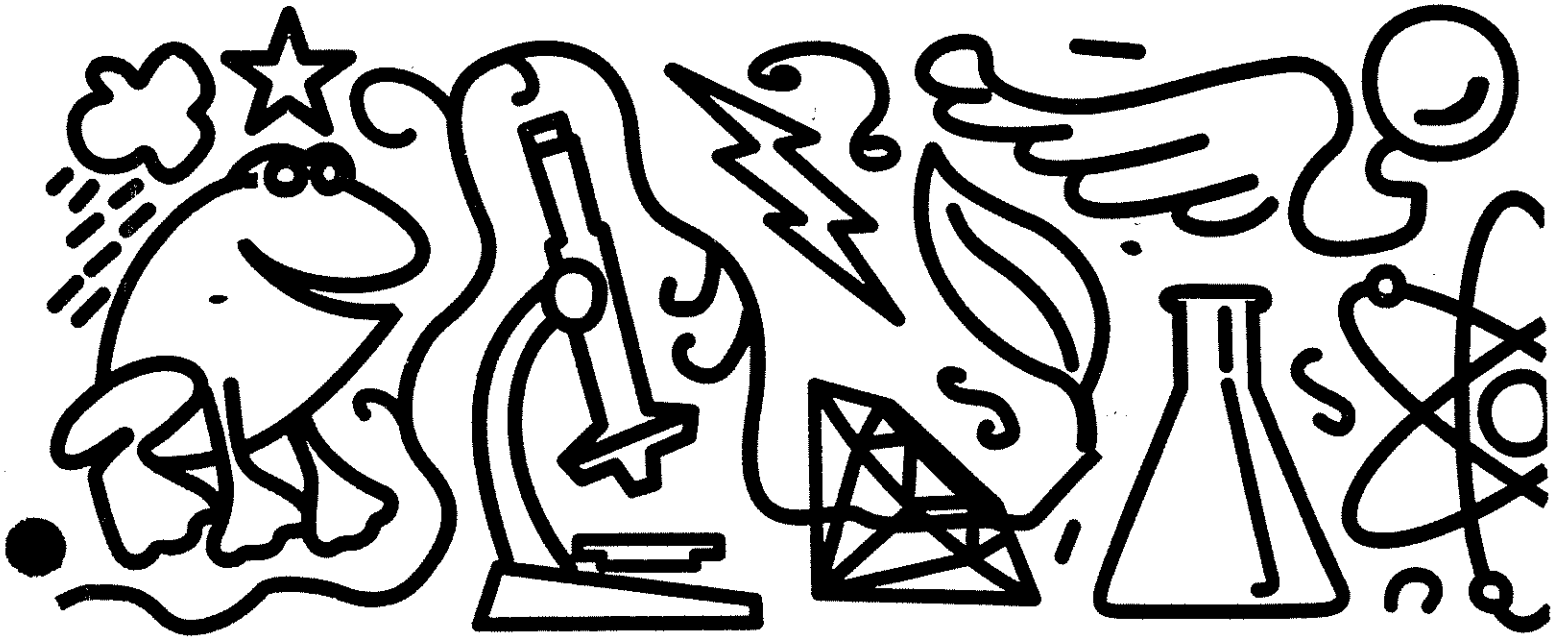
CHEMISTRY THAT APPLIES



NEW DIRECTIONS TEACHING UNITS

Michigan Science Education Resources Project

Michigan Department of Education

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Special thanks to: Project assistant: Linda Vermeersch Artwork: Anthony Johnson. Editor: Marilyn Laughlin. Thanks to th many workshop participants who offered constructive suggestions fo. revising this unit. Much of the research and initial teaching approaches were developed by Joseph Hesse, Grand Rapids Community College, to whom we are highly indebted.

How to use the "Chemistry That Applies" unit
(8th, 9th or 10th grade)

The student book: Each student should have a copy of the student book. This book includes reading, lab activities, and discussion questions, all integrated into lessons. The lessons are clustered into four sections (simply called "Clusters"), each based on a key question.

Student lab notebooks: The student books have no space for writing answers to questions, so that they can be used by several classes. For writing answers, recording data from investigations, and posing new questions, we recommend that students use a lab notebook or journal. Notebooks have several advantages over single sheets of paper handed out and collected on a daily basis: They let students compile their work, as in a portfolio, gaining some sense of pride in their collection; and they allow students to look back on their early ideas, appreciating the way their understanding grows. In a few lessons, prepared handouts are available for students' use (in the appendix), which can be kept in a pocket in their lab notebook.

Annotated teacher's edition of the student book: The teacher's guide contains several pieces of information that should be helpful to teachers as they prepare and teach this unit. They include:

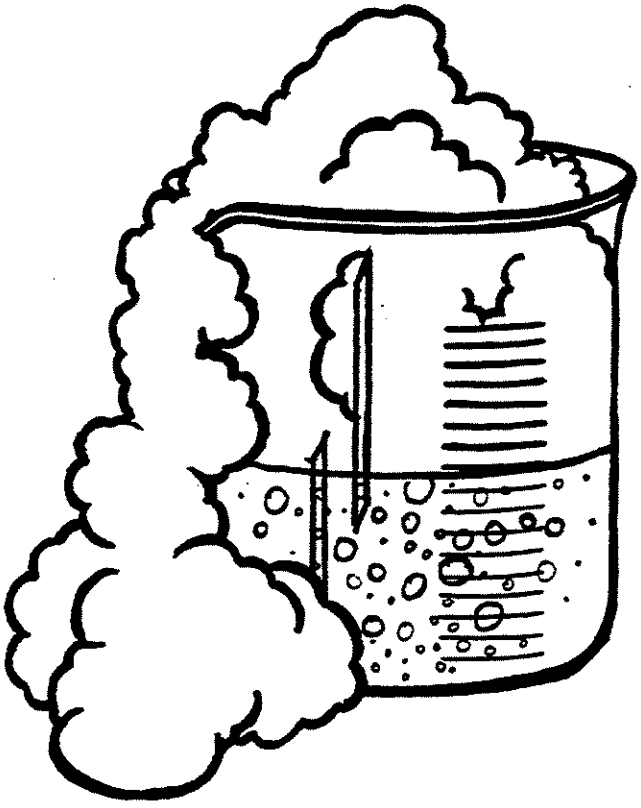
- **background information** to help teachers see the broad directions and intent of the unit;
- **lesson background and lab preparation** (on yellow sheets prior to each cluster) to prepare for the hands-on activities in each lesson:
- **lesson statement, purpose, and approximate time** for each lesson;
- **margin notes** on student thinking and content; and
- **answers to questions** posed in the text.

Overhead transparency masters: The appendix contains three drawings of the human body, one showing the digestive system, one showing part of the circulatory system, and one showing the lungs. These three can be overlaid to illustrate discussions in the text.

Feel free to contact Mr. Theron Blakeslee, Project Director, at (517) 373-0454 with any questions, suggestions for improvements or concerns.

CHEMISTRY THAT APPLIES

8th, 9th, or 10th grade



Michigan Department of Education

Artwork by Mark Galik (except pages 53 and 54 by Anjela Curtis).

Philosophy and Rationale

New Directions teaching materials have been created to help teachers develop scientific literacy and conceptual understanding for all of their students. As companions to the new Michigan Essential Goals and Objectives for K-12 Science Education, they illustrate the ideas about teaching, learning, and curriculum that underlie the new objectives.

Chemistry That Applies is an 8th, 9th, or 10th grade unit that helps students construct a clear understanding of how new substances form from the old ones and how the Law of the Conservation of Matter applies to all of these situations. It also helps students learn to pose questions, search for solutions to problems, work together with others, and value the need for evidence in making decisions.

Specifically, it illustrates the four important goals for science education listed in the Introduction and Rationale of the new state science objectives:

1) SCIENTIFIC LITERACY FOR *ALL* STUDENTS

Scientific literacy includes the ability to **use** scientific ideas to understand the world around us, **construct** new ideas by asking questions and searching for answers, and **reflect** on the adequacy of explanations and solutions. In this unit, students perform four reactions—combining baking soda with vinegar, burning butane, rusting iron, and decomposing water. They learn how to write good descriptions of reactants and products as a way to predict whether new substances have formed. They trace the atoms from reactants to products and see how the reactions observe the Law of the Conservation of Matter. They build molecular models that simulate chemical change in order to understand how new substances form. As they do this, they make predictions and learn how to test their predictions through experiments they design. They sharpen their abilities to ask questions and construct answers, and reflect on the evidence needed to support arguments and decisions.

Scientific literacy is not just for those who show an early interest in science or those who might pursue science-related careers. It is for ***all*** students. Because fewer and fewer young women and minority students develop an interest in science and technology, these **New Directions** units incorporate materials and approaches to support and encourage them to succeed and stay in science.

2) UNDERSTANDING OVER CONTENT COVERAGE

To be scientifically literate, students need to have a deep and connected understanding of the "big ideas" of science. In this unit, these ideas include

1) that matter is conserved in all chemical reactions;
2) that all matter is composed of atoms that join together to form molecules;
3) that new substances form when the atoms of the reactants come apart and reassemble in new arrangements to make the products; and
4) that all chemical reactions involve energy changes and usually they need "boosters" to get them started.

This kind of conceptual understanding takes time. That's why these units are relatively long. For some teachers, 6 to 8 weeks for one unit in science seems like a sacrifice of other important content. But to really understand the big ideas, students need to understand theoretical concepts, such as chemical change and conservation of matter and energy, and be able to translate this understanding to real-world situations, like conserving resources and getting rid of trash. They need to see how the concepts they learn make sense in terms of what they are already familiar with, whether that is baking cookies or watching a fire burn or recycling pop cans. This kind of learning fundamentally differs from science teaching that skims across many topics, often overwhelming students with chemical formulas and equations. It is especially important for developing scientific literacy in *all* students.

3) LEARNING THAT IS USEFUL AND RELEVANT OUTSIDE OF SCHOOL

Scientific literacy means an understanding of science that can be put to good use outside of school. For that reason, we have chosen topics for the **New Directions** teaching materials that connect scientific ideas, skills, and habits of mind with important real-world systems, events, and problems.

But research continues to show that students bring to the classroom theories about how the world works that are sometimes at odds with scientific explanations. In this unit, for example, students often believe, naively, that matter changes into heat and energy when it burns and therefore weighs less. They fail to recognize that new molecules form from the old ones and that the heat and energy released come from the energy involved in holding the atoms within the molecules together. One of the important goals of these new materials is to connect students' developing scientific ideas with the ideas they already use to make sense of the world. Sometimes this involves relatively little change; sometimes it involves "mind-bending" change.

4) INTERDISCIPLINARY TEACHING

The world is interdisciplinary. Chemistry alone, or physics alone, or social science alone, does not provide the answers to important social questions. And students should not see the world as compartmentalized, with language arts occurring between 9 A.M., mathematics between 10 A.M. and 11 A.M., and science only after lunch.

These units draw from as many scientific disciplines as necessary to dig deeply into the topic. In this unit, chemistry, physics, and environmental science are closely woven together. The unit also provides multiple opportunities for using and strengthening students' expressive and quantitative abilities.

On the whole, we hope that these units provide new resources to teachers to improve student achievement in science. The outcome we are all striving for, though, is not just better test scores. What we really want are scientifically literate citizens.

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CLUSTER 4—ENERGY AND "BOOSTERS"

APPENDICES

About This Unit

What's going on when iron rusts or fires burn or cakes bake or caves form? And where does trash go when it burns up or when we throw it away?

How do hand and toe warmers work? Does a house really turn into heat and energy when it burns? Where does the light in a light stick come from?

These ordinary questions arise from the things that happen around us everyday. But one's ability to answer them requires a deep understanding of scientific knowledge, especially chemistry and physics. As an introduction to chemistry, this unit gives students opportunities to explore various everyday chemical reactions, contrast them to physical changes, and construct explanations for them in terms of changes in the molecules that make up the substances. Current research reflects how students typically describe and explain everyday chemical reactions. This research will help pinpoint the difficulties that students typically have in learning about chemistry.

This unit focuses on important, everyday reactions rather than obscure "chemistry set" reactions or those that come out of the mysterious chemistry stock room. This is not meant to suggest that theoretical chemistry research or chemical engineering with complex substances is unimportant. But students' introduction to chemistry should be in an everyday context so that it does not seem remote or magical. By focusing on just a few reactions in depth, students will probably be able to extend their knowledge to understand the world around them in a more scientific way.

Equally important in understanding chemistry in the world around us are certain skills and habits of mind—the ability to make predictions and then test them to see if they are right, to pose questions and design experiments to answer those questions, to demand evidence and logical reasoning to support assertions, and to think critically about others' claims or ways of thinking. This unit will also help students develop these abilities.

Cluster by Cluster

This unit is composed of four clusters, each building toward a comprehensive story of how changes in matter relate to atoms and molecules and energy—one of the key questions in the Framework of the Michigan Essential Goals and Objectives for K-12 Science Education. As a unit, these materials put the goals for Michigan science education into practice (see the Michigan Essential Goals and Objectives for K-12 Science Education, page 1, Philosophy and Rationale).

How the unit works:

To develop a broadly-connected understanding of how new substances form, this unit applies ideas about atoms, molecules, chemical reactions, and energy changes to four relatively simple reactions: burning, rusting, the decomposition of water, and the "volcano" reaction of baking soda and vinegar.

Students will, in general, have studied changes of state (melting, freezing, evaporating, condensing) and other physical changes (dissolving, crushing, coloring, etc.) prior to doing this unit. They usually will not, however, have studied the properties of many everyday substances (such as gasoline, baking soda, bleach, metals, bread, wood, paper, etc.) or the chemical changes that take place with them (burning, rusting and other oxidation reactions, baking, the effects of acids, etc.)

