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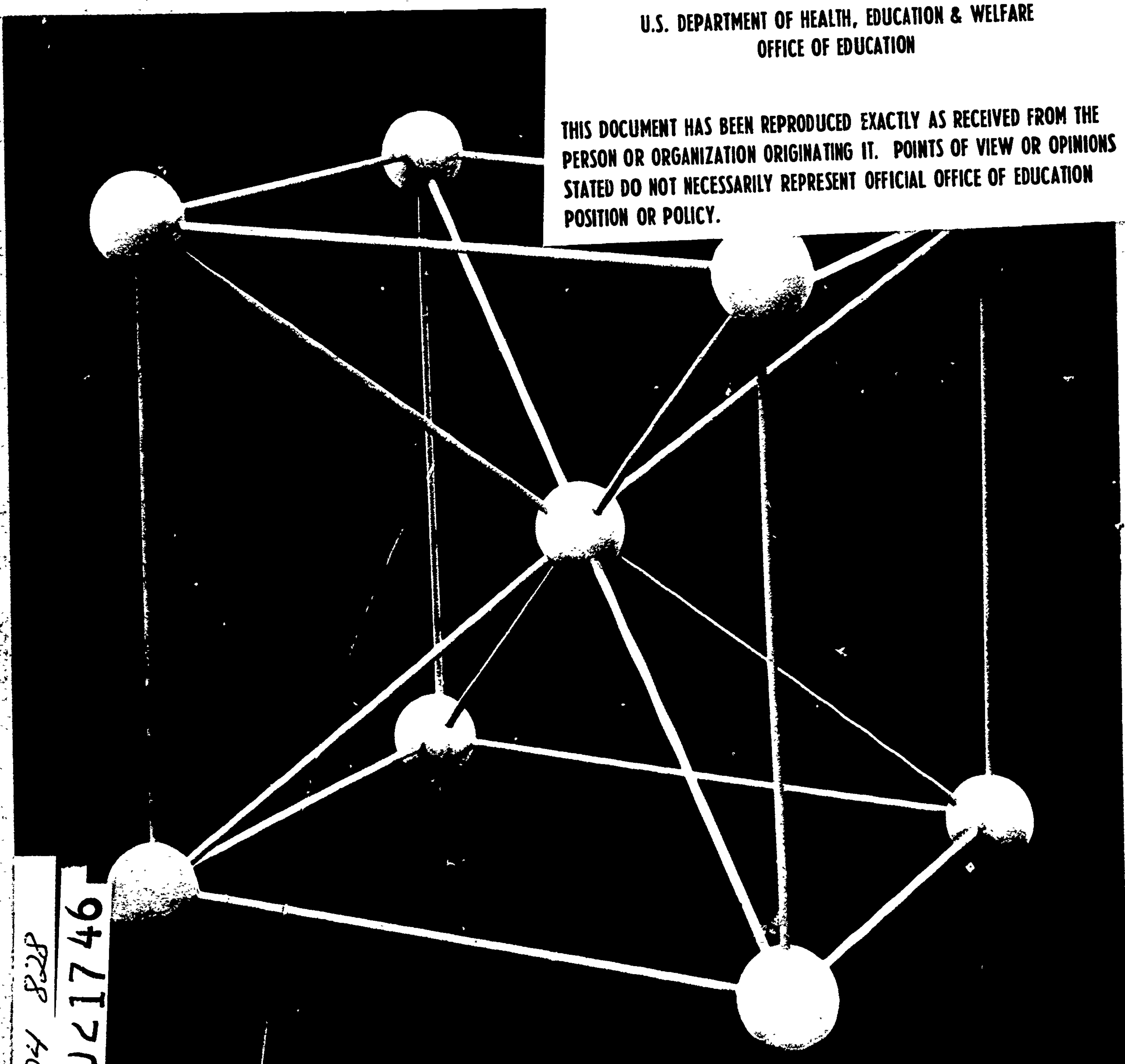
This is the third in a series of guidebooks written for elementary school teachers to assist them in improving their science instruction. The book attempts to emphasize processes and creativity as well as content. Atoms and molecules constitute the subject matter of the publication. Many experiments and demonstrations are included. (BC)

INVESTIGATING SCIENCE WITH CHILDREN / VOLUME 3

ATOMS AND MOLECULES



National Science Teachers Association

INVESTIGATING SCIENCE WITH CHILDREN

VOLUME 3

ATOMS AND MOLECULES

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INVESTIGATING SCIENCE WITH CHILDREN SERIES

Volume 1 LIVING THINGS

Volume 2 THE EARTH

Volume 3 ATOMS AND MOLECULES

Volume 4 MOTION

Volume 5 ENERGY IN WAVES

Volume 6 SPACE

The National Science Teachers Association is a department of the National Education Association (NEA) and an affiliate of the American Association for the Advancement of Science (AAAS).

