORMS OF PRECIPITATION HAVE IN COMMON?**

- **rain**
- **snow**
- **dew**
- **fog**

**ALL FORMS OF PRECIPITATION ARE CREATED BY THE SAME STEPS:**
1) EVAPORATION
2) SPREADING OF WATER VAPOR
3) COOLING AND CONDENSATION

**Bottom layer: Most students know the various forms of precipitation, but they may not know that all forms are created by the same steps.**

**Overlay: Stress that all forms of precipitation are created by the same steps: evaporation, spreading, cooling and condensing. You should encourage students to explain the three steps for at least one form of precipitation, in terms of molecules.**
Then comes cooling and condensation. As this warm, moist air moves higher in the atmosphere, it becomes colder and colder. The water molecules slow down, move less freely, attract each other, clump together, and form visible water droplets. If there are lots of water droplets we can see them from the ground; we call them clouds. If the air continues to get colder, these droplets of water get larger and larger until they fall to the earth as rain.

Fog. Have you ever wondered what the inside of a cloud looks like? You actually know what it is like inside clouds because you have been inside clouds that are close to the ground. Only you didn’t call them clouds. When clouds form at ground level we call them fog.

Fog forms in about the same way as clouds do high up in the sky. First the water evaporates, then the water vapor is carried around by the wind, then the air cools off and drops of water form. Fog often forms at night, when the air is cooler. If you have ever been in a thick fog, you know that the tiny droplets of water collect on your hands, face, and clothing, making you moist.

1. Evaporation: Water evaporates and air becomes warm and humid in sunshine.

2. Spreading: Warm humid air spreads around.

3. Condensation: Air cools off at night and water vapor condenses into droplets: FOG.

Sequence of events leading to forms of precipitation: FOG

Dew. Have you ever walked through grass in the early morning hours when the grass was wet or had water droplets on it? This is called dew. How do you think dew is formed? First comes evaporation. During the day, when the sun is shining, the ground and the plants in the ground become warm. Water evaporates from the lakes, rivers, and streams, as well as the plants and the air and becomes humid. This humid air spreads all around. What do you think will happen after the sun goes down and the ground and plants become cool?
You probably know the next step. It is **cooling and condensation**. As the air next to the ground becomes cool, the water molecules in the air move slower, hit each other less often, attract each other more, and move closer together, forming clusters of trillions of molecules of water that we call droplets. Drops of water clinging to plants and other materials on the surface of the earth are called dew.

1. **Evaporation**: Water evaporates and air becomes warm and humid in sunshine.

2. **Spreading**: Warm humid air spreads around.

3. **Condensation**: Grass cools off at night and water vapor condenses on it: **DEW**.

   ![Diagram of sequence: Sun above trees, dew drop on blade of grass]

   **Sequence of events leading to forms of precipitation**: DEW

**Snow, sleet, frost, and hail.** Sometimes water vapor condenses in places where it is really cold, so cold that liquid water freezes into ice. When that happens, instead of water droplets you get—crystals of ice! Many of the clouds that you see are actually made of ice crystals rather than drops of water. When those pieces of ice come down to the ground, we call them other forms of precipitation: Snow, sleet, frost, or hail.

Whether it comes in the form of ice or liquid water, though, all precipitation is formed by the same basic steps. First water evaporates, then the water vapor spreads around with the wind, then it cools off and condenses (and sometimes freezes, too).

---

Do Question Set 9.5 in your Activity Book
Students should answer Question Set 9.5 in their Activity Books at this point.
Lesson 9.6: You Drank the Water that George Washington Used to Wash His Boots

The rain that falls to earth today is not new water, but water that has been on earth for centuries. You know that molecules are very, very small. In fact, a gallon of water has about $120,000,000,000,000,000,000,000,000,000$ molecules in it. The chances are, therefore, that some of the water you drank today had at least one molecule of water that George Washington used to wash his boots with in 1776.

Imagine that in 1776, George Washington stood under a cherry tree and washed his boots. Some of this water was soaked into the ground, was taken up by the roots of the cherry tree, and evaporated from the leaves of the cherry tree. The wind carried these molecules far across the Atlantic Ocean and they rained down on the ocean in a thunderstorm.