In Cluster 1, students are asked to develop descriptions of various substances and changes that occur in those substances, with the purpose of eventually being able to recognize when chemical reactions have occurred—that is, when new substances are produced. This is often difficult because students typically use the language of physical changes to talk about what scientifically literate people recognize as chemical changes. For example, students may say that rust is nothing more than discolored or flaky metal, or that when an egg white cooks it goes through a phase change from liquid to solid, or that gasoline goes through a phase change from a liquid to a gas when it burns. They fail to understand that chemical changes produce new substances or how those substances form. Students learn to write more accurate descriptions of reactants and products and use their descriptions to find evidence for the formation of new substances.

Cluster 2 asks whether the weight of substances changes during physical and chemical reactions. Students make predictions about weight changes and then actually weigh the starting substances and the ending substances to check their predictions. They learn to account for the invisible gases either as reactants or as products and are eventually led to the Law of the Conservation of Matter. Many students think that solids weigh more than liquids, that gases have no weight, and that burning makes things disappear. They often have great difficulty letting go of these misconceptions even when experimentation has shown them otherwise.

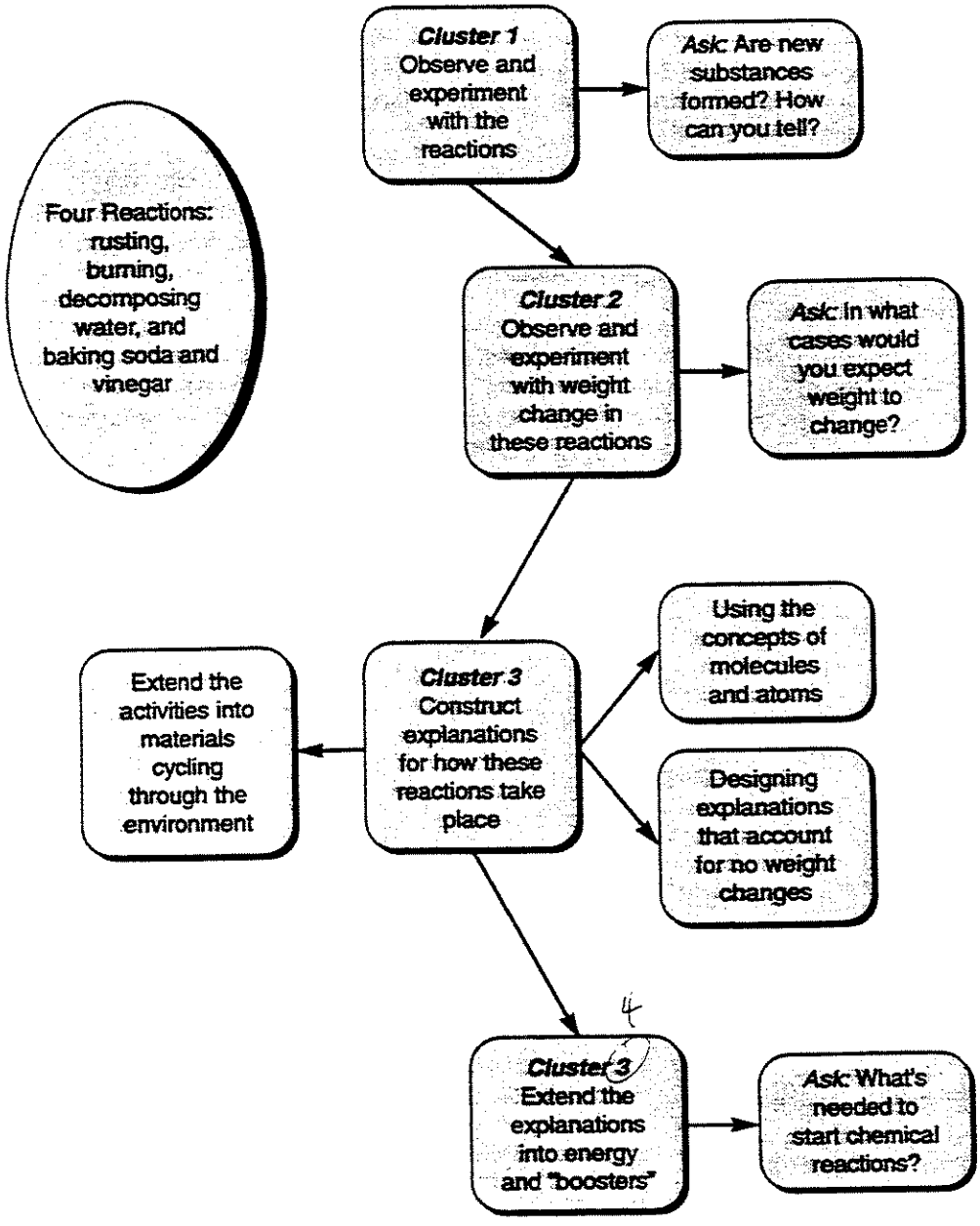
In Cluster 3, students construct explanations for both the formation of new substances and the Law of the Conservation of Matter. These concepts

are explained and understood in terms of the rearrangement of atoms in molecules during chemical reactions. The cluster introduces molecules as a way to distinguish between substances and as a way to account for what happens during chemical reactions. It presents chemical equations as a way to account for and conserve atoms and to show how new substances form. It poses many questions that extend students' thinking to similar situations in the world around them.

Cluster 4 explores the energy changes that take place between reactants and products and uses separate energy equations to express these changes. It then focuses on reactions that require a "booster" to get started, either in terms of energy or chemical substances that remain after the reaction (catalysts).

Throughout the entire unit, students conduct their own research of a chemical substance. They apply the concepts learned in each cluster to their specific substance as they learn its chemical name, physical properties, history, uses, chemical composition, disposal method, and energy requirements. At the conclusion of the unit, students make presentations using formats they have chosen.

Unit Outline



Working in Groups

The activities in this unit are written to be done in small, collaborative groups, where students have distinct responsibilities for various tasks in the activities. We suggest that you assign students to groups—rather than letting students choose their own groups—to ensure diversity of thinking and action-orientations within the group. Be observant of how groups operate together, and restructure them if anyone is dominating a group or anyone is allowing others to do their work.

Many questions are also developed for discussion in students' small groups. These discussions are ones where students debate with each other in a collaborative effort to find solutions to problems. Students should still be responsible for writing individual answers to questions, so that those who do not contribute strongly or learn well from group discussions have opportunities to articulate their own ideas in writing.

Classroom Environment

Even though different teachers have different personalities and different approaches to helping students learn, what is common in classrooms where students are really making sense of science is student *activity*—students working, students thinking, students explaining. "Hands-on, minds-on" means that *doing* and *thinking* are linked together in developing scientific literacy.

Classrooms where students really make sense of science and learn to use its key ideas and habits of mind in their daily lives have a culture where students are continually trying things out, discussing their ideas, debating solutions to problems, being critical as well as open-minded, listening and thinking. Whether they are learning how to explain why something works, or how to describe a natural system in detail and show the connections of its parts, or how to use information to make predictions, or how to design and build a tool or a system, students have to be allowed to try out their ideas and explain their reasoning.

And teachers have to value students' thinking, both for the insight it provides to further a student's development and because it is the product of the student's honest efforts to grapple with the important questions being raised in the class. In this environment of working, thinking, and listening to others, students learn that their ideas are important and valued and that science is not authoritarian, dogmatic, and esoteric.

Supporting Young Women and Minority Students in Science

Unfortunately, there are far more white males in scientific and engineering enterprises than women and members of minority groups, including African Americans, Hispanics, and American Indians. We say "unfortunately" because the contributions of women and minority persons to the scientific and engineering enterprises has historically been strong, even though they have been underrepresented in their numbers.

Clearly science and technology are fields that many persons can make strong contributions to and that all persons should have the opportunity to choose. Many of our educational practices have pushed women and minority students away from science, though.

These materials, coupled with the best intentions of Michigan's teachers, provide support and encouragement for all students to take more science and mathematics courses and consider scientific and technical fields. They do this by integrating culturally-relevant science materials that reflect the perspectives, experiences, events and interests of different ethnic groups relative to their roles in the scientific enterprise into these teaching units. These culturally-relevant materials emphasize the impact that all groups, including women, have had on science and technology, and the significant consequences and implications for scientific improvement and achievement.

We do this for several reasons. Integrated culturally-relevant examples promote student pride in their ethnic, cultural, and gender heritage, as well as provide an understanding and appreciation of how their culture influences the nature and structure of science. Also, all students need multicultural science education, even if they live in entirely white communities, in order to appreciate the full spectrum of ethnic diversity that exists in our society, in preparation for the day when they will most likely work along side someone of a different physical appearance and cultural background.

State Objectives for This Unit

Specific objectives for this unit, from New Directions for Science Education in Michigan: Essential Goals and Objectives are listed below, along with specific unit learning outcomes derived from each objective.

The Constructing Scientific Knowledge and Reflecting on Scientific Knowledge objectives are integral parts of each New Directions unit. Each Constructing and Reflecting objective is woven throughout each unit, tied closely together with Using Scientific Knowledge objectives.

CONSTRUCTING SCIENTIFIC KNOWLEDGE

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
13) Develop questions or problems for investigation that can be answered empirically.	Understanding the need to build on existing knowledge and to ask questions that can be investigated.	Appropriate scientific contexts: See Using Scientific Knowledge.

- Pose questions about weight changes in physical and chemical systems.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
14) Suggest empirical tests of hypotheses.	Hypothesis, prediction, test, conclusion.	Appropriate scientific contexts: See Using Scientific Knowledge.
15) Design and conduct scientific investigations.	Types of scientific knowledge: hypothesis, theory, observation, conclusion, law, date, generalization. Aspects of field research: observations, samples. Aspects of experimental research: variable, experimental group, control group, prediction, conclusion.	Appropriate scientific contexts: See Using Scientific Knowledge.

- Predict whether weight changes during several physical and chemical reactions and design experiments to test these predictions.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
19) Gather and synthesize information from books and other sources of information.	Scientific periodicals, reference books, trade books.	Libraries, technical reference books.

- Use various reference materials to find information on the chemical composition use, production, disposal, and energy involvement of a common substance.

REFLECTING ON SCIENTIFIC KNOWLEDGE

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
11) Justify plans or explanations on a theoretical or empirical basis.	Aspects of logical argument, including evidence, fact, opinion, assumptions, claims, conclusions, observations.	Appropriate scientific contexts: See Using Scientific Knowledge.

- Use chemical formulas of reactants to justify possible products of a reaction.
- Justify weight gain and loss by accounting for invisible reactants and products.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
10) Recognize the contributions made in science by cultures and individuals of diverse backgrounds.	Cultural diversity, response to local conditions.	Diets of other cultures.

- Recognize the significance of specific resources in the historical development of other cultures.
- Appreciate the ingenuity of other cultures in using resources.

USING SCIENTIFIC KNOWLEDGE

OBJECTIVES—5-7	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
5) Describe common chemical changes in terms of properties of reactants and products.	Common chemical changes: burning paper, rusting iron, formation of sugars during photosynthesis.	Chemical changes: burning, photosynthesis, digestion, corrosion.

- Contrast the characteristics of reactants and products in everyday chemical reactions including burning, rusting, decomposition of water, and reacting vinegar with baking soda.

OBJECTIVES—5-7	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
11) Describe matter as consisting of extremely small particles (atoms) that bond together to form molecules.	Molecule, particle, matter, bond, atom.	Common substances such as those listed above.

- Explain what atoms are and how they form all the different kinds of matter.
- Explain the difference between solids, liquids, and gases using models and pictures of molecules.
- Use marshmallows and toothpicks to build models of simple molecules.
- Interpret chemical formulas in terms of the kinds and number of atoms.
- Describe the molecular structure of various reactants and products.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
13) Explain chemical changes in terms of arrangement of atoms and molecules.	Description of chemical change at molecular level, see Matter and Energy objective 12. Description of chemical change, see objective 5 above Atom, molecule, bond, reactant, product, conservation of matter.	Examples of chemical change: See objectives 5 and 6 above.

- Explain the difference between reactant and product molecules in terms of molecular structure.
- Build models of reactants and use these models to show how molecules come apart and rearrange as the products form.
- Explain chemical changes as molecular rearrangements.
- Write equations to represent chemical reactions.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
9) Explain how mass is conserved in physical and chemical changes.	Law of conservation of mass.	Common physical and chemical changes above. See objectives 1, 4, 5, 6 above.

- Observe and predict how weight changes as steel wool is compacted, an ice cube melts, sugar is dissolved in water, or water boils.
- Observe and predict how the mass of the system changes as vinegar and baking soda or Alka-seltzer and water react in an open and a closed system.
- Observe and predict how the mass of steel wool changes as it rusts or burns.
- Explain how mass is conserved in systems where substances such as gasoline seem to disappear when burned in a car, by accounting for the invisible gas.
- Account for the apparent increase in mass in systems where things seem to appear out of nothingness, such as in the burning of steel wool.
- Explain the Law of Conservation of Mass by accounting for atoms in chemical equations.

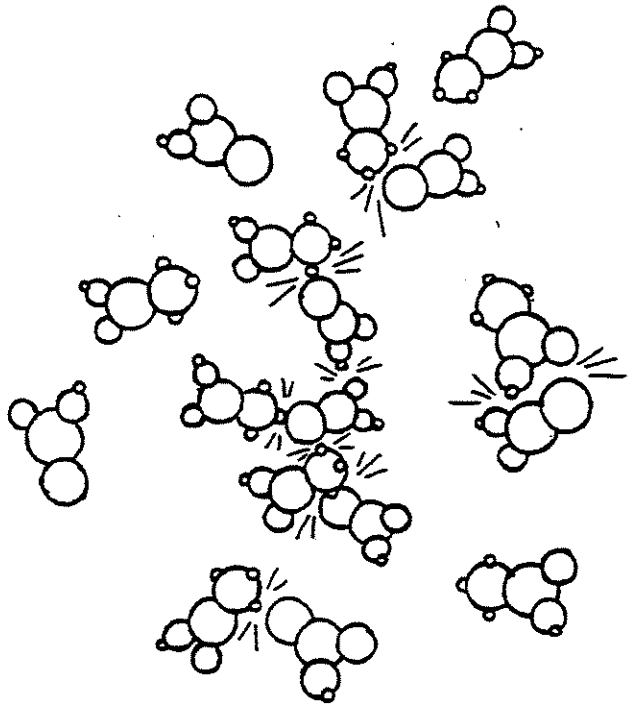
OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
12) Describe how common materials are made and disposed of or recycled.	Descriptions of physical and chemical changes. Manufacturing: refining, mining, waste disposal.	Manufacturing processes: steel mills, auto assembly lines, paper making. Recycling: glass, aluminum, paper, plastic, water treatment.