About the cover: The model illustrates the spatial arrangement of atoms in a unit crystal of iron. The balls at the corners of the cube and the ball at the center indicate positions that iron atoms in the crystal occupy.

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CONTENTS

About the INVESTIGATING SCIENCE WITH CHILDREN Series

These six handbooks for the teaching of science in the elementary school have the distinguished sponsorship of two leading groups concerned with the improvement of science teaching: NSTA (The National Science Teachers Association) and NASA (The National Aeronautics and Space Administration). Initiated by NSTA, the series received technical and financial assistance from NASA. The six authors were carefully chosen by NSTA and NASA from among leading science educators in the United States and Canada. The series has been carefully planned, developed, and edited over a period of two years. It updates and replaces the widely successful SCIENCE TEACHING TODAY series by Dr. Guy Bruce, published by NSTA in 1950.

General approach and philosophy. As they planned this series of books, members of the writing team were concerned with the following questions: What are some things we can or should do to help teachers as they investigate the world of science with children? In what direction should we move? How can we incorporate into our writings the processes and content of science, the fostering of creativity in children, provisions for children's varying abilities?

The age and culture in which we live demand that children in the elementary schools have a variety of real science experiences that lead them to an understanding of the world about them. Through a variety of science experiences, each individual will come to understand and to use scientific processes and skills, as well as to acquire the specific science learnings that will help him live intelligently.

Since each book in the series is concerned with one area of science and moves from simple concepts to more complex ones within each chapter, *each* teacher, at any grade level, will find that *all* the books have materials that she can use in her teaching.

Question–discovery approach used. Throughout each book, questions are used in several different ways. At the beginning of each chapter is a list of questions that children of different ages might ask. Answers to these questions and others are found when the children become involved in doing the Activities of the specific chapter. Other questions, with answers containing the science information given in parentheses for the teacher, are included within each Activity to help teachers as they guide the children's learning. More questions are listed later, as open-end Activities to be used with those children who may wish to make further investigations.

Organization keyed to varying abilities. To provide for varying abilities of the children in a group and at different grade levels, as well as to make possible a developmental approach to concept formation, the Activities and learnings are purposely not "graded," but are designated by the following symbols: *x* for those Activities involving beginning learnings; *y* for those Activities requiring more skill and involving several learnings; and *z* for those Activities of considerable difficulty and involving more complex thought patterns. An introduction is included with each Activity, which is merely suggestive and which may give the teacher ideas helpful in challenging children's thinking.

Illustrations and format. All six of the volumes are filled with helpful illustrations that will help the teacher as she directs the children's participation in the Activities. A two-column format allows for easy reading and clear organization, for in-class presentation.

Summaries and references. Each chapter concludes with a summary of the main ideas developed by the author. Throughout each book, cross references are made to Activities and science content found in the other books of the series. At the end of each book there is a list of bibliographical references that contain additional science information.

Scientific accuracy assured. One of the concerns of the writing team was the scientific accuracy of the information appearing in each book. To insure such accuracy, leading scientists who are specialists in their respective fields were asked to read and review the content during the preparation of the manuscripts. Their names appear at the end of this section.

It is hoped that this series of books, INVESTIGATING SCIENCE WITH CHILDREN, will be helpful in providing opportunities for children to use many processes of inquiry —investigating, observing, problem-solving, hypothesizing, experimenting, thinking, checking, analyzing—as they try to find the *what, how,* and *why* of the world around them. There are no final answers in these books. Let the series be thought of as a challenge to teachers to further learning.

Acknowledgments. Many people have made this series possible. The authors and series editor wish to express their appreciation to Robert Carleton, Executive Secretary of the National Science Teachers Association, for his confidence in the project and for his many words of encouragement; to Frank Salamon, Specialist in Elementary Science, National Science Teachers Association, for his guidance through various stages of the project; to Everett Collin, Mattison L. Story, and George Gardner, Specialists, National Aeronautics and Space Administration Education Program, for their interest in the project and for their reading of the manuscripts; and to Lila J. Phillips, Editor for this series, Teachers Publishing Corporation, for her suggestions and aid in the preparation of the final manuscripts for publication.

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1

INTRODUCTION

Would you be more likely to hear the following questions asked by scientists or by elementary school children?