In the ocean, they were constantly moving like all the other molecules of water in the ocean, and they were constantly being hit by all the other molecules. Eventually, some of the molecules from George Washington's boots moved fast enough to escape into the air, where they moved freely.

The air currents moved them northward and eastward until they were again part of a big, beautiful cloud that was cooled by air coming from the north. They lost some of their speed and became part of rain droplets that fell over the lush vineyards of France. The roots of the grapevines took the molecules in, and again they evaporated from the leaves and became part of the free-moving air.

This continued until the molecules moved through three or four more water cycles all the way to the Pacific Ocean. They were carried across the United States from the West to the East Coast. In the Central plains, a cold Canadian mass of air pushed the molecules high in the air where they slowed down, became part of a cloud, and eventually fell as rain.

They made their way deep in the soil and continued down until they reached the ground water. Many cities pump their water from this ground water. It became part of the drinking water and this morning you drank some of the very same molecules George Washington used to wash his boots in 1776.

The purpose of this story was to show you that the amount of water that is on the earth remains about the same, and is only recycled over and over again through evaporation, spreading, and condensation. This repeated evaporation, spreading, and condensation is called the water cycle.

Most of the water molecules on earth are very, very old; they have been around since the earth began. During that time they have been through many, many water cycles, evaporating, spreading, and condensing, and evaporating, spreading, and condensing.
Lesson 9.6: You Drank the Water that George Washington Used to Wash His Boots

Purpose:

To help students comprehend that the water we use in everyday life is water that has been recycled over and over again through the processes of evaporation and condensation.

Teaching Suggestions:

After you finish reading the story, discuss it with your students. Creative students may wish to add to the story.

When you are through discussing, have students complete Question Set 9.6. This question set is a cluster review, and it can be used as an evaluation tool.
again. They have been carried all over the earth by wind and rivers and ocean currents. Through all of the changes and movements, though, the molecules themselves have stayed the same. The water molecules and the water cycle go on and on.

* * * * * *

Do Review Question Set 9.6 Now
* * * * * *

THE LAST PAGE

Yes, this is the last page of this unit. Your long study of molecules is over. We hope you have learned a lot about molecules and about how they can help you explain many different things. Can you think back to how molecules can explain the way things dissolve? What about thermal expansion? Compression of gases? Changes of state?

Even if you have learned a lot about molecules, there is still much more to learn. We can use ideas about molecules to explain what happens inside our bodies when we breathe, for example, or how we grow, or what happens when things burn or decay. We cannot explain those things in this unit, but we hope that this unit will prepare you to learn and understand much more in the future. There is always more to learn; we hope you find it interesting!
Question Set 9.6 is the cluster review, and can be used as an evaluatory tool.
MATERIALS LIST

Lesson 1.1:
For each group of students: one ice cube and one ziplock plastic bag. For the class: one balance (optional).

Lesson 1.2:
One hot plate, one small Erlenmeyer flask with a one hole stopper, glass tubing including two right angles, one test tube, and one beaker.

Lesson 1.3:
Transparency 1

Lesson 1.4:
None

Lesson 2.1:
Transparency 2

Lesson 2.2:
For each group:
1. six plastic cups
2. salt
3. pepper
4. sugar
5. syrup
6. dirt or soil
7. water
8. Transparency 3

Lesson 2.3:
Transparency 4

Lesson 3.1:
For each student group:
1. a small plastic bag
2. a plastic cup or small jar
3. a large container of water
4. a 2-ft length of plastic or rubber tubing
5. a grease pencil for marking water levels of cup

Lesson 3.2:
1. Transparencies 5 and 6
2. perfume to be released in the classroom

Lesson 3.3:
For each student group:
1. a plastic cup
2. a soda straw
3. BTB solution
Lesson 4.1:
1. ping-pong ball
2. inflated ball
3. hair dryer
4. wind-chimes--optional

Lesson 4.2:
For each group of students:
1. syringe
2. a plastic cup
3. water
4. Transparency 7