- Explain how copper and other metals are obtained from their ores.
- Explain what happens to copper and other metals when disposed of in various ways.
- Explain why recycling and conserving resources is important in terms of the needs of future generations.
- Research a common substance and find out how we get it and how we get rid of it at the end of its useful life.

OBJECTIVES—8-10	RELATED CONCEPTS, TERMS AND TOOLS	REAL-WORLD CONTEXTS
15) Describe energy changes associated with physical and chemical changes.	Physical change, chemical change, potential energy, kinetic energy.	Physical changes: dehydrated foods, solid air fresheners, recycling glass. Chemical changes: some hot and cold packs, burning fuels, corrosion

- Observe and explain energy changes associated with chemical reactions involving heat, cold, light, and electrical energy.
- Make hand warmers and explain the energy changes that occur.
- Explain various kinds of energy involved in chemical reactions.

Molecules and Atoms



Vinegar

Cluster 3—Lesson 12

Lesson 12: WHAT MAKES ONE SUBSTANCE DIFFERENT FROM ANOTHER?

In Cluster 1, you observed reactions of some common, everyday substances. You made careful observations and wrote descriptions of the starting substances. That part was fairly easy. But when you described the ending substances and examined them to see if these substances were different from the original ones, it wasn't always easy to tell.

One reason for this is that many substances look alike. For example, vinegar and water look alike. They are both clear liquids. If you pour them, they both run out of the container about the same, that is, neither of them runs out of the container like syrup or oil would. Another reason it's hard to identify substances is that most people are familiar with only a few common substances out of millions of possibilities.

KEY QUESTION

What makes substances different even though sometimes they may look alike?

Think about this last question for a minute. What are some differences between vinegar and water? What are some differences between baking soda and sugar? Between hydrogen gas and oxygen gas?

??????

The basic difference between substances, one that chemists have figured out over the last several centuries, is that *different substances are made up of different kinds of molecules.*

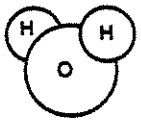
LESSON STATEMENT: Students begin the process of constructing an explanation for chemical changes by building models of the three phases of matter and considering how molecules are unaffected in changes of state. Then they use letters and words as a basis for understanding that molecules are built from atoms. They develop a model of their own and compare it to real molecules.
PURPOSE: To introduce the concepts of molecules and atoms; to explore the question of how there can be so many different substances.
APPROX. TIME: 2 class periods.

A

THINK AND WRITE

1. Write what you remember about **molecules** in your journal.

Chemists have come to understand that common substances in our environment—really all substances, common or not—when they are magnified millions of times, are composed of different kinds of molecules. Water, for example, has its own kind of molecule, which we often refer to as H_2O.



a water molecule

Sugar has its own kind of molecule.

Vinegar is made up of its own special kind of molecule.

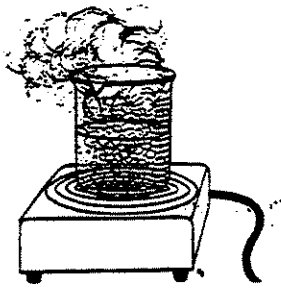
Oxygen is made up of still another kind of molecule.

Carbon dioxide is composed of molecules different from oxygen.

So are aluminum, and iron, and copper, gold and many, many, many other solids, liquids and gases.

Take a chunk of ice. Magnify it millions of times, and you would see water molecules joined together into sort of a cage-like structure, jiggling a little, but staying in the same place. Solids are made of molecules that are close together in neat, orderly, regular arrangements.

When ice gets warmer, it becomes liquid water. The molecules jiggle faster as the ice gets warmer, until they break free from the forces that hold them together as solids. As a liquid, the molecules are moving freely within the container, sliding around past each other. *But nothing about the individual molecules has changed.* They are still H_2O.



When water is heated, it boils and becomes water vapor. The molecules are given increased speed by the heat, and fly off the surface of the water, into the air. As gaseous water vapor, molecules are very far apart. But they are still H_2O molecules.

Whether a substance is in the solid, liquid or gaseous phase has only to do with how the molecules are

A. 1. This question is intended not only to get students to think about what they know, but also to help teachers become familiar with students' thinking on this subject and become aware of any misconceptions. Some students will know more about molecules than others. One typical misconception is the idea that molecules are in substances, rather than making up the substance—e.g., that there are molecules inside an ice cube, perhaps between the water, or that the molecules in liquid water are similar to germs, floating around in the water. Underlying this misconception is the general notion that substances are continuous, not made up of discrete particles—that water is a continuous liquid, or that solid aluminum is a continuous substance, not actually composed of discrete, individual particles.

If possible, show models of solids, liquids and gases. The solid should be a rather rigid, orderly arrangement of molecules. Be careful that the models you use represent molecules, not atoms which students haven't learned about yet. Since the models should represent entire molecules, marbles or styrofoam balls work well. Marbles or styrofoam balls moving freely in a dish make a good model for a liquid. Blowing ping-pong balls around in space with a hair dryer is a good model for molecules of gaseous substances.

2. Students pictures should show the arrangement and distance between molecules—that the spacing in solids is close and very orderly. The spacing in liquids is very close and in gases the molecules are very far apart. Only distance and arrangement (orderliness or randomness) are changing. In this question, students are drawing molecules as a single particle and atomic representation is not expected. Students should use different symbols, such as circles and squares, or different color circles, or size for different kinds of molecules.

In preparation for understanding the difference between chemical and physical changes, it is important that students recognize that the molecules stay intact during physical changes.

The molecules don't change in any way during melting, freezing, etc.

If students draw pictures of ice cubes that contain molecules, rather than being made up of molecules, you might ask them to describe what the other stuff in the ice cube is.

3. a. You would heat it, for example, bring an ice cube to room temperature or put it in the sun. You could heat water on the stove.
b. You would cool it, for example, gases in the air change to liquid on the outside of a glass of cold pop. Lakes freeze in the winter time.
c. Yes, but in the case of a metal, you would have to get it very, very hot.

4. Fruits dry out when the water in them evaporates. See the fruit is still there, just less water. Think about grapes to raisins. The molecules of water in the fruit leave it by flying off into the air.

5. Can't be a change of state, since you add heat to make it seem more solid (adding heat usually melts things). It must be some other kind of change. (It's actually a chemical change, where the heat affects the proteins in the egg.)

arranged and how they move. If you heat a solid, it changes to a liquid and, if you heat it more, the liquid changes to a gas. The opposite is also true. If you cool a gas, it changes to a liquid and, if you cool it more, the liquid becomes a solid. The molecules themselves are the same in all three forms. They have simply gone into different arrangements because of the increased speed (when heated) or decreased speed (when cooled.) And because the molecules are still the same, **no new substances are formed.**

2. Draw a picture of what you think pure ice, water and water vapor would look like if magnified millions of times.
3. a. How could you get a solid to change to a liquid or a liquid to a gas? Give an example of each.
   b. How could you get a gas to change to a liquid or a liquid to a solid? Give an example of each.
   c. Would your methods work for butter? for chocolate? for a metal such as aluminum? Explain.
4. All the food we eat (fruits, vegetables, milk, juice, meat, bread, etc.) contains large amounts of water. If fresh fruits or vegetables are left around for a while, they begin to wither and dry out. What kind of change is this? Use molecules to explain why you think this.
5. When an egg white is cooked, it goes from sort of a liquid to some sort of a solid. Is this a change of state or some other kind of change? (This is really a tough one, so here's a hint. If water changes from liquid water to solid ice, do you heat it or cool it? When the egg white changes from liquid to solid, do you heat it or cool it?)

DIFFERENT KINDS OF MOLECULES

A gold ring can be melted into liquid gold, and then poured into a mold to make a new ring. Its gold molecules never change in this process. But if you poured water into the ring mold, and froze it, would it come out as gold metal? Why not?

??????

Every pure substance has its own special kind of molecule, different from the molecules of all other substances.

B How might a vinegar molecule be *different* from a water molecule? How might a salt molecule be *different* from a sugar molecule? Brainstorm answers to these questions, and write them on the board. Then work through the following questions. They help explain how there can be so many different kinds of molecules in the world.

6. a. Think of all the letters of the alphabet. How many letters are there?
   b. What can you *build* out of letters?
   c. How many words can you build from the 26 letters of the alphabet?
   d. Where could you find a complete list of all these words?
   e. Are new words ever added to these lists?

LETTERS MAKE WORDS

ESNESNON EKAM OSLA SRETTEL

7. a. Do all combinations of letters make words?
   b. Does it make a difference what order the letters are in?
   c. Does it make a difference if you add or take letters away?
   d. Think of an example that will illustrate each of these last 3 questions.

C So how do letters and words help us understand molecules? Well, it's like nature has a construction set too, only nature's set is made up of 92 different kinds of pieces called **atoms**.

B. Let students speculate about the differences between water and vinegar, salt and pepper. Some students may suggest (rightly) that molecules are built from various types of atoms, and that water molecules have different atoms than vinegar molecules. Some students may also suggest (and this is naive thinking) that vinegar molecules smell like vinegar does, or attribute some other macroscopic property of vinegar or water to their molecules.

6. a. 26
   b. Words
   c. Billions, trillions...
   d. An unabridged dictionary or the Oxford English Dictionary (OED) would be the best source for finding a complete list.
   e. Yes, just recently it was announced that several new words had gone into the OED—words like nerd.

7. a. No
   b. Yes, "also" makes sense in English, but "osla" doesn't. The phrase above is "Letters also make nonsense" spelled backwards.
   c. Yes. "To" is a different word from "Tom" or "Today."
   d. (Given above.)

C. It is important when using models to point out that no model or analogy is perfect. Therefore, be sure to always talk both about similarities and about differences. This lesson should lead students to formulate an explanation for the structure of matter, so don't give them explanations before they have arrived at their own. Also, don't provide additional information about the structure of atoms and molecules. Keep it simple at this point.

D. Some students may know that there are about 109 elements. We refer here to the 92 NATURALLY OCCURRING ones. The elements beyond number 92 on the periodic chart are made in laboratories.

A copy of the periodic table of elements can be found in any chemistry book. We encourage teachers NOT to have students memorize anything from the periodic table.

ATOMS

D Nature uses atoms as pieces to build hundreds of thousands of different substances—much like the 26 letters of the alphabet are used to build hundreds of thousands of different words. Many of these atoms are familiar to you. Others have very strange names. The chart lists the most common atoms.

The most common chemical "building blocks"	Its chemical symbol and normal state	
Oxygen	O	gas
Hydrogen	H	gas
Nitrogen	N	gas
Chlorine	Cl	gas
Fluorine	F	gas
Carbon	C	solid
Silicon	Si	solid
Sulfer	S	solid
Iron	Fe	metal
Aluminum	Al	metal
Zinc	Zn	metal
Mercury	Hg	metal
Silver	Ag	metal
Gold	Au	metal
Tin	Sn	metal
Sodium	Na	metal
Lead	Pb	metal
Nickel	Ni	metal
Platinum	Pt	metal
Calcium	Ca	metal
Chromium	Cr	metal
Copper	Cu	metal
Iodine	I	solid
Arsenic	As	solid

Think about how letters make words and use this information to answer the following questions.

8. How can all the different materials of the earth be made from only about 20 building blocks?
9. Where do you think you could find a complete list of all the different kinds of molecules?
10. Do all combinations of atoms make real molecules?
11. Does it make a difference what order the atoms are in when they form molecules?
12. Would it make a difference if you add atoms to a molecule or take them away?

E Like with words, where not all combinations of letters make a real word, not all combinations of atoms make real molecules. When atoms join together to form molecules, they must fit together, much like particular legs fit on certain chairs. Not all legs fit on all chairs; you must get the right leg to fit a given chair. In the same way, you must have the right atoms to fit together to make a certain molecule.

You may have noticed that we are using a lot of models to talk about atoms and molecules. Why? Because atoms and molecules are so small that we cannot see them even under the most powerful microscope. So scientists use things we can see to help them understand how the things that we cannot see work. No model is ever perfect, so when using models it is important to think about how the model is similar to and how it is different from what it represents. Now it's your turn to be a scientist and think of a good model for atoms and molecules.

8. These building blocks (atoms) are put together with different numbers of pieces that are arranged differently. There are many, many possibilities, producing all the different substances on the earth.

9. There must be some reference that has it. Actually, it is put out by the International Union of Pure and Applied Chemistry.

10. Probably not. Students are expected to use the analogy of letters and words from above to answer these questions. But since it was a model, the use of the word "probably" is to be encouraged.

11. Probably it does.

12. Probably it would.

E. You may want to mention that because molecules are too small for visible light to bounce off them, even ordinary light microscopes can't resolve molecules or atoms. Something with a shorter wavelength than visible light has to be used; electron microscopes, using beams of electrons, can take an image of molecules which can then be displayed on a monitor.

13-14. These two questions should help students formulate the "big picture" that everything is made of molecules. And since molecules are made of atoms, everything is made of atoms. Some students will hesitate a long time trying to think of something. Give them plenty of time as they try to conceptualize the particle model of matter.

15. Try to get students to realize that the lists could be identical or they could be very different since everything is made of molecules and all molecules are composed of atoms. Every answer is a correct answer except empty space (truly EMPTY space as in outer space, not the atmosphere which is composed of gases).