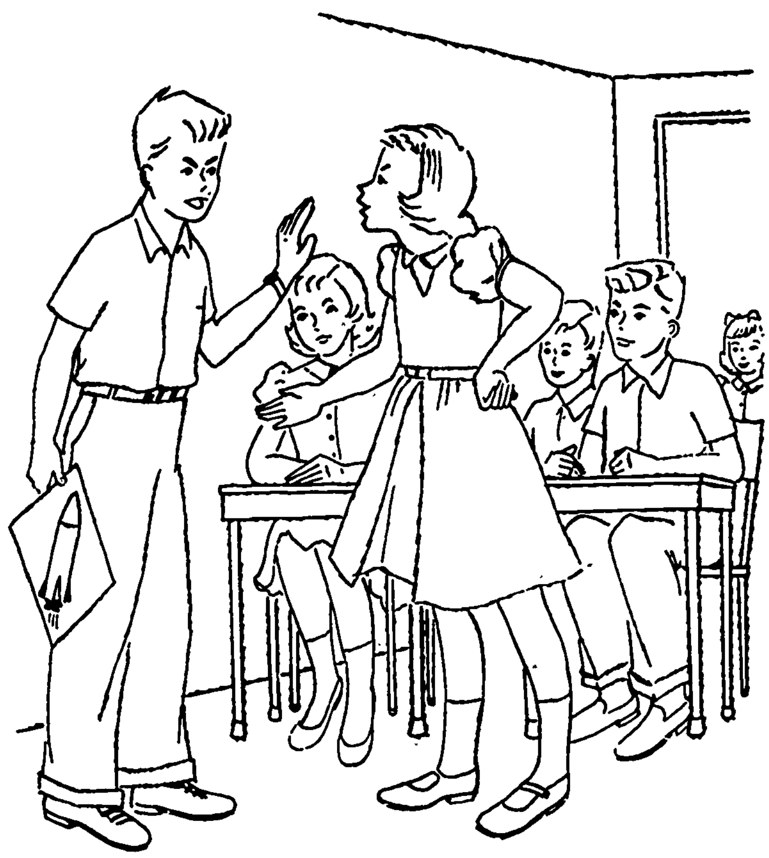
"What is the real shape of the Earth?"

"Why is sugar sweet and a lemon sour?"

"How does food give us energy?"

"What is the world made of?"

The answer is that both scientists and children ask such fundamental questions in trying to understand the world about them. Some of the most exciting moments in teaching occur when children ask such basic questions. Here's how it happened in one third grade classroom.



The lunch period had just ended, and the room was very quiet on a warm and sunny autumn day. From her desk, Miss Dean could see Betsy and her friends leafing through magazines, Roger sketching his favorite rocket ships, and Billy gazing dreamily out the window.

The calm was broken by a giggle that came from Betsy's group. In a gently teasing voice, she read aloud:

What are little boys made of?
Snips and snails and puppy dogs' tails,
That's what little boys are made of.

What are little girls made of?
Sugar and spice and all things nice,
That's what little girls are made of!

"Yes! Girls are big sissies," Roger retorted, and the other boys joined in with similar replies. Betsy, however, had more serious business on her mind.

"I know that poem is silly, Miss Dean, but what are we really made of?" The answers came quickly as Miss Dean looked at the class.

"We're made of skin, bones, flesh, hair, and other things," said Roger.

"Yes, but what are they made of? They must be made of something," questioned Billy. "My father said that everything in the whole world is made of atoms."

"Oh, no!" said Helen. "We can't be made of atoms. Atoms are used in bombs. They would hurt you!"

"Maybe there are good atoms and bad atoms," Tom said, "and people are made of the good kind."

"Well," said Roger with a serious frown, "even if that's so, what are atoms made of?"

Now there were no hands raised. Everyone was thinking long and hard.

"I guess we're stumped now," said Miss Dean, "but I'm sure we could find out some of the answers to our questions. People have wondered about these things for a long time. Let's make some plans to find out what has been discovered.

We can look in our science books and other books. Billy might ask his father for more information. We could ask the science teacher in the high school. And I think that all by ourselves we could do some experimenting with different materials to help us find out what we and the world are really made of."

The basic theme of this book is the very question that aroused the curiosity of Miss Dean's third-graders: *What is the world made of?*

This is also, of course, a question that has challenged the curiosity of the human race for a long, long time. It was about 2,500 years ago that the first answers to this question were put forward in terms of elements and atoms. Some of the ancient Greek philosophers reasoned that the immense variety of known materials might be made up of a small number of "elementary building blocks" in different combinations. Fire, air, earth, and water were the four most elementary substances of which they could think. The philosophers also suggested that these "elements" were held together by a force of attraction (love) and broken apart by a force of repulsion (strife), thus producing all the different combinations of materials in the world. About 400 B.C., Democritus, the Greek philosopher who founded a school of "atomists," proposed that all matter was made up of extremely small bits, or "atoms," which could not be further subdivided into smaller particles.