Lesson 4.3:
aerosol cans or CO₂ fire extinguisher (optional)
pictures of scuba divers or mountain climbers (optional)

Lesson 4.4:
1. (optional) A bicycle pump and tire (or entire bicycle)
2. Transparency 8
3. Poster 1

Lesson 5.1:
For each student or each group:
1. magnifying glass
2. sugar
3. empty tea bag
4. plastic cup
5. water
6. Transparency 9

Lesson 5.2:
For each group of students:
1. two tumblers
2. two spoonfuls of salt (Kosher salt or canning salt)
3. two plastic cups
4. a coffee stirrer

If you do the optional activity suggested in question 6 or the Activity Book, you will need a large pan or container to allow the salt solution to evaporate.

Lesson 5.3:
Cups of:
1. soda
2. mouthwash
3. catsup
4. honey
5. syrup
6. kool-aid
7. clear shampoo
8. apple juice
9. liquid dish detergent
10. hair color dye
11. dish water
12. Transparency 3

Lesson 6.1:
1. two plastic cups
2. two pieces of hard candy
3. hot and cold water
4. Transparency 10
5. Poster 2
Lesson 6.2:
For this demonstration:
1. a ball and ring apparatus
2. a heat source such as a propane burner or candle
3. Transparency 11

Lesson 6.3:
For each group of students:
1. one thermometer
2. two plastic cups
3. hot and cold water

Lesson 6.4:
1. one large soda bottle, cold
2. one dime
3. one balloon for optional activity

Lesson 7.1:
1. Transparency 12
2. Poster 3

Lesson 7.2:
1. one hot plate
2. two beakers
3. olive oil, shortening, chocolate, and paraffin
4. four test tubes
5. test tube rack
6. ice

Lesson 7.3:
None

Lesson 8.1:
1. paper towels and water
2. Transparency 13

Lesson 8.2:
world map or globe (optional)

Lesson 8.3:
1. for the activity: for each student, 2 ml of alcohol
2. For the demonstration: You will need a pre-heated hot plate and 2 beakers, one with 2 ml of alcohol, the other with a larger amount so that students can view the bubbles. Caution: There should be no open flames in the room when you boil alcohol.
3. Transparency 14

Lesson 8.4:
1. Transparency 6
2. for demonstration (optional): bottle of perfume, vinegar, or ammonia
3. Bartholomew and the Oobleck by Dr. Seuss (optional)
Lesson 9.1:
You will need the distillation apparatus:
1. hot plates
2. Erlenmeyer flask
3. glass tubing
4. test tube
5. water, food coloring or dye, and salt
6. Transparency 15

Lesson 9.2:
1. overhead projector
2. two gallon aquarium/terrarium
3. two cups
4. "dirty water"—water, salt, food coloring
5. clear plastic wrap
6. rubber band
7. a weight (coin)

Lesson 9.3:
Videotape: Episode "Making Dew" from "The Voyage of the Mimi"
To obtain, contact: Sam Gibbon
"Voyage of the Mimi"
Bank Street College
610 W. 112th St.
New York, NY 10025
(212) 663-7200

Lesson 9.4:
1. glass and ice water
2. Transparency 16

Lesson 9.5:
Transparency 17

Lesson 9.6:
None
HOW BIG IS A SPECK OF DUST COMPARED TO A MOLECULE?

speck of dust
The speck of dust is really trillions of times bigger than any of the molecules in air.
WHY CAN YOU CHANGE LIQUID WATER INTO ICE BUT NOT INTO ALCOHOL?
Liquid water and ice are made of the same kind of molecules: water molecules.

Liquid water and alcohol are made of different kinds of molecules.
WHAT WOULD OCEAN WATER LOOK LIKE?

How many different kinds of molecules would you see?
You would see water molecules, salt molecules, and dozens of other kinds.
HOW ARE MOLECULES ARRANGED AND HOW DO THEY MOVE....

...in grains of solid sugar?

...in liquid alcohol?

...in oxygen gas?
Solid sugar: molecules are locked in a rigid pattern and vibrate in place.