16. This is an application question that ought to get students to think of the entire universe as being made of particles—the particle model of the universe. At the molecular level, they would see individual particles of the wood vibrating in place.

TRY THIS

A. Consider bricks as a model for how atoms make molecules. List three things that can be built from bricks.

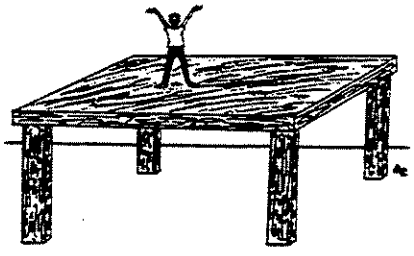
B. Use the chart below to think about ways that objects made from bricks are like molecules, and ways that they are different.

Bricks	Molecules
A house is made out of smaller pieces called bricks.	Molecules are made out of smaller pieces called ATOMS.
Bricks can be used to make many different objects, including HOUSES, WALKS, ETC.	Atoms can be used to make many different molecules, including WATER, SALT, NYLON
A house is made of only one kind of building block (the brick.)	Most molecules are made of: a) only one kind of atom, or ✓ b) different kinds of atoms.
If someone adds bricks to the house (to build an addition) it is not the same house as it was before.	If somehow one or more atoms is added to a molecule, it is: a) just a larger molecule of the same substance, or ✓ b) a totally new and different molecule making a new substance.

13. Write a list of at least ten things in your classroom that are made of molecules.

14. Write a list of at least ten things in your classroom that are made of atoms.

15. What's the difference in these two lists? What's the similarity? Explain.



16. a. Pretend you are standing on your desk and somehow you are shrunk so small that you were the size of molecules. Draw a picture of what you think you would see as you looked around your desk top.

b. Present your drawing to your group and explain it. Allow each other group member to ask questions to clarify what you say, and let them comment on your drawing.

Did your drawing include molecules? What kind of molecules were they? Were they all the same kind?

Did your drawing indicate that the molecules were built up of atoms? If yes, how many atoms did you have for each molecule—the same number for each, or different?

17. Is there anything between the molecules in your drawing? What?

18. Is sand made of molecules? Is each sand grain a molecules? Why do you think what you said?

19. Is clay made of molecules? Why do you say that?

20. a. Is soup made of molecules?

    b. How could you explain how soup is made of molecules? Fill in the blanks below, putting the following parts in their right order:

    a. broth, vegetables, rice, maybe meat

    b. proteins, and proteins are molecules

    c. cell parts, like a nucleus, mitochondria, cytoplasm

    d. animal and plant cells

Soup is made of

1. _____ ... which are made of:
2. _____ ... which are made of:
3. _____ ... which are made of:
4. _____ ... and molecules are made of:
5. _____

In the next several lessons, you will build models of the substances involved in some of the reactions you have done.

17. There is nothing between the molecules that make up substances, but students might suggest that there is, especially if they hold the naive view that materials are "continous"—with no breaks in them. They might suggest that "glue" is between the molecules, or "wood fibers" etc. Eventually students should come to believe that all substances are made of molecules, each molecules held to the others close to it. Molecules are the tiniest pieces of substance, therefore nothing could be smaller to be between them.

18. Yes, as is everything. But each grain is made of billions of molecules.

19. Some students may be confused by clay, because it seems so hard to believe that it could be made of discrete, individual particles. Of course, it is.

20. 1. a
    2. d
    3. c
    4. b

Cluster 3—Lesson 13

A. KEY QUESTION: We've been preparing for this "big idea" for a long time now. Allow students to speculate about answers. This will help you understand their current thinking so you can guide better them through these difficult concepts.

The four reactions that form the backbone of this entire unit are used again in this cluster as a basis for understanding how new substances are formed. Since each reaction has already been done by the students, it will be done here as a teacher demonstration. The purpose of observing the reaction again is to help students make the connection between the actual reactants and products observed in the reaction and the words and symbols they will be using. This is an extremely difficult conceptualization for most students. You need to use every possible visual aid in your presentation. By now, students should be aware that gases can be part of the system of the reactants and/or the products and they should be looking for signs that gases are involved.

In this cluster, the teacher should work with the students, step-by-step through the entire first (and possibly second) reaction. For each successive reaction, the teacher role should diminish gradually and students should begin to work in groups independent of the teacher as much as possible. By the end of the cluster, students should be able to work through the process on their own. Do not expect students to balance dozens of equations. That is not the purpose. Rather, a conceptual understanding of the principles and laws involved, along with the association of the real world context, is much more important.

Lesson 13: ATOMS IN EQUALS ATOMS OUT: Decomposing Water

In Cluster 1, you observed some chemical reactions of common substances and wrote descriptions of what you observed. Then in Cluster 2, you learned one of the most basic laws of nature, the Law of Conservation of Matter. Take a few moments to think about what this law means and share your ideas with the class.

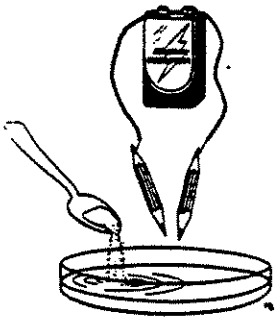
In the first lesson of this cluster, you learned how atoms combine to form molecules. Now you will see how atoms and molecules can explain both the formation of new substances and the Law of Conservation of Matter.

Ⓐ

KEY QUESTION

How can atoms and molecules be used to explain the formation of new substances? How can they be used to explain the Law of Conservation of Matter?

In an earlier lesson, you used a battery to make bubbles appear under water. The water level went down as the bubbles were formed.



How can atoms and molecules be used to explain the formation of bubbles from water?

LESSON STATEMENT: Students will make models of the molecules involved in the decomposition of water; they will take the water molecule apart and use the atoms to build hydrogen and oxygen molecules. They will draw pictures of the reactant and product molecules, write formulas showing how the atoms have recombined, and consider why mass is conserved in chemical reactions based on the idea that no atoms are created or destroyed, only rearranged to form new molecules.
PURPOSE: To begin to construct a picture of how new substances are formed by observing the decomposition of water reaction and building models to demonstrate how reactants form products; to write balanced equations based on these models; and to consider why mass is conserved in chemical reactions.
APPROX. TIME: 1 class period.

TRY THIS

YOU WILL NEED

Marshmallows or gumdrops and toothpicks for model building.

SAFETY!

If your model kits contain gumdrops, marshmallows, and toothpicks, do not place any of them in your mouths. Upon completion of this project discard these materials as instructed by your teacher.

Use a data chart like the one below:

A. Write the common name of the reactant (the starting substance) on your data chart in the appropriate space.

B. You probably know the chemical formula for water. Write it on your chart.

The formula for any substance is the shorthand way that chemists use to show the kind and number of atoms that are needed to make a molecule of that substance. Can you figure out what the formula for water means? The H stands for hydrogen, and there are 2 atoms of hydrogen in a molecule of water. The O stands for oxygen, and since there are no numbers beside it, there is only 1 atom of oxygen in the water molecule.

	REACTANTS	PRODUCTS
COMMON NAMES	WATER	
FORMULA		
PICTURE OF MODEL		
PICTURES OF MODELS FOR THE REACTION		
ACCOUNTING FOR ATOMS	Number of oxygen atoms: Number of hydrogen atoms:	Number of oxygen atoms: Number of hydrogen atoms:
BALANCED EQUATION		

The gases produced as water decomposes look exactly the same and students need to be convinced that there are two different substances being formed. If you have a Hoffman apparatus with platinum, stainless steel or nichrome electrodes, you will be able to set up this experiment in advance and generate enough oxygen and hydrogen gas to test them with a burning splint. Other electrodes do not work well, since although it is easy to make and collect the hydrogen gas, the reaction at the anode tends to be with other ions rather than with water to produce oxygen gas. If you do collect the gases, you can test them with a burning splint to show that they are different gases. The evidence that oxygen gas has been produced is that a glowing or burning splint bursts into flame or burns very brightly when brought to the mouth of the upright test tube. The evidence that hydrogen gas has been produced is a "bark" or a pop when a burning splint is brought to the mouth of the test tube. You will need to explain these two tests to the students. If you do not have the materials to generate the gases, you can use a few drops of bromthymol blue indicator in the water, which will produce different colors at each of the electrodes. This ought, at least, to convince the students that the gases being produced are different. You can use the same set-up used in Cluster 1, a petri dish and pencil lead (graphite) as the electrodes, salt and water with bromthymol blue indicator. Bromthymol blue will turn yellow where the oxygen is being produced and blue where the hydrogen is being produced. An overhead projector or microcam can be used and will project the color quite well.

	REACTANTS			PRODUCTS		
COMMON NAMES	WATER			HYDROGEN	OXYGEN	
FORMULA	H_2O			H_2	O_2	
PICTURE OF MODEL						
PICTURES OF MODELS FOR REACTION						
ACCOUNTING OF ATOMS	H 4	O 2	Atoms Total 6	H 4	O 2	Atoms Total 6
BALANCED EQUATION	$2\,H_2O$		→	$2\,H_2 + O_2$		

B. Since bonding is not taught in this unit, space-filling models such as the marshmallows or gumdrops, rather than ball and stick models which represent double, single or triple bonds, work best. You need to decide what colors represent each kind of atom depending on what model kits you have. It is best to be consistent in the color representations so that students begin to think about different kinds of atoms as being different. The toothpicks should be broken into halves or thirds and the model built so that the marshmallows or gumdrops are touching and the toothpicks are pushed all the way in. This eliminates any need to discuss bonding of any type which is beyond the scope of the unit. Students should always check their models with the teacher to be sure they are correct.

C. Students should realize very quickly that it is not enough to know the formula which tells what pieces are required and how many of each piece, but they also need to know how these pieces are connected. In water, for example, the 2 hydrogens are both connected to the oxygen, not to each other. Some students may have connected the two hydrogens to each other and the oxygen to the outside of the two hydrogens.

Now think about the products that were formed. What could they be? They were bubbles, of course, but what was in the bubbles? Since the water level went down, we might assume that the water changed into the bubbles. We know, though, that the water wasn't boiling, because it never got hot. So the bubbles couldn't have been water vapor. What else could they be?

Here's a hint. Look at the types of atoms that make up a water molecule. Since water molecules are made up of only hydrogen and oxygen atoms, the substances formed inside the bubbles can only contain hydrogen and oxygen. Would it be possible to have carbon dioxide (CO_2) as a product of this reaction? Why?

So what substances are inside the bubbles? Did someone say "Maybe there's oxygen gas inside some of the bubbles, and hydrogen gas in the other bubbles?" Yes! **The water molecule is coming apart and making hydrogen and oxygen molecules. Hydrogen gas is in the bubbles coming off one of the pencil leads, and oxygen gas is in the bubbles coming off the other lead.**

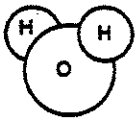
You can prove this by collecting the gases and conducting tests on them. The tests are easy. Hydrogen explodes with a loud pop when a burning piece of wood is placed in it. Oxygen makes a slightly burning (glowing) piece of wood burn very brightly. You need to collect these gases separately before you can test them.

C. Write the common name of the ending substances (the products.) In this case, they are oxygen gas and hydrogen gas.

B **D.** Obtain a model-building kit and find the necessary pieces to build a water molecule. Your teacher will tell you which colors represent which kinds of atoms. Try making a model of a water molecule. You need two hydrogen atoms (the same color) and one oxygen atom (a different color).

C Do all the models in the class look exactly alike? Why not?

Chemists have found that both hydrogens attach on opposite sides of the oxygen, not to each other, like in the picture on the left. If your model has the two hydrogens attached to each other, change it.



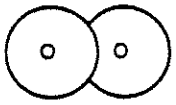
H_2O—a water molecule

Model-building is an extremely important tool that enables students to develop their understanding of the structure of matter. The transformation of students' thinking about matter from continuous to the particle model is usually very gradual. As students make models of various molecules, the way they talk about matter as being made up of molecules and of molecules as being made up of atoms will indicate changes in their thinking that often do not occur without model-building. Changing students' view of the world around them is not a concept that is taught in a day or a week. Only very slowly over time will you see the correct scientific picture evolve and take shape. Don't omit any of the model-building lessons if you expect this transformation in your students.

D **Make two water molecules.**

Draw a picture of your model of the water molecule on your data chart. Label each atom or color it to show what kind they are.

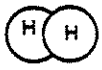
E



O_2—an oxygen molecule

E. Now build models of the ending substances. Start with oxygen. Are you wondering what the formula is? Chemists found—a long time ago—that two oxygen atoms join together to make an oxygen molecule, so what would the formula be?

Write the formula in the proper space. Then make the model. Remember to use the same color that you used above for oxygen. Draw a picture of your model of the water molecule on your data chart. Label each atom or color it to show what kind they are. Remember to use the same color that you used above for oxygen.



H_2—a hydrogen molecule

F. Now try making a model of a hydrogen molecule. Like oxygen, two atoms of hydrogen join together to make a hydrogen molecule.

Write the formula in the proper space.

Draw a picture of your model of the water molecule on your data chart. Label each atom or color it to show what kind they are. Remember to use the same color that you used above for hydrogen.

Now that you know the formula and can make a model of each reactant and each product, you are ready to figure out how new substances form.

Recall from the last lesson what makes one substance different from another: Each substance is made up of its own kind of molecule, made of different kinds of atoms. Water is a collection of water molecules, each molecule made from 2 hydrogen and 1 oxygen atoms. Vinegar is a collection of vinegar molecules, each molecule made from 2 carbon atoms, 4 hydrogen atoms, and 2 oxygen atoms. Sugar is made of sugar molecules, each molecule made from 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms.

D. Students will need two water molecules later (in step G) from which to make hydrogen and oxygen molecules.

E. Most model-building is done by making models of the reactants and models of the products. This method often does not get the point across of where these product molecules come from, so in step G we have students take apart the water molecules and use those atoms to build the oxygen and hydrogen molecules.