In the centuries that followed, these early ideas were refined into the more complex conceptions of elements and atoms we have today. It was not until the first decades of this century, however, that man's understanding of matter leaped to the point where control over the atom became possible. The event is commemorated by a plaque on the wall of the University of Chicago's football stadium, which reads:

On December 2, 1942
Man Achieved Here
The First Self-Sustaining Chain Reaction
And Thereby Initiated The
Controlled Release Of Nuclear Energy

Today, more and more discoveries continue to flow out of man's new knowledge of the innermost structure of atoms. Elements not found in nature have been created in the laboratory. Nuclear materials are used in everyday applications in medicine, agriculture, and industry, and as important tools of research in these fields. The pursuit for more knowledge about the nature of matter goes on, although many important questions remain to be answered, and new ones arise out of the continuing flood of discoveries.

Therefore, when children ask such questions as, "What is fire?" "Why is the grass green?" "Is a tree alive?" and "What is the world made of?" they are sharing with scientists, and indeed with all mankind, strong drives to comprehend the universe around them.

The information and Activities presented here have been designed to help the teacher provide experiences for children with some of the major concepts scientists have developed about the nature of matter. Great emphasis has been placed on Activities in which many children can have first-hand contact with materials in an "open-ended" way. This simply means that the experiences in this book encourage children to use their findings to answer their questions, to extend their understandings to new questions, and to find out how their concepts about matter are involved in the materials of everyday living.

2

INVESTIGATING THE PROPERTIES OF MATTER

All around us in nature we see a tremendous variety of materials and objects in different forms, sizes, and structures. All these materials, such as water, wood, and sugar, are different kinds of matter. Any particular kind of matter is called a substance. Children attempt to sort out their experiences with the substances of the world in terms of meaningful experiences or concepts. Similarly, the teaching approach in this chapter begins by describing the world as it appears from a child's point of view: What does matter look like at first sight? What can a commonsense, naked-eye study of the general characteristics of substances reveal about the nature of matter? On the basis of simple "first-sight" experiences, the general outlines of such concepts as element, atom, mixture, and compound are developed just as they were by philosophers and scientists long before the present era of cyclotrons, Geiger counters, and other modern devices.

We will begin with Activities that introduce children to a wide variety of materials and their properties. Many common substances, such as metals, chalk, wood, water, and salt, are examined to find out their color, odor, texture, form, hardness, and other properties. These experiences help build the following concepts: There are many materials around us. We can discover what materials are like. Materials are alike and different in various ways. Matter can exist in the form of a solid, a liquid, or a gas. Materials can be sorted into categories according to their properties.

From the theme of variety in matter, the focus moves to a consideration of what materials are made of in a fundamental sense. The Activities deal with the major concept that all the many kinds of matter are basically composed of a small number of simple "building blocks"—the chemical elements. At the present time there are 103 elements that have been discovered or made by man. An element is a pure substance that cannot be changed to a simpler or different substance by ordinary means (such as heating, using electricity, or treating with chemicals). Iron, gold, oxygen, and carbon are examples of elements. Different elements can be combined to form other substances; the combination is called a compound.

The smallest "bit" of an element or a compound that retains its identity is called a molecule. There are millions of molecules in even a tiny speck of any substance. (Molecules can usually be subdivided into smaller particles called atoms, but these atoms do not have the same properties as the molecules from which they came. For some substances, such as the element iron, a molecule is made up of only one atom. The molecules of most substances, however, contain two or more atoms.) A water molecule has three atoms in it —two of hydrogen (H) and one of oxygen (O); the chemist represents a water molecule by the formula H_2O. A molecule of table sugar (sucrose) has 45 atoms—12 of carbon (C), 22 of hydrogen, and 11 of oxygen (the chemist writes this as $C_{12}H_{22}O_{11}$). Many molecules that are much larger than this are known. Hundreds of thousands of compounds can be made by combining a wide variety of elements in varying proportions.

Elements and/or compounds may also be combined to form mixtures. Compounds and mixtures differ in some of the following ways:

(1) Compounds have a definite composition. In mixtures, however, the ingredients are dispersed in each other and can vary greatly in their proportions. Sugar solutions (which are mixtures of the compounds sugar and water) can be made weak or strong, but the sugar itself always contains the same number of each kind of atom in its molecules.

(2) The components of a compound are usu-

ally held together quite strongly. They can be broken apart, however, by the application of some form of energy, such as heating or passing electricity through them, or by the action of other elements and compounds on them. Some compounds, such as the explosive dynamite, can be decomposed by a sudden shock. The release of large quantities of energy in the form of heat, light, and sound indicates the strength of the forces that hold compounds together.