Liquid alcohol: molecules slide and bump past each other, but stay close together.

Oxygen gas: molecules are far apart and move freely in space. They sometimes hit each other.
WHAT DO MOLECULES OF AIR LOOK LIKE?

How many different kinds of molecules would you see in this jar of air?
Air is made up of the following kinds of molecules:

- nitrogen (N₂)
- oxygen (O₂)
- water (H₂O)
- carbon dioxide (CO₂)
WHAT IS THE SMELL OF BAKING COOKIES?
The smell of baking cookies is a gas. Some of the molecules of the cookie move through the air.

\[ \text{air molecules} \]

\[ \text{cookie smell molecule} \]
WHAT HAPPENS TO AIR MOLECULES WHEN THE PLUNGER IS PUSHED IN?

Air molecules spread far apart.
Air molecules move closer together
WHERE DOES THE AIR GO WHEN YOU PUMP IT INTO A TIRE?
THE AIR MOLECULES SPREAD EVENLY THROUGH THE TIRE.
WHAT HAPPENS WHEN SUGAR DISSOLVES IN WATER?
Water molecules knock sugar molecules off grains of sugar.
WHY DOES THE SUGAR DISSOLVE FASTER IN HOT WATER?
The water molecules move faster, so they break off sugar molecules faster.
WHY DOES HEATING THE METAL BALL MAKE IT EXPAND?
HEATING MAKES THE MOLECULES MOVE FASTER AND PUSH EACH OTHER FARTHER APART.
WHY DOES LIQUID WATER CHANGE INTO ICE WHEN IT GETS COLD?
The attraction among the molecules makes them stick together in a rigid pattern.
WHERE DOES THE WATER GO WHEN CLOTHES DRY?
The water evaporates. The water molecules mix with other molecules in the air.
WHAT'S INSIDE THE BUBBLES OF BOILING WATER?

hot plate
Water vapor is in the bubbles.
WHAT IS THE "STEAM" ABOVE BOILING WATER?
The water vapor condenses into tiny droplets.
WHERE DID THE WATER COME FROM ON THE OUTSIDE OF THE COLD GLASS?
Water molecules in the air are slowed down by the cold glass and stick together in drops.
WHAT DO ALL FORMS OF PRECIPITATION HAVE IN COMMON?

rain

snow

dew

fog
ALL FORMS OF PRECIPITATION ARE CREATED
BY THE SAME STEPS:
1) EVAPORATION
2) SPREADING OF WATER VAPOR
3) COOLING AND CONDENSATION
EXPLAINING CHANGES IN MATTER

SUBSTANCES

1. **Wind or pressure:**
   Gases push on other objects.

2. **Compressing and expanding gases:**
   Gases can be pushed into a smaller space, then push back out into a larger space again.

3. **Dissolving:**
   Solids dissolve in liquids.

4. **Thermal expansion:**
   Solids, liquids, and gases expand when heated (or contract when cooled).

5. **Melting:**
   Solids change into liquids when they are heated.

6. **Freezing:**
   Liquids change into solids when they cool down.

7. **Boiling:**
   Liquids turn into gases and bubble away when they are heated.

8. **Evaporation:**
   Liquids that are left standing become gases that mix with the air.

9. **Condensation:**
   Drops of liquid water form when air containing water vapor is cooled.

MOLECULES

Gas molecules hit the objects and bounce off of them.

Molecules of a gas can be pushed closer together because there is empty space between them. They push back out by hitting the sides of the container.

Molecules of the liquid hit molecules of the solid and break them away. The two kinds of molecules mix together.

Molecules of hot substances move faster, so they push each other farther apart.

When they are moving fast enough, molecules of the solid escape from their rigid pattern and start moving past each other.

Attraction between molecules of a liquid pulls them into a pattern if they go slow enough.

Fast-moving molecules of the liquid break away from each other and begin to fly around freely, making bubbles of gas.

Faster moving molecules escape from the liquid and mix with air molecules.

Water molecules in the air are attracted to each other and come together in drops when their motion slows down.