F. Be sure to collect all unused "atoms" so they cannot pick up these pieces to make the products. If they balance the equation by using multiples of the expected equation (doubling or tripling the quantities), don't have them change it since the equation is balanced and the concept is equally well demonstrated.

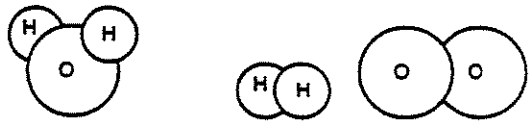
What happens when an electric current runs through water, and the water decomposes into hydrogen gas and oxygen gas? The atoms of the water molecules come apart and then form into new molecules. **No new atoms of any kind are added.** Its like taking a Lego building apart and using all the pieces to make two smaller objects, like a plane and a tree.

Let's try doing this with your models.

F

G. Take a molecule of water apart and USE THESE SAME ATOMS to make the products, in this case, oxygen and hydrogen molecules.

starting substance "reactant"	ending substances "products"	
H_2O	H_2	O_2



What happens? You can make the hydrogen molecule (H_2), but you cannot make the oxygen molecule (O_2), because you have only one oxygen atom. Where can the other oxygen atom come from to make an oxygen molecule?

In the real chemical reaction you watched, with many bubbles being formed, there were billions and billions of molecules. Billions of water molecules were coming apart at the same time. And all the other water molecules coming apart also have an oxygen atom. So two oxygen atoms from different water molecules find each other and join together to form an oxygen molecule.

H. Try doing that with your models now. Take a second molecule of water apart and make another hydrogen molecule. Use this single oxygen atoms to join the oxygen atom from the first water molecule. Together they form an oxygen molecule.

G **I.** How many water molecules did you use in all? Draw exactly that many water molecules in the space on your data sheet labeled PICTURES OF MODELS FOR THE REACTION. Color your models using the same color code as above.

How many hydrogen molecules were formed? Draw exactly that many hydrogen molecules in the appropriate space on your data sheet. Color your models using the same color code as above.

How many oxygen molecules were formed? Draw exactly that many oxygen molecules in the appropriate space on your data sheet. Color your models using the same color code as above.

Are you beginning to see how atoms rearrange themselves to make new substances?

G. When the models are completed, students will draw pictures of the 3-D models that represent the balanced equation. Since the drawings are two-dimensional and the models, like real molecules, are 3-dimensional, the models will look somewhat different from the pictures. It is a good idea to bring this to the students' attention since students often have great difficulty seeing this connection. Be sure they use the same color coding for different kinds of atoms throughout their entire data sheet.

CONSERVATION OF MATTER

Now let's see how atoms and molecules can be used to explain conservation of matter. Remember that conservation of matter in chemical reactions means that the beginning weight of all of the reactants is exactly the same as the ending weight of all of the products. Can you speculate about why this might be?

? ? ? ? ?

J. How many atoms of oxygen are there in the molecules of the reactant—the starting substance? How many atoms of hydrogen are there in the molecules of the reactant? Record this information on your data sheet under ACCOUNTING FOR ATOMS.

How many oxygen atoms are there in the product molecules—the ending substances? How many hydrogen atoms are there in the product molecules ? Record this information on your data sheet in the appropriate space.

H WHAT DO YOU NOTICE ABOUT THE NUMBERS OF **ATOMS** IN THE STARTING SUBSTANCES AND THE ENDING SUBSTANCES? They are the same! The atoms don't disappear or appear out of nowhere... they just rearrange themselves into new molecules.

And if each atom has a certain weight (which it does), then how does the weight of the reactant compare with the weight of the products?

H. Students will begin to construct new knowledge as they see that not only must the kinds of atoms in the reactants and products be the same, but the number of each kind of atom must also be the same. They should also begin to see that the Law of the Conservation of Matter is true because atoms are conserved.

I. Students should write the balanced equation by thinking about their models and looking at the pictures of the models that they drew. If they write the correct formula first and then "how many," they should not have trouble figuring out where the numbers go. Don't use abstract ideas to explain equations.

QUESTIONS:

The following questions should be used for discussion in small groups. Students should use this opportunity to work out any discrepancies in their thinking as well as "fine tune" their thinking. After group discussions, students should be given time to write their answers on the back of their data sheet.

1. Boiling: The gas given off is water vapor, which has the same molecules as water. No atoms are rearranged to form new molecules in boiling.

2. a. Any substance that contains only hydrogen and/or oxygen atoms are possible products. There are no chlorine atoms available and no carbon atoms available.

b. Yes, these molecules only involve atoms that are available in water. Students may need some help in understanding that the individual products formed do not need to use every different atom from the reactants.

3. The subscripts tell how many atoms are in a molecule. They are like the "recipe" for making a molecule. The coefficient tells how many "whole" molecules are involved. If students have trouble with this, have them go back and look at the pictures of the models they drew.

This is the Law of Conservation of Matter, or the Law of Conservation of Mass. No weight is lost or gained in chemical reactions. No mass is lost or gained. No matter is lost or gained. Why? Because no ***atoms*** are lost or gained during chemical reactions.

CHEMICAL EQUATIONS

Chemists use a shorthand to write about this reaction. They show the starting substances on one side of an equation, and the ending substances on the other side, to show how their weights are equal. They use an arrow instead of an equal sign, to show that the left side reactants change into the right side products. The formula for this reaction is

$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

The 2 in front of the H_2O means that two molecules of water were used in the reaction. The 2 in front of the H_2 means that two molecules of hydrogen gas were formed. No number in front of the O_2 means that one molecules of oxygen gas was formed.

K. Write the formula for this reaction on your chart.

THINK AND WRITE

1. When water boils a gas leaves its surface, and the level of the water goes down. When water is chemically decomposed, like in this experiment, it forms gas and the level of the water also goes down. What's the difference between boiling and decomposing water? Talk about the different gases that are formed in your explanation.
2. a. Could chlorine gas, Cl_2 be a product in this reaction? What about carbon dioxide, CO_2? Explain why you think this.

   b. Do you think it would be possible for ozone, O_3 to form as a product in this reaction? What about hydrogen peroxide, H_2O_2? Explain why you think this.
3. Find a partner and explain the difference between the two number 2's in $2\,H_2O$. Use your models to help you. Then write your explanation.

4. After doing the same experiment with water that you just completed, and doing it until all the water was gone, the teacher asked what happened to the water. Jamie responded quickly with "Oh, that's easy. It just decomposed into nothing." You are now an expert on this. How would you help Jamie understand what happened?

4. The gases inside the bubbles go into the air when the bubbles pop, adding new substances and new weight to the atmosphere. The water is gone, but new substances (hydrogen and oxygen gases) have appeared to take its place. (Of course, the hydrogen and oxygen can react in other ways to form new products. Actually, hydrogen gas is so light that it floats out of the atmosphere and into space. Oxygen, when breathed in by animals and absorbed by plants, is used to chemically react with glucose to give organisms the energy they need for life processes. The products of this reaction—cellular respiration—are carbon dioxide and water. Yes, the oxygen atoms have recombined to form water again!)

Cluster 3—Lesson 14

This is the second of the four reactions that form the backbone of this entire unit. Since this reaction has been done earlier by the students, it is done here as a teacher demonstration. The purpose of observing the reaction again is to help students make the connection between the actual reactants and products observed in the reaction and the words and symbols they will be using. Be sure to use the reaction with the balloon sucked into the flask for the demonstration so students remember to include the invisible gas as a reactant.

In this lesson, the teacher should continue to work step-by-step through each part with the students. As students catch on, they will start going a little faster. Don't let them omit the model-building steps. Usually, students who do this have trouble later when the formulas and equations get a little more involved. As they build their models, have them hold them up for you to see and give a nod of approval.

For building the molecular models, students need two iron atoms and three oxygen atoms. Provide students with only enough parts to make one model of each molecule. They should take these apart before beginning making models for the reaction. Space-filling models with marshmallows or gumdrops work best since bonding is not taught in this unit. Again, you need to decide what colors represent each kind of atom depending on what model kits you have. Students should, if possible, use the same color for oxygen that was used in the last lesson. They should decide what color will be used for iron.

Lesson 14: ATOMS IN EQUALS ATOMS OUT: Rusting

Let's repeat the whole process now with a different chemical reaction: rusting. Take a minute or two to remember what a fresh piece of steel wool and a piece that has reacted (perhaps the one with the balloon on top) look like.

TRY THIS

YOU WILL NEED

Marshmallows or gumdrops and toothpicks for model building

SAFETY!

If your model kits contain gumdrops, marshmallows, and toothpicks, do not place any of them in your mouths. Upon completion of this project discard these materials as instructed by your teacher.

A. Draw a new data chart in your journal.

THE REACTANTS

B. Write the common names of the reactants in the proper place on your data sheet. One is steel wool, which is just threads of steel. What's the other reactant? (Can you remember how you knew that it was used in this reaction?)

C. The steel in steel wool (or in cars, bikes, etc.) is made by adding small amounts of carbon or other metals to iron. Probably "iron wool" would be a better name since it is mostly iron and it's the iron in steel wool that reacts. The chemical formula for iron is Fe (from the Latin word for iron: ferrum). The molecule is made from just one atom. **Write the formula** in the appropriate space on your data chart.

Write the formula for an oxygen molecule in the reactants column also. If you don't remember it, look in the last lesson.

D. Make a model of the iron molecule. You need only one atom. **Draw a picture of it** and label or color it to

LESSON STATEMENT: Students will build molecular models of the substances involved in the rusting of steel wool; they will use the reactants, iron and oxygen molecules, to build models of the product, iron oxide (rust) molecules. They will draw pictures of the reactant and product molecules, write formulas showing how the atoms have recombined, and consider why mass is conserved in chemical reactions based on the idea that no atoms are created or destroyed, only rearranged to form new molecules.
PURPOSE: To continue to develop an understanding of how new substances are formed by modelling the formation of rust molecules from rust molecules and oxygen molecules.
APPROX. TIME: 1 class period.

show that it is different from the other atoms you have worked with.

Make several molecules of iron, in case you need them later.

Make a model of the oxygen molecule and draw a picture of it on your chart.

Make several molecules of oxygen, to take apart and use to make rust molecules. Return ALL unused pieces to the model kit.

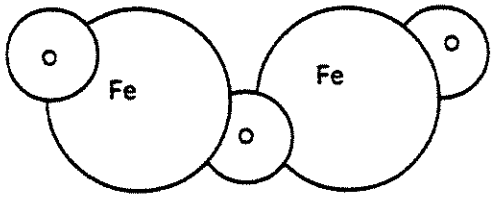
THE PRODUCTS

What is the formula for rust? Steel wool needs oxygen from the air in order to rust. So what kind of atoms can be present in rust?

????

If you said that rust can be made only from iron and oxygen atoms because only those two kinds of atoms are present in the reactants, you are correct. Chemists have found that the formula for rust is Fe_2O_3. **Write the formula** in the products column.

E. Make a model of rust. It looks like this:



Draw a picture of it on your chart. Use the same labels or color codes you used above.

MODELING THE CHEMICAL REACTION

F. Use your models to show how the rust forms from the steel wool and the oxygen: Take an oxygen molecule apart, grab an iron molecule (yes, it's just one atom) and start building a molecule of rust. Is one molecule of oxygen and one molecule of iron enough? No. So take a second molecule of oxygen apart. How many iron molecules do you need?

Is anything left over? Once again, an oxygen atom is left over. Remember, in chemical reactions, reactant molecules never break into atoms that are left over in

Remember to break the toothpicks into halves or thirds and build the models so that the marshmallows or gumdrops are touching and the toothpicks are pushed all the way in.

	REACTANTS			PRODUCTS		
COMMON NAMES	IRON		OXYGEN	IRON OXIDE (RUST)		
FORMULA	Fe		O_2	Fe_2O_3		
PICTURE OF MODEL						
PICTURES OF MODELS FOR REACTION						
ACCOUNTING OF ATOMS	Fe 4	O 6	Atoms Total 10	Fe 4	O 6	Atoms Total 10
BALANCED EQUATION	$4Fe + 3\,O_2 \rightarrow$			$2\,Fe_2O_3$		

A. It is important that students do not have left-over molecular models when they show how the reaction works.

Stress the idea that billions of molecules are reacting, not just the one or two that we write in an equation. Remind them that they'll start with a more realistic number but real reactions work in a similar manner.

the reaction. This is a very, very important characteristic of chemical reactions. So what happens? Yes: Two molecules of rust are formed. Make another molecule of rust, using the left over oxygen atom, and any more oxygen molecules and iron molecules you need. (Remember, the steel wool contains billions of molecules and so does the oxygen in the air. There are plenty of iron and oxygen molecules available to react. Now can you see why you started with several models of each reactant molecule?)

Ⓐ Put all the unused reactant molecules back in the kit. They did not react in your model.

G. Count how many iron molecules and oxygen molecules you used and how many rust molecules you formed and draw them on your data chart, in the row marked "Pictures of models for the reaction." Color or label your models using the same color codes or labels you used above.

CONSERVATION OF MATTER and THE CHEMICAL EQUATION

Would the weight of the iron and oxygen used equal the weight of the rust formed? Remember the experiment with the balance? If you put the flask with the rusting iron and balloon on a scale and watched the weight as the steel wool rusted, would it stay the same?

What do you think, and why?

????

You can use what you know about atoms and molecules to prove that the weight (or mass) stays the same. Here's how:

H. On the next line of your chart, labeled ACCOUNTING FOR ATOMS IN REACTANTS AND PRODUCTS, **decide what kinds of atoms are present in the reactants and the number of each kind. Do the same for the product.** Record this information on your chart.

Are there the same number of oxygen atoms in the starting substances as in the ending substances?

Are there the same number of iron atoms in the starting substances as in the ending substances?

Can you use this discovery to answer the question about weight changes?