The ingredients of most mixtures can be separated more easily than those of compounds. In a mixture of sugar and sand (a compound of silicon and oxygen), the different grains of each can be seen easily through a magnifying glass and picked apart. In a sugar solution, the water can be allowed to evaporate and the sugar reclaimed.

(3) The components of a compound often show a drastic change in their properties when they combine. For example, chlorine, a poisonous greenish-yellow gas, combines with sodium, a silvery metal, to produce table salt, a white crystalline solid that is necessary to life. In a mixture, the ingredients retain their distinctive properties. For example, a water solution of salt tastes salty even though the liquid is clear and no salt can be seen.

Many Activities in this book will help children find out what compounds and mixtures are like, such as building up some substances from elements and breaking apart others into the elements making them up.

When a compound is formed or decomposed, the resulting substance or substances have new properties different from the original substance and a *chemical change* is said to have taken place. If only the shape or size of a substance is changed, as by crushing a piece of chalk, tearing a piece of paper, or changing water to steam, a *physical change* is said to have occurred. The enormous variety of matter in the universe is the result of such chemical and physical changes taking place among the basic elements and the compounds and mixtures they have formed.

The starting point for most of the experiences with materials lies in the questions children often ask about what things are made of:

"Is it animal, vegetable, or mineral?"

"What's the strongest thing in the world?"

"What are boys and girls made of?"

"When were atoms first invented?"

"Are atoms only good for bombs?"

"If sugar has carbon in it, why isn't it black?"

"How many different kinds of things are there in the world?"

WHAT ARE THE PROPERTIES THAT DIFFER IN MATERIALS?

There are many materials around us, and children should be helped to develop this theme of variety in nature. Materials seem to differ in an almost infinite number of ways—in color, smell, shape, weight, size, strength, solubility in water, in being a solid, liquid, or gas, in susceptibility to magnetism, in electrical properties, in being transparent, opaque, etc. There are several simple observations and tests that children can make to determine these characteristics of materials.

ACTIVITY 1 (x)

MAKING A CLASS-WIDE SEARCH FOR DIFFERENT MATERIALS

Purpose: To help the children discover the vast variety of materials in nature

Concept to be developed: The variety of materials around us is so great that it seems to be infinite.

Materials needed:

Glass of water
Book
Jar
Piece of chalk
Small jar of salt
Small jar of sugar

INTRODUCTION: Place the objects where everyone in the class can see them. Identify each and announce the beginning of a class-wide investigation to find out what materials are like. Guide the discussion with such questions as "What do you think water is made of?" "What is in the empty jar?" "Is the water just water or do you think it might be made of something else?" "What is the salt like?"

Mention to the children the need to collect and examine many kinds of things to see how they are alike or different. Explain that this is a first step in finding out what things are, and that by doing this they can discover for themselves what chemists call the properties of matter. Suggest that the children bring in small samples or objects made of the materials listed below. These materials will be used in most of the Activities in this chapter. Point out that, in studying science, a number of new words will be introduced, and tha* words will be used that are familiar to children but have a special scientific meaning. Such words are *hardness, luster, elastic, soluble, crystal,* etc. Children will have an opportunity to discover the meaning of each.

Suggested Materials for Collection:

*bell wire
coins
*nails
aluminum foil
*other metals
rock samples
eggshells
glass objects
rubber bands
paper cups (1-2 oz.)
sewing thread
magnifying glasses
chalk
pencils
coal
wood scraps
*plaster of paris
washing soda
*baking soda
*limewater
salt
paper clips
candles
*door bell or buzzer
sugar
*rubbing alcohol
*mineral oil
*calcium chloride
moth flakes or balls
yeast pellets
plasticine clay
soda straws
steel wool
*6-volt lantern battery
magnets

*available from hardware and/or drug stores

Learning: There is a vast variety of materials in nature.

ACTIVITY 2 (x,y,z)

MAKING TESTS FOR PHYSICAL PROPERTIES

Purpose: To discover some of the physical properties that differ in materials

Concept to be developed: Some of the physical properties that may differ in materials are color, luster, odor, taste, form, texture, magnetism, strength, and hardness.

Materials needed:

A variety of materials such as those suggested for collection in Activity 1
Magnifying glass
Steel wool or sandpaper

INTRODUCTION: When a number of different materials have been collected, ask the class how they can discover what materials are like, since all of these seem so different. What similarities can be found among them? Point out that certain tests can be made to determine the special characteristics (the physical properties) of these materials in more exact fashion than can be accomplished by simple observation. Because of the large number of tests that can be made, suggest that groups of children be formed to test the materials for their various properties.