B I. To write a balanced equation for this reaction, write the correct formula under each kind of molecule. Then show how many molecules of each kind were involved in the reaction, by putting a number in front of the formula for the molecule (for example, 2 Fe).

The balanced equation should look like this, with numbers in front of each molecule:

$$\_\_ Fe + \_\_ O_2 \rightarrow \_\_ Fe_2O_3$$

THINK AND WRITE

1. You have a friend who doesn't know the first thing about chemistry. He thinks that rust just starts somehow and then "eats" away at cars or pipes—sort of like termites eat wood—and this makes holes in the car or the pipe. You must explain to him what is really going on. Tell him what the reactants are and where they come from. Explain what product is formed and how this happens.
2. Is rust just the same thing as iron, only brown? Explain.
3. A friend of yours says that she left a shovel outside during the winter and it got rusty. She says that if you scrape off the rust with a steel brush, the shovel will be as good as new. To test her knowledge of chemical reactions, you ask her if it will weigh the same after the rust is scraped off as when she bought it. She says she's not sure, but it seems like it should—after all, rust just grows on the shovel like moss on a tree or mold on stale bread.

   Do you agree? Explain. Use atoms and molecules in your explanation, too, if you can.
4. Some cars and trucks get so rusty that holes start to form in the metal. How can this happen?

B. Students should write the balanced equation by thinking about their models and looking at the pictures of the models that they drew. If they are having difficulty, remind them to write the correct formula first and then "how many."

QUESTIONS:

1. Students should explain that the iron in the car body combines with oxygen from the air to form the rust. The rust is a reddish-brown color, and is flaky—significantly different in color and texture from the original iron (this is why this unit stresses student observation and description of products early on). The rust can fall away from the car.

2. No. It's a new substance. This can be seen by its properties—it is quite different from iron.

3. Since rust is a combination of some of the iron from the shovel with oxygen from the air, if the rust is scraped away the shovel loses some of its original iron and therefore wieghs less.

4. Rust starts when iron is exposed to the oxygen in the air and reacts with it. The iron has not disappeared, but is present in a new form in the rust that formed. It has chemically combined with the oxygen to form iron oxide which is rust. Since the iron is actually involved in the reaction (it is reacting to form a new substance), there will eventually be a hole in the original substance.

5. The experiment might place a car on a truck scale, inside a closed large plastic bag with air inside and perhaps a pan of salt water, and observe for 10 years as it slowly rusts. The weight should stay the same, although the bag might collapse as some of the oxygen is removed from the air.

6. We grease tools, paint cars, spray a protective silicone coating on jewelry or statues. This protects iron from rusting by preventing the iron from coming in contact with oxygen from the air which it needs to react. However, any little nick or scratch in the finish is enough for the reaction to get started.

5. Design an experiment that shows that weight is conserved when a car rusts. Use a car that stays in the same place for 10 years, getting rustier and rustier.
6. Give some examples of how we protect things made of iron and keep them from rusting. Then explain how the protection works.

You are now ready to explore what happens when vinegar and baking soda are combined and that great bubbling reaction begins!

Lesson 15: ATOMS IN EQUALS ATOMS OUT: Baking Soda & Vinegar

Now, what about the baking soda and vinegar reaction? These molecules get a little more complicated, but you are getting to be an expert at this, so you should not have difficulty.

Your teacher will perform this reaction. Observe it carefully. It is easy to tell that a reaction is occurring (because of the bubbles) but it is not so easy to tell what the products are. What do you think is in the bubbles? Can you see anything else that might have been formed? You'll be able to figure out what all the products are as you proceed with model-building.

TRY THIS

YOU WILL NEED

Marshmallows or gumdrops and toothpicks for model building

A. Use a chart to help study this reaction, as you did with the decomposition of water and with rusting of iron.

THE REACTANTS

B. **Write the common names of the reactants** in the proper place on your data sheet.

C. Chemists have discovered that the chemical formula for baking soda is $NaHCO_3$. Each of the oxygens are joined to the single carbon atom. The hydrogen and sodium (Na is from the Latin name for sodium, natrium) are each connected to different oxygens. **Write the formula** for baking soda on your chart, and **draw a picture** of the molecule. Label or color each atom appropriately using the same color code you used earlier.

By now, students are beginning to understand how chemical reactions work. Depending on your students, you may want to allow some students to work on their own while you help students who are having difficulty. Or you may want to pair a student who is having difficulty with another who seems to understand the process. Or you may find that you still need to work with the whole class. Don't let students omit the model-building steps. Again as they build their models, just have them hold them up for you to see and give a nod of approval.

For building the molecular models, students need two carbon atoms, four hydrogen atoms, three oxygen atoms and one sodium atom. Try to use the same color codes for oxygen, hydrogen, and carbon that were used earlier. Students can decide what color they will use for sodium.

Both of these molecules are pretty big so students could get confused. Usually, by now they are taking it as a personal challenge to be able to build the molecule without directions from the teacher. Be sure they get teacher approval when finished.

Stress again the idea that billions of molecules are reacting, not just the one or two that we write in an equation. You might call their attention to all the bubbles being formed and that it took lots of molecules to make all these. Because of the probability for confusion, students will start with only one of each reactant molecule. That's all they need for the balanced equation.

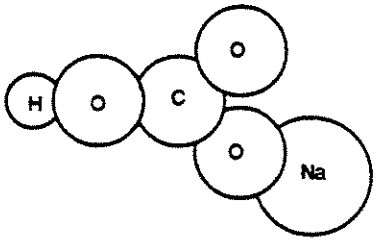
LESSON STATEMENT: Students will build molecular models of the substances involved in the reaction of baking soda and vinegar; they will use the atoms from the reactants to build models of the products. As in the two previous lessons, they will draw pictures, write formulas, and consider why the weight of the reactants equals the weight of the products.
PURPOSE: To continue to develop an understanding of how new substances are formed by modelling the reaction.
APPROX. TIME: 1 class period.

Be sure students identify or color code all the different atoms in their pictures.

Once they have made the models, students will probably be able to finish the data sheet quite independently. If they have trouble when writing the balanced equation, refer them back to their models.

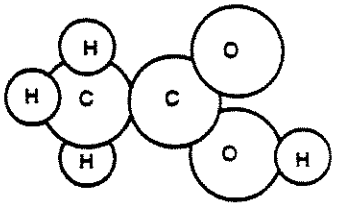
SAFETY!

If your model kits contain gumdrops, marshmallows, and toothpicks, do not place any of them in your mouths. Upon completion of this project discard these materials as instructed by your teacher.



baking soda

D. Vinegar is made up of 2 carbon atoms, 2 oxygen atoms, and 4 hydrogens: CH_3COOH. It is written that way because that is pretty much how the atoms are arranged in the molecule. The two carbon atoms join to each other. Three hydrogen atoms join to one of the carbon atoms and are spaced equally around it. Two oxygens join to the other carbon atom. The other hydrogen atom joins to one of the oxygens. **Write the formula** for baking soda on your chart, **and draw a picture** of the molecule. Label or color each atom appropriately using the same color code you used earlier.



vinegar

E. Make models of the reactant molecules. Make **two** models of each, then replace all the unused atoms in your kit.

THE PRODUCTS

What are the products from this reaction? What is in the bubbles?

Look at the atoms that make up vinegar and baking soda: carbon, oxygen, hydrogen, and sodium. What substances can these atoms make that you are familiar with?

Carbon dioxide, CO_2?

Oxygen, O_2?

Water?

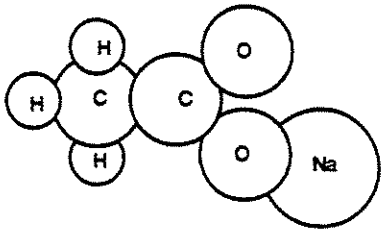
Hydrogen gas?

Butane?

Salt—sodium chloride, NaCl?

Something had to be in the bubbles. It could be any of the gases listed above. (Which substances are gases?)

A Actually, three substances are formed in this reaction. Chemists have analyzed what's left over after the reaction, by doing tests on the products. They have found carbon dioxide in the bubbles, water in the liquid, and another substance called sodium acetate. Its formula is CH_3COONa.



sodium acetate

F. Record the appropriate information about the products in your chart.

G. Draw pictures of each molecule in your chart.

MODELING THE CHEMICAL REACTION

H. Use your models to show how the products form from the vinegar and baking soda:

First, look carefully at the pictures you have of the baking soda and sodium acetate molecules. Notice the cluster of atoms on the right side, the COONa? That cluster stays together during the reaction, as part of the baking soda molecule becomes part of the sodium acetate molecule.

Second, look carefully at the pictures of the vinegar and sodium acetate molecules. Notice the cluster of atoms on the left side, the CH_3? That cluster stays together, as part of the vinegar molecule becomes the other part of the sodium acetate molecule.

Now take a baking soda molecule apart, leaving the COONa cluster of atoms together. Take a vinegar molecule apart, leaving the CH_3 cluster together. Then make one sodium acetate molecule out of the two clusters.

Look at what you have left, and try to build a carbon dioxide molecule and a water molecule.

A. Sodium acetate is a solid, indistinguishable from any baking soda that might be left over in the bottom of the beaker. The vinegar in the reaction already has lots of water mixed with it, so the water produced in the reaction just mixes with the vinegar's water.

	REACTANTS		PRODUCTS		
COMMON NAMES	BAKING SODA	VINEGAR	CARB. DIOX.	SODIUM ACETATE	WATER
FORMULA	$NaHCO_3$	CH_3COOH	CO_2	CH_3COONa	H_2O
PICTURE OF MODEL					
PICTURES OF MODELS FOR REACTION					
ACCOUNTING OF ATOMS	Na H C O Atoms Total 1 5 3 5 14		C O H Na Atoms Total 3 5 5 1 14		
BALANCED EQUATION	$CH_3COOH + NaHCO_3 \rightarrow$		$CO_2 + H_2O$ $NaCH_3COO$		

B. You may either ask students to verbally explain this to the class, or ask them first to write this explanation in their journals and then add to it after a class discussion. The connection we want them to make here is that if all of the atoms that made up the starting substances are present in the ending substances, then no weight was lost or gained, since it is the atoms themselves that make up the weight of any substance.

These questions should be used for discussion in small groups to allow students to express their ideas and find any discrepancies. After group discussions, students should write answers in their journals.

1. There is more baking soda in the beaker that has not yet reacted with vinegar.

2. Use BTB after trapping the gas in some way. BTB turns yellow when carbon dioxide is present.

3. No, since the bubbles produced from boiling water have water vapor in them, which is not a new substance—it is the same molecule as makes up liquid water. If no new molecules are produced, then no new substances are produced, and no chemical change has occurred.

4. Students answers may vary on these. Remember, they are going on visual descriptions now and may or may not know the formulas which are needed to be sure if a chemical change occurred. As long as their explanations make sense, they should be accepted as feasible answers. We are trying to get away from teachers always having the correct answers and jumping in whenever there is doubt.

1. Yes: Water, which is a transparent liquid, has very different properties from the invisible gases hydrogen and oxygen.

CONSERVATION OF MATTER and THE CHEMICAL EQUATION

I. Check the kinds of atoms and number of each kind in both reactants and products and fill in the ACCOUNTING FOR ATOMS IN THE REACTANTS AND PRODUCTS portion of your data sheet.

Are there as many atoms of carbon in the reactants as in the products?

Are there as many atoms of oxygen in the reactants as in the products?

Are there as many atoms of hydrogen in the reactants as in the products?

Are there as many atoms of sodium in the reactants as in the products?

B *Explain how this proves that if you trapped all the gas given off in this reaction, the weight of the original baking soda and vinegar would be the same as the weight of all the products after the reaction.*

J. To write a balanced equation for this reaction, write the correct formula under each kind of molecule. Then show how many molecules of each kind were involved in the reaction, by putting a number in front of the formula for the molecule (for example, 1 $NaHCO_3$).

The balanced equation should look like this, with numbers in front of each molecule:

__ $NaHCO_3$	+	__ CH_3COOH	→	__ CH_3COONa	+	__ CO_2	+	__ H_2O
BAKING SODA	+	VINEGAR	PRODUCES	SODIUM ACETATE	+	CAR. DIOX.	+	WATER

THINK AND WRITE

Discuss each question below in your group. Then write the answers on the back of your data sheet.

1. Sometimes when you do this reaction, after all the bubbles have popped (and the fizz settles down) you can add more vinegar and start the reaction going again. What does this tell you about the baking soda?
2. Design an experiment to show that carbon dioxide is actually what's inside the bubbles.
3. The change that you observe when baking soda and vinegar are mixed is a chemical reaction. The reaction produces bubbles with carbon dioxide in them. When water boils, bubbles are also produced. Is this a chemical reaction? Explain.
4. a. For each of the following changes, tell if you think new substances formed. Tell why you think as you do.
   1. Hydrogen and oxygen gas are ignited with a spark and explode to form water.
   2. Copper jewelry tarnishes (turns green after being exposed to air and water for a long time).
   3. An iron nail is magnetized by rubbing it against a magnet.
   4. Salt is stirred into water until it all dissolves.
   5. An egg is cooked, turning from a drippy liquid to a rubbery solid.

   b. Which of the above were you unsure of? What information would you need in order to make a correct decision?
5. Think about all the reactions you have done in this cluster, including the mixing you did in Lessons 1 and 2 of common household substances. Write a short paragraph telling what happens when new substances form. Be sure to tell both what you would observe with your eyes and what happens to the atoms and molecules which your eyes cannot see.

You are now ready to explore what happens when butane burns.

2. Yes, because of significant change in color and texture of the tarnish.

3. No, the nail is still the same and can be used as a nail in exactly the same way. Nothing new was seen forming.

4. No, the salt is still there as is evidenced by the taste. Also, the water could be evaporated and you would have salt and water. So they were just mixed together. Students often think that dissolving is a chemical change because the solid "changes into a liquid." They usually know that it did not melt but they do not know what is happening. Tell them to think about the properties of the substance, especially taste. Ask them what would happen if they evaporate the water?

5. Yes, the egg is different in color (the egg white) and taste. Most people don't eat raw eggs. This is confusing because we call both the cooked and the uncooked egg an egg so students often say "it is still an egg." Sometimes students say that it was liquidy and it went to solid as in a physical change but remind them that heat was added to cook the egg and when liquids change to solids (water to ice), the substances must be cooled.

4. b. Answers vary. You need to know the chemical formulas for the reactants and the products to see if they are the same or different.

5. Important points to include are:

- the properties that you can observe with your senses change, usually in an obvious way but sometimes in a less discernible way.
- the reactant molecules come apart and then go back together again in new arrangements.
- the total number of atoms in the reactants and in the products does not change.

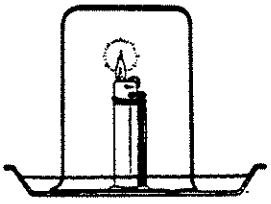
Cluster 3—Lesson 16

This is the last of the four reactions that form the backbone of this entire unit. Since this reaction has been done earlier by the students, it is done here as a teacher demonstration.

A. When burning the butane in the lighter, it is easy to see that the amount of the butane is decreasing, but observing the products is much more difficult since two invisible gases—carbon dioxide and water vapor—are formed. Students probably observed water vapor on the inside of the beaker when they did this experiment earlier but they did not have any evidence for the presence of carbon dioxide. You can test for the presence of carbon dioxide by turning the beaker over quickly, placing a small amount of bromthymol blue in the beaker and swirling it. The carbon dioxide will stay in the beaker since it is heavier than air. The bromthymol blue changes to yellow when carbon dioxide is present. Students have probably used this test before so they may remember the test. In any case, review with them how the test works.

By now, students are beginning to understand how chemical reactions work. Depending on your students, you may want to allow some students to work on their own while you help students who are having difficulty. Or you may want to pair students who are having difficulty with another who seems to understand the process. Or you may find that you still need to work with the whole class. Don't let them omit the model-building steps. Again as they build their models, have them hold them up for you to see and give a nod of approval.

Lesson 16: ATOMS IN EQUALS ATOMS OUT Burning Butane



A Recall the burning of butane from Cluster 2. Your teacher will demonstrate the reaction for you, to refresh your memory and to try to identify the products.

What did you learn about starting substances when the beaker was put over the lighter?

What product formed as little droplets on the inside of the beaker?

Turn the beaker upright and add a little dilute Bromthymol blue to the dish and swirl it around. What does this chemical test show you about one product formed when butane is burned?

	REACTANTS		PRODUCTS	
DESCRIPTION	Clear liquid	Invisible gas	Liquid droplets	Turns BTB yellow
COMMON NAME	Butane	???	??? (don't write here!)	???
FORMULA	C_4H_{10}	???	??? (don't write here!)	???
PICTURE OF MODEL	(write on chart in journal)			

LESSON STATEMENT: With less direction from the teacher than in the previous three lessons, students make models of the burning butane reaction to explain what is happening.
PURPOSE: To help solidify students' understanding of how new substances are formed in chemical reactions and why mass is conserved.
APPROX. TIME: 1 class period.

TRY THIS (B)

YOU WILL NEED

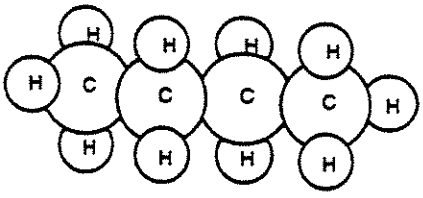
Marshmallows or gumdrops and toothpicks for model building.

A. Use a chart to help study this reaction, as you did with the decomposition of water and with rusting of iron.

B. Fill in whatever you can about the starting and ending substances.

C. Build models of the reactant molecules.

Chemists have analyzed butane as it burns, and found that its formula is C_4H_{10}—four carbon atoms and 10 hydrogens.



D. Draw pictures of the product molecules in your chart. Use the pictures as you do the next step.

E. Take apart the starting molecules and rearrange them to form the ending molecules. You'll need to start with two butane molecules and many molecules of oxygen.

F. As a special project, make a video, or draw a cartoon strip to show what happens when butane burns—how butane molecules come apart and recombine with oxygen atoms to make the ending substances. In the video or cartoon explain why a butane lighter gets lighter when it burns, but why the lighter under the beaker **doesn't** change its weight.

SAFETY!

If your model kits contain gumdrops, marshmallows, and toothpicks, do not place any of them in your mouths. Upon completion of this project discard these materials as instructed by your teacher.

(C)

B. For building the molecular models, students need four carbon atoms, ten hydrogen atoms and two oxygen atoms. Provide students with only enough parts to make one model of each molecule. They should take these apart before beginning making models for the reaction. Again, you need to decide what colors represent each kind of atom depending on what model kits you have. Students should, if possible, use the same color for oxygen and hydrogen that were used in the last two lessons. They should decide what color will be used for carbon.

Butane is the biggest molecule students have used and there are lots of different ways that the four carbon atoms and ten hydrogen atoms could be attached together so there is plenty of opportunity for confusion. Be sure they get teacher approval when finished.

It is important that students do not have left-over molecular models when they begin making models for the reaction.

C. Because butane is a large molecule and students may get confused, they will start with two butane molecules. Both of these react and students are told to show how TWO butane molecules come apart and form products. They get frustrated if they start with only one and then find they have to repeat the whole process with a second butane molecule in order to balance the equation. Do be sure to collect all unused "atoms" so they cannot pick up these pieces to make the products.

Be sure students identify or color code all the different atoms in their pictures.

Students will probably be able to finish the data sheet quite independently. If they have trouble when writing the balanced equation, refer them back to their models.

	REACTANTS		PRODUCTS	
COMMON NAMES	BUTANE	OXYGEN	CARB. DIOX.	WATER VAPOR
FORMULA	C_4H_{10}	O_2	CO_2	H_2O
PICTURE OF MODEL				
PICTURES OF MODELS FOR REACTION				
ACCOUNTING OF ATOMS	C H O Atoms Total 8 20 26 54		C O O H Atoms Total 8 16 10 20 54	
BALANCED EQUATION	$2\ C_4H_{10} + 13\ O_2 \rightarrow$		$8\ CO_2 + 10\ H_2O$	

QUESTIONS:

The following questions should be used for discussion in small groups as students refine their thinking. After group discussions, students should write the answers on the back of their data sheet.

1. 13

2. $2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$

3. You can't burn trash up and get rid of it. This violates the Law of the Conservation of Matter. When burning trash, the trash and the oxygen it needs to burn change into new forms, much of it being gases which are given off into the atmosphere, including carbon dioxide and water vapor. Other gases can be produced, depending on what is burned; some of those gases contribute to air pollution. (Butane does not release other gases, as can be seen from the chemical equation; it is therefore a "clean" fuel. See note below.) Students frequently have the misconception that when things burn up, they weigh less. They fail to realize that the total weight of all the ash and the gases formed is exactly equal to the weight of the trash before it burned.

4. a. The gasoline in cars reacts to form carbon dioxide and water vapor and a few other products which are also mostly gases. These are given off into the atmosphere. The total weight of these products is less than the weight of the gasoline alone but it is exactly equal to the weight of the gasoline and the oxygen in the air needed to burn the gasoline. Nothing disappears or is lost.

THINK AND WRITE

Discuss each question below in your group. Then write the answers on the back of your data sheet.

1. How many molecules of oxygen did you need to react with the two butane molecules?
2. Write the balanced equation for the reaction in the appropriate place on your data sheet.
3. Charlie has been hearing a lot recently about all the trash that we are making and the problem of getting rid of it. He just had a brainstorm! Just burn it all up and it will be gone! What do you think about his brainstorm? Will it work? How would you explain this problem to a friend. Write your explanation in your journal.
4. The gasoline in your car is a fuel very similar to butane. When it enters the engine, it combines with oxygen in the cylinders and a spark makes it explode!
   a. What products are formed when gasoline is burned? (Hint: The products are the same as the products you got when your burned butane.) Would these products weigh more, less, or the same as the gasoline your started with? Where do these products go? Tell why you think this.
   b. Explain why you eventually run out of gasoline: What happens to the gasoline?
5. Your friend doesn't believe that butane or gasoline needs an invisible reactant to make them burn. Design an experiment to prove the invisible reactant is needed.
6. Some homes use bottled gas for their stoves, or for heating water for the shower, or for drying clothes. Some houses in cities get their gas from a pipe connected to their house, just like water and electricity come into your house. Other people, often those who live out in the country, get their gas from a tank in their back yard.

In all of these cases, a pipe takes the gas from the tank into the house and then to the stove or water heater or furnace or dryer. When you turn on the stove, the gas

A note about burning: Many substances burn (chemically react with air, releasing a great deal of heat), including gasoline, paper, wood, butane, coal, oil, natural gas, kerosene, charcoal, candle wax. These substances are all composed of carbon and hydrogen atoms, like butane; many also have oxygen atoms, nitrogen atoms, sulfur atoms. When each substance burns, it chemically changes into carbon dioxide and water; but in most cases (not butane) othe substances are produced as well. Burning wood, paper and wax can produce smoke (small particles like dust) and

comes out, and a small flame called a pilot light (or, in newer furnaces, an automatic, sparking electronic device) ignites the gas.

a. Every few months, a truck has to come to the houses in the country and fill up the tank. Why?

b. If you said that the gas is used up or burned up, what do you mean? Does it just disappear leaving nothing behind? Use the idea of molecules to answer these questions? For instance, are there molecules in the gas tank? Is there anything other than molecules in the tank? What happens to those molecules when the gas is burned?

7. Miguel knows that people drown in water because they don't have any oxygen to breathe. But now he also learned that water is made up of oxygen and hydrogen. How can it be that a person drowns because of lack of oxygen but water is made up of partly oxygen? Can you help Miguel with this dilemma?

8. Natalie's problem is similar to Miguel's. She knows that fire needs oxygen in order to burn. She also knows that water, which is made up partly of oxygen, is used to put fires out, not to help them burn. What is going on in this world of chemistry anyway? Help!

b. Cars eventually run out of gasoline because it is chemically changed into carbon dioxide, water vapor, and other products. It does not disappear!

5. One design of an experiment would be to put a butane lighter in a flask with a balloon on top and observe what happens to the balloon as the oxygen is used—the balloon will be sucked into the flask, just as with the rusting steel wool. Another design would put a butane lighter in a vacuum chamber where the air could be sucked out; the butane lighter would stop working as the oxygen decreased.

6. a. The tank has to be filled up because the propane is reacting and forming carbon dioxide and water (and releasing heat in the process). The carbon dioxide and water vapor float off and mix with the air. The amount of gas in the tank decreases as it reacts (burns).

b. Nothing ever disappears. So it means that although the gas was no longer there, the products formed from it are still around somewhere.

7. Even though water molecules have oxygen atoms as a part of their make-up, water as a substance is not oxygen. Oxygen, as a substance, has a molecule made of two oxygen atoms combined. Humans and other animals cannot separate the oxygen atoms from the water molecules and make oxygen molecules in their lungs: this requires a chemical process, similar to the decomposition of water activity done earlier. (There is, of course, oxygen as a substance dissolved in water. This is why fish can extract oxygen from water in their gills. Fish do not change water into oxygen.)

8. Water as a substance is not any kind of mixture of oxygen and hydrogen gases. It is its own substance, totally distinct from oxygen gas or hydrogen gas. Even though the water molecule is made from oxygen atoms, water as a substance has no characteristics of the substance oxygen.

The ideas used in these last two questions have to do with the distinction between elements and compounds, which is not discussed explicitly in this unit. Here's the distinction: There are 92 naturally occurring types of atoms in our world. These 92 can make their own substance (called elements), or they can combine with each other to make zillions of other substances (called compounds). Elements are therefore made of only one kind of atom, although sometimes the molecule of an element is made from more than one of the same kind of atom. For example, the element oxygen is made from two oxygen atoms. The element carbon, in some forms, is made from 8 carbon atoms. Some elemental substances, like iron and sulfur, are crystals, or long structures of connected atoms.

ashes. Some of the products are hazardous, in different ways. The carbon monoxide produced when gasoline, kerosene, or charcoal burn can suffocate people who burn them in closed areas. The sulfur dioxide produced from burning coal or oil can change to sulfuric acid in the air, returning to the ecosystem as acid rain. Other air pollutants come from burning fossil fuels. While burning reactions are all similar at a basic level—producing carbon dioxide and water—each has its own additional products.

Cluster 3—Lesson 17

An optional reading assignment is in the Appendix. It answers the question of how chemists learn what the formulas are for various chemical substances.

Also, there is an excellent article from *Discover* magazine that relates rusting to photosynthesis. A copy is in the Appendix.

A. KEY QUESTION: Allow students to share their thoughts with a partner and then perhaps with the class. No answers are expected and should not be given at this time.

Lesson 17: WHERE DOES IT GO?

If new substances are really made from the atoms of old substances...

if atoms are never destroyed in chemical reactions, but only rearranged to make new materials...

could it be true that the atoms that make up my body may have once been part of a dinosaur?

Could it be possible that some atoms that are part of me could someday be part of a spaceship that travels to distant galaxies?

And would it be true that the materials we throw in landfills don't just rot into nothingness?

A

KEY QUESTION

Where do the materials and substances we use go when we are finished with them and throw them away?

TRY THIS

YOU WILL NEED

- a small beaker about 3/4 full of a solution of copper chloride
- a piece of aluminum cut from an aluminum pie pan
- model kit

A. Draw a data chart in your journal.

B. Observe the solution of copper chloride. It was made by dissolving a crystal of copper chloride ($CuCl_2$) in water.

Observe the piece of aluminum. It is a thinly rolled piece of metal. Its molecule has only one atom: Al.

Write the names, descriptions and formulas on your data chart for the reactants.