Have the children examine the materials listed for such properties or characteristics as color, odor, taste, texture, hardness, luster, form (crystals), magnetism, and strength (resistance to breaking into smaller pieces). Make a list of the terms used, and be sure that children have an accurate definition of each for their science vocabularies.

Encourage the children to use magnifying glasses for a closer study of these materials. Have them keep records of their findings.

Color and Luster: Call attention to the need for some standard color chart to which the samples can be matched. This may be a water-color set, box of crayons, a printed color chart, or the like. Each specimen should be checked for color under the same conditions of light, and by a consistent technique. Metals and alloys (two or more metals melted together) generally have a characteristic metallic luster when polished with steel wool or sandpaper. The color may range from silver or silver grey (as in silver, aluminum, nickel, and mercury) to almost black (as in iron). Copper and bronze are reddish brown; brass and gold are light shades of yellow.

Odor and Taste: (*Safety Note:* The tests for taste should be restricted to substances known to be nontoxic. None of those in the list above is dangerous, unless large amounts of some are swallowed. The following are in this category, or are rather unpleasant in taste: plaster of paris, washing soda, rubbing alcohol, calcium chloride, and moth flakes.) Individual variations in the sense of taste, and of smell, make it advisable to have several children perform and compare their odor and taste tests for these materials. Such terms as salty, bitter, sweet, sour, etc. may be helpful in labeling their findings.

Form and Texture: In many cases the children will be able to notice that some substances, such as salt and "rock candy," are made of crystals. These substances show a more or less regular geometric form in their crystals. When children look at salt with a magnifying glass they will discover that many of the grains look like tiny "boxes" or "cubes." Point out that these are tiny cubical crystals of salt. If the crystals are not visible in a sample, they can be made to appear by dissolving a pinch of salt in a few drops of water and letting the water evaporate. The children will find it interesting to follow the same procedure with a bit of each material in the list, such as the sugar, washing soda, wire, rock, etc.

Salt crystals seen through a magnifying glass.

The residue left after the water evaporates should be examined with a magnifying glass. Did each material tested dissolve? Did all those that dissolved form crystals? What was the shape of each crystal? Did they look like salt crystals? *(Not all solids will form crystals. Substances like tar, glass, wax, and many others belong to a category called noncrystalline, or amorphous, solids.)*

The texture of materials is another aspect of the property of form that children may use to describe differences and similarities in their samples. Have them feel the surfaces of the large solids and rub the other solids and liquids between their fingers. What differences do they find between crystalline and noncrystalline samples? *(Crystallized salt and sugar feel "gritty" compared with the smoothness of baking soda, wax, or glass).* What are some words they can use to describe textures? *(Soapy, gritty, silky, etc.)*

Magnetism: Have the children touch each object in their collection with a magnet to see if it is attracted. Let them test other objects in the room to see if these are magnetic. Was the magnet attracted to a radiator? Were all the parts of a desk attracted? Which parts were, and why? What generalization can the children make about the materials they tested that proved to be magnetic? *(They should note that all iron and steel objects are strongly magnetic, as are the metals nickel and cobalt. A United States five-cent piece does not contain enough nickel to show attraction, but a Canadian "nickel" does.)*

Strength: The children may try to break such objects as a stick of chalk, a wooden peg or dowel, a large nail, a piece of wire, and other objects similar in size and shape. Did they find it easy to break the chalk? Could they break the wooden peg? The nail or the wire? Why not? Is it easier to break some materials than others? Why? *(The forces of attraction between the molecules are stronger in some materials than in others.)*

Most metals can be bent, twisted, and stretched within broad limits before they break, while many nonmetals such as chalk, pencil lead, wood, plaster, and glass will break readily when put to such stresses.

The children might use a pair of pliers to determine the "crushability" or lack of it among the test objects. This will be another indication of the differences in the strengths of materials. What discoveries did the children make? Have them suggest why some materials were easier to crush than others. Keep a list of these suggestions on a chart or on the chalkboard for further checking as their study of matter develops.

(Chapter 4 deals with the bonds that hold substances together.)

On the basis of the children's observations about the strength of materials, which of their samples would be best to use for building bridges, toys, and buildings? To what use could weaker materials be put, such as the plaster or clay? *(For making statues, for the construction of inside walls of buildings, etc.)*

Hardness: This may be determined by trying to scratch one substance with another, such as a piece of chalk with the fingernail, or a penny (copper) with a nail (iron). The substance that is scratched is softer than the other. Have the children try the hardness test with the fingernail on chalk, and the nail on the penny. Did the nail scratch the penny? *(Yes.)* Did the fingernail make a mark on the chalk? *(Yes.)* Which one is softer, in each case, and which one is harder? What happens if they try these tests "backwards"—that is, try to scratch the iron nail with the penny, or the fingernail with the chalk? *(The softer substance will not scratch the harder.)* Will the penny or the nail scratch the chalk? *(Yes.)* What generalization can the children make from these experiences? *(The hardest substance in any collection will make a scratch mark on all of the softer ones. If two substances are of equal hardness they will scratch each other. A standard scale, known as Mohs' scale, that is used to rate the hardness of materials, has been devised by scientists.*)* Encourage the children to test the other materials on the list, and any others that they may have brought to school. Let the children give their ideas about where hard and soft materials would be most useful. *(Tools, such as drills, knives, sandpaper, scouring pads, etc., are made from hard substances, while objects that need to be shaped or cut are usually soft.)*

Learning: The physical properties of different materials vary.

*For a fuller discussion of Mohs' scale and other Activities to show differences in the properties of materials, see *The Earth* by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

ACTIVITY 3 (y,z)

TESTING ELECTRICAL CONDUCTIVITY

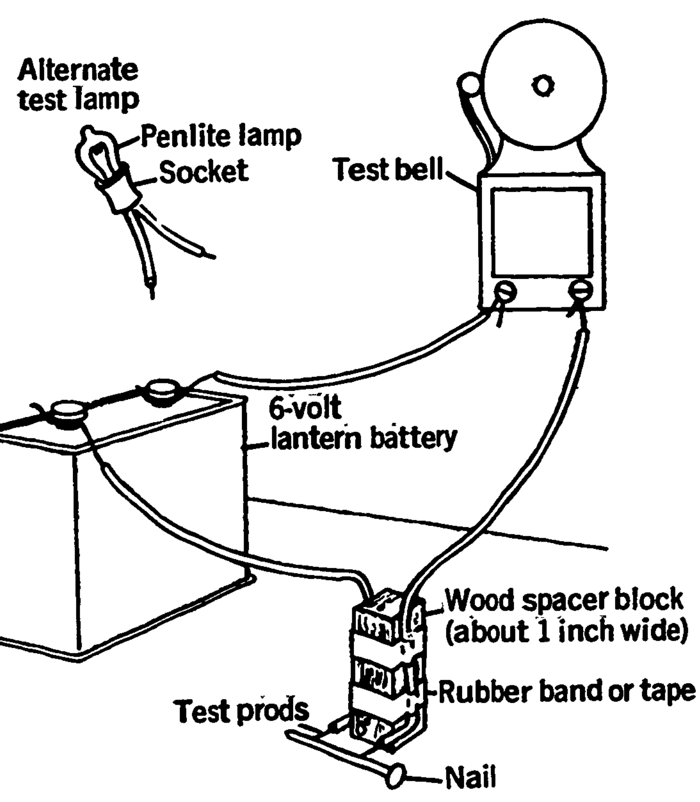
Purpose: To show that another of the physical properties that vary in materials is electrical conductivity

Concept to be developed: Materials differ in their ability to conduct electricity.

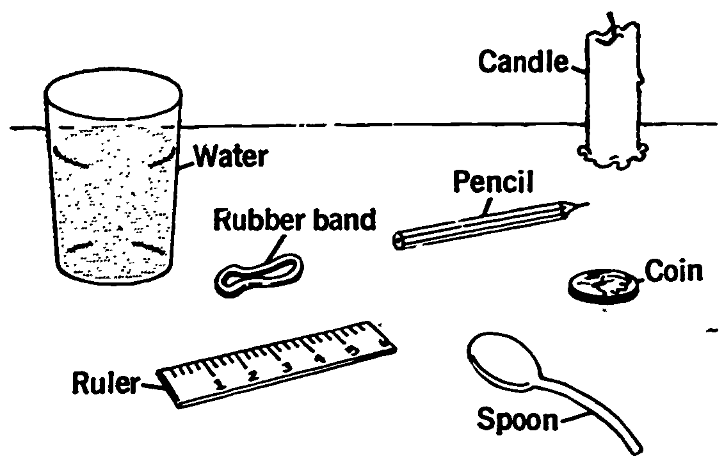
Materials needed:

A variety of materials such as those found in the table in Activity 1
6-volt lantern battery
Bell wire
Doorbell or test lamp
Wood block
Electrical tape

INTRODUCTION: Mention to the children that they have now observed and tested several of the physical properties of matter. Review with them the nine properties they have tested. Point out that in most of these cases, they have been able to discover the various properties by feeling or tasting, or by using one of the other senses. In some cases, however, the varying properties of matter are not as simple to detect. One of these is the ability of the substance to conduct electricity. Encourage ideas as to how to determine whether or not various kinds of matter can conduct electricity. Then proceed with the Activity.

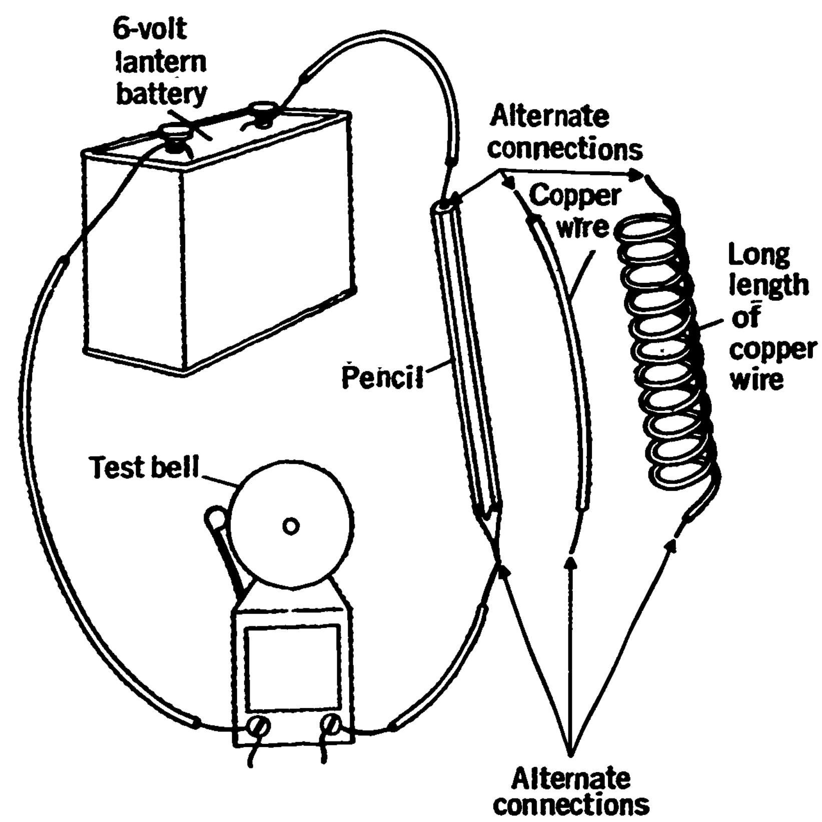


Have the children prepare a conductivity tester as shown in the illustration. Explain that the material to be tested, such as the nail, is being made part of a circuit containing a bell and a source of electricity. If the material is a conductor of electricity, the circuit will be completed and the bell will sound. If the material is not a conductor, the circuit will not be completed and the bell will not sound. The ends of the wires touching the nail or other objects should be kept the same distance apart for all specimens being tested. (There is no danger of electrical shock if a 6-volt lantern battery is used as the source of electricity.)



The children can find out if some materials are better conductors of electricity than others. Have them use a variety of materials and keep a record of their findings. *(In general, the metals will be good conductors, while the nonmetals, such as rocks, eggshell, glass, and rubber, will not.)* If the bell rings more strongly for some materials than for others, ask the children to suggest some explanations. *(Some materials are better conductors than others, and will allow the current to flow through them more easily, causing the bell to ring louder. A weak dry cell or poor contact of the wires against the test object may be other causes of varying current flow. These should be eliminated.)*

Extending Ideas: An interested group of children may wish to pursue the electrical conductivity of different materials further. They can make another testing device such as the one shown in the illustration. Explain that graphite and copper are two substances that do not conduct electricity equally well. Have the children test a soft lead pencil (graphite mixed with clay) and an equal length of copper wire. The bare end of the wire from the bell should be pressed firmly against the pencil point, and the wire from the lantern battery pressed against the opposite end of the pencil where the lead is visible. Does the bell ring more feebly than when the copper wire was tested? *(A noticeable difference in the loudness of the sound should be detected.)* In fact, if the children connect 100 feet of copper wire to the testing device, the bell will still ring more strongly than when the pencil was tested, because copper is a very good conductor of electricity. They may wish to try this, and compare their findings using a longer length of pencil lead. Suggest that two or more pencils could be held together so that the point of one makes good contact with the end of the lead in the other. What do the children discover? *(If enough pencils are used, not enough electricity will flow through the lead to ring the bell.)*



Help the children to apply their findings to the use of good and poor conductors of electricity in common electrical devices. Bring out during discussion the need for good conductors to carry the electricity where it is wanted, and the need for nonconductors as insulators.

Learnings: Materials vary in their ability to conduct electricity. In general, metals are better conductors than nonmetals.

ACTIVITY 4 (z)

LEARNING ABOUT RELATIVE WEIGHT

Purpose: To discover that relative weight is another of the properties that differ in materials