LESSON STATEMENT: Students will perform an experiment involving various forms of copper to see how copper can exist in both its elemental form and in a compound that looks nothing like it. Students use this experiment to explore ideas about how the atoms that make up earths' resources and life forms cycle into each other over time.
PURPOSE: To extend students' understanding of chemical reactions in the context of the earth's resources and life forms. To draw on and build students' ideas about recycling, landfilling, and resource conservation.
APPROX. TIME: 1 class period.

Copper chloride is a mineral found in the earth. You'll see in a few minutes where it gets its name (at least part of its name!)

C. Place the piece of aluminum into the copper chloride solution. Observe for several minutes. How many changes can you find? **Discuss these changes in your group.**

D. **Write a description of any product you notice.** One of them is coating the aluminum pie pan. Can you identify it? (Hint: What kinds of atoms could be present in this product?)

B

E. Your class will figure out, with your teacher's help, what the products are. **Make models of the reactants and products,** and draw pictures on your chart.

F. **Write a balanced equation** for this reaction.

THINK AND WRITE

Discuss these questions in your group before writing answers.

1. Would every blue solution work like this to form copper? Why do you think this?
2. What do you think you would get if you tried this experiment again but started with a solution of iron chloride instead of copper chloride?
3. There are many chemical reactions that can be used to obtain various metals from the rocks (ores) of these metals. You have used only one of them. What is the essential chemical property of a rock or ore in order to obtain a certain metal from it?
4. Where do you think the copper in the electrical wiring in your home came from? Explain your thinking.
5. Have you ever seen an outdoor copper statue or monument, or perhaps nuggets of copper near a mine in the Upper Peninsula? Can you relate what it looked like to this activity? Explain.

B. Students should easily see the copper metal forming on the pie tin and they will notice that the blue solution is clear. However, they may fail to recognize that the clear solution is not just water: it contains aluminum chloride. The teacher will need to help construct the explanation. For building the molecular models, students need three copper atoms, six chlorine atoms and two aluminum atoms.

The equation is $3CuCl_2 + 2Al \rightarrow 2AlCl_3 + 3Cu$. For both chloride compounds, the chlorine atoms each attach to the metal atom (copper or aluminum).

Optional experiment: After completing the experiment given here, you can have the class do another experiment with a copper solution, that shows a very interesting reaction—a reaction that forms stalactites and stalagmites as in caves. It is printed in the appendix.

QUESTIONS:

1. The blue solution must contain copper in a different chemical form from copper metal. If it were not present in the solution, then no copper would form in the reaction with aluminum.

2. If you started with iron chloride, you would get iron metal, assuming that this reaction actually does work. You certainly wouldn't get copper.

3. Rocks and ores must contain the desired metal in a different chemical form in order to get a new chemical form, namely the metal, from it. Then one must know the correct chemical process in order to get the specific chemical reaction to occur.

	REACTANTS				PRODUCTS			
COMMON NAMES	COPPER CHLORIDE			ALUMINUM	ALUMINUM CHLORIDE			COPPER
FORMULA	$CuCl_2$			Al	$AlCl_3$			Cu
PICTURE OF MODEL								
PICTURES OF MODELS FOR REACTION								
ACCOUNTING OF ATOMS	Cu 3	Cl 6	Al 2	Atoms Total 11	Al 2	Cl 6	Cu 3	Atoms Total 11
BALANCED EQUATION	$3\ CuCl_2 + 2\ Al \rightarrow$				$2\ AlCl_3 + 3\ Cu$			

4. From the earth, either from copper nuggets or from ore or various rock forms. Ores that contain copper, such as copper sulfate, are chemically changed to form copper metal. This is often done in solutions using electrolysis. The metal is then melted and formed into useful materials.

5. Copper nuggets or copper statues have the characteristic copper metal color. But they can also have a blue or blue-green tarnish on their surface, from being exposed to oxygen in the air and water. This is a new form of copper formed when the copper in the statue or monument reacted with oxygen and/or water vapor in the air to form a new substance.

6. When you throw away materials made of copper, the copper will eventually react with air, water and other substances in contact with it and go into a different chemical form that does not at all resemble copper metal. It may then be dissolved in water and carried away to rivers, lakes and oceans, where it becomes available again to form copper metal under the right conditions.

6. What happens to copper wires, pots, jewelry, etc. when you throw them away?

7. Almost everyday you hear that you should recycle such things as aluminum, copper, paper, etc. Do you think this is important? Use what you have learned in this unit to explain why you think this.

As you thought about the Law of the Conservation of Matter, you wondered if it could possibly apply to this situation. What do you think?

8. Now what do you think about the KEY QUESTIONS for this lesson? Here they are again:

Could it be true that the atoms that make up my body may have once been part of a dinosaur?

Could it be possible that some atoms that are part of me could someday be part of a spaceship that travels to distant galaxies?

And would it be true that the materials we throw in landfills don't just rot into nothingness?

Explain your thinking about each question.

In this cluster, you have learned where new substances come from and how they form. As you continue your research in the next lesson, think about atoms and molecules, and how new substances are formed.

7. The earth's supplies of ores that contain many of the metals we use everyday is getting very depleted. When there is no more ore from which to obtain various metals, the only way to get them is to recycle them. The same is true of paper which is made from trees. We are cutting down trees faster than the new ones can grow. When we run out of trees, either substitutes must be found for paper as we know it today, or paper must be made from recycled paper. When the materials we use are just buried in large dumps with all our other trash, it is doubtful that the useful substances could ever be sorted out and refined in order to use them again. Hence, we must "sort" our trash before it is thrown out and recycle the useful materials so they will be around for future generations.

8. Yes, the atoms that made up dinosaurs now make up some portions of plants, animals, or non-living substances on the earth. When a dinosaur died—like any living thing—the matter that made up its body was recycled into other materials, by the processes of decomposition and growth of new plant material. Some of the matter that made up some dinosaurs changed into the fossil fuels we use today. Some of the atoms that make up the minerals in our bodies—minerals like calcium, potassium, zinc, iron, etc.—will return to the soil when we decompose, and be picked up in plants, which will be eaten by animals, including humans, etc. But some will also be mined and possibly used in spaceships. The materials we throw into landfills do not just "rot into nothingness."

Cluster 3—Lesson 18

Lesson 18: MORE RESEARCH!

To end this cluster, you will use your new knowledge of chemistry to continue your research. Consult your resources and try to find answers to the following questions. Each of these are big questions and could require a lot of research and information. Do the best you can with the time allowed!

Here are the questions you have already researched.

- the chemical name, and any other name it goes by.
- a complete description of the substance.
- what it's used for, present and past.
- any special importance to various cultures or ethnic groups.
- the history of its discovery and development.

Here are the questions for this cluster:

1. What is the chemical composition of this substance? Find the chemical formula if you can.
2. How do we get more of this substance? Try to trace its origin all the way back to its source. This may require several steps. If you find any chemical processes involved in its production, be sure to include these in your report.
3. How is this substance disposed of at the end of its useful life? There may be more than one process or more than one step in the process. You may find some chemical reactions that occur. You should include all of these facts in your report.

At the end of cluster four, there will be one more question to answer for your research: How is energy involved in the production and disposal of your substance.

Students have already researched the names of their substance and a description of the physical properties. They have investigated its uses and any special significance to various cultures or ethnic groups. Now they will find the chemical composition of the substance and what natural or earth materials it comes from. They will find out how it is or how it ought to be gotten rid of at the end of its useful life. They will be able to give the consequences of various methods of disposal.

LESSON STATEMENT: Students continue investigating their substance, this time focusing on the questions of this cluster—the chemical composition of the substance, where the materials come from and where they go after we finish using them.

PURPOSE: To expand students' knowledge of their assigned research substance based on new knowledge gained .

APPROX. TIME: 1 class period.

Lesson 20: WHERE DOES FUEL GET ITS ENERGY? . . . . (page 88)

Students examine how energy can be stored in rubber band and magnets as well as ways to increase or decrease the amount of stored energy.

MATERIALS NEEDED:

- rubber bands
- strong magnets
- paper, about 2 inch squares
- forceps
- pan of water
- wooden splint
- butane lighter

PITFALLS AND CAUTIONS:

1. Be sure students do not use the matches to light larger pieces of paper or anything else. Careless handling of fire can easily get out of control.
2. When burning the paper, students should hold it with the forceps and should drop it into the pan of water when it is finished burning.
3. Use small pieces of paper. Two inches square is about the right size for students to make observations but yet not have too big a flame as to be dangerous.
4. Try to find strong magnets as these will demonstrate the concepts better. Radio Shack usually carries a good supply of strong magnets.
5. You may need to combine groups when using more than 2 magnets.

Lesson 21: HOW DO CHEMICAL [redacted] (page 94) ..REACTIONS GET STARTED?

Fast Rusting of Steel Wool with a Bunsen Burner or Torch

This is a teacher demo of an earlier lab. This time, the focus is on the heat that begins the reaction and sustains it. As before, the torch is applied to the steel wool until a reaction begins (the steel wool turns black.) If the lights are turned off, the steel wool can be seen to glow—the glowing is the release of energy from the reaction. Some of the heat released continues to boost other parts of the steel wool.

MATERIALS NEEDED:

- steel wool
- Bunsen burner or propane torch
- ring stand and clamp,
  or something to hang the steel wool from

PITFALLS AND CAUTIONS:

1. The steel wool is very hot, and remains hot even after the glow has disappeared. Do not let students touch it.

Striking Matches; The Butane Lighter

Students strike two kinds of matches, wooden kitchen matches and safety matches. They observe what is needed to light the match and what is needed to keep it burning. Then they light a small piece of paper and decide what "booster" is needed. They end the activity by figuring out how the butane lighter works and writing about it.

There are actually two reactions needed to successfully light a match. The match head contains phosphorus sesquisulfide (P_4S_3) which has a low ignition temperature and is ignited by the low heat of friction when striking. The heat from burning the P_4S_3 then ignites the sulfur which burns at a slightly higher temperature. Finally, the wood ignites and sustains burning. Students are not expected to know what the chemicals are or that there is more than one chemical reaction involved.

MATERIALS NEEDED:

- wooden matches and a rough surface
- safety matches

- small pieces of paper
- pan of water
- forceps

PITFALLS AND CAUTIONS:

1. Be sure students do not use the matches to light larger pieces of paper or anything else. Careless handling of fire can easily get out of control.

Lesson 22: OTHER KINDS (page 101) .....OF BOOSTERS?

Decomposing Water

Students will perform the decomposition reaction again, setting it up to discover which of the components of the reaction are boosters. They perform the reaction without connecting the wires to the battery, to see if electricity is a booster. Then they perform it again, leaving out the salt from the water.

The salt is a "matter booster," also known as a catalyst. The electricity is an energy booster.

MATERIALS NEEDED

- battery, wires and pencil leads from Lesson 3
- Petri dish
- water
- pinches of salt (you may substitute sodium sulfate for the salt)

PITFALLS AND CAUTIONS

1. Either short pieces of lead removed from a pencil or pencils sharpened at both ends will work well for these electrodes.
2. Salt (sodium chloride, NaCl) is not as good as sodium sulfate since it produces chlorine gas at the anode.

Making Handwarmers

Students will make their own hand warmers, just like some of the commercial ones that use the rusting reaction to release heat. The reaction uses salt water as a booster (catalyst). They perform the experiment with and without the salt water as well as with and without oxygen. They use their results to identify which is the "booster" and what the role of the other substance is as well as to decide how energy is involved in the reaction.

Students will first observe the iron filings with the bag open (oxygen available) without the salt water in which case nothing happens. Then they add the salt water and observe again. They discover that salt water is the "booster" since it is required for the reaction to get started. They close the bag (cutting off the supply of oxygen) and the reaction stops even though the "booster" is still available. The sand in this reaction is necessary to absorb and store the heat. Without it, the heat dissipates so quickly that it cannot be felt.

MATERIALS NEEDED

- 1 tbsp iron powder
- sand
- Ziploc bag
- salt water solution
- commercial hand or toe warmers for observation and comparison

PITFALLS AND CAUTIONS

1. It may take a few minutes of kneading in order to feel the heat being produced.
2. The bag must be held open in order to allow contact with plenty of oxygen from the air which is required in order for the iron and oxygen to react.
3. Since sand retains heat very well, these warmers can get quite hot.

Lesson 22: OPTIONAL ACTIVITY: Reaction of Ground Liver or Potato with Hydrogen Peroxide . . . . . (page 106)

Since almost all biological reactions proceed only with a catalyst (booster), students may investigate a biological reaction that requires an enzyme. The liver or potato cell contains a booster which is called an enzyme. It immediately decomposes the hydrogen peroxide produced in some cells into two harmless substances, oxygen gas and water. This is an important chemical reaction in cells, since the hydrogen peroxide produced in some cells is toxic to them. The reaction is $2H_2O_2 \rightarrow O_2 + 2H_2O$. The liver or potato is a matter booster.

A potential difficulty with this experiment is that students may confuse what they know about hydrogen peroxide with what is happening in this reaction. They know that hydrogen peroxide is used to disinfect wounds, and may, in a naive way, think of the hydrogen peroxide as the "active" component in this reaction, rather than the enzyme in the potato as the "active" component.

MATERIALS NEEDED:

- ml of fresh, 3% hydrogen peroxide solution, H_2O_2
- freshly ground liver or freshly ground potato pulp (red-skinned or Idaho potatoes work best)
- large test tube

Procedure: Put a small amoung of freshly ground liver or potato in a test tube. Add fresh hydrogen peroxide. Observe.

PITFALLS AND CAUTIONS

1. Enzymes are very sensitive and decompose very readily. Therefore, be sure that the liver or potato is freshly ground.
2. Large amounts of heat are generated in this reaction. Use Pyrex test tubes and provide a way to support the test tubes.
3. Hydrogen peroxide decomposes after being opened. You may want to test it ahead of time if it has been open for a while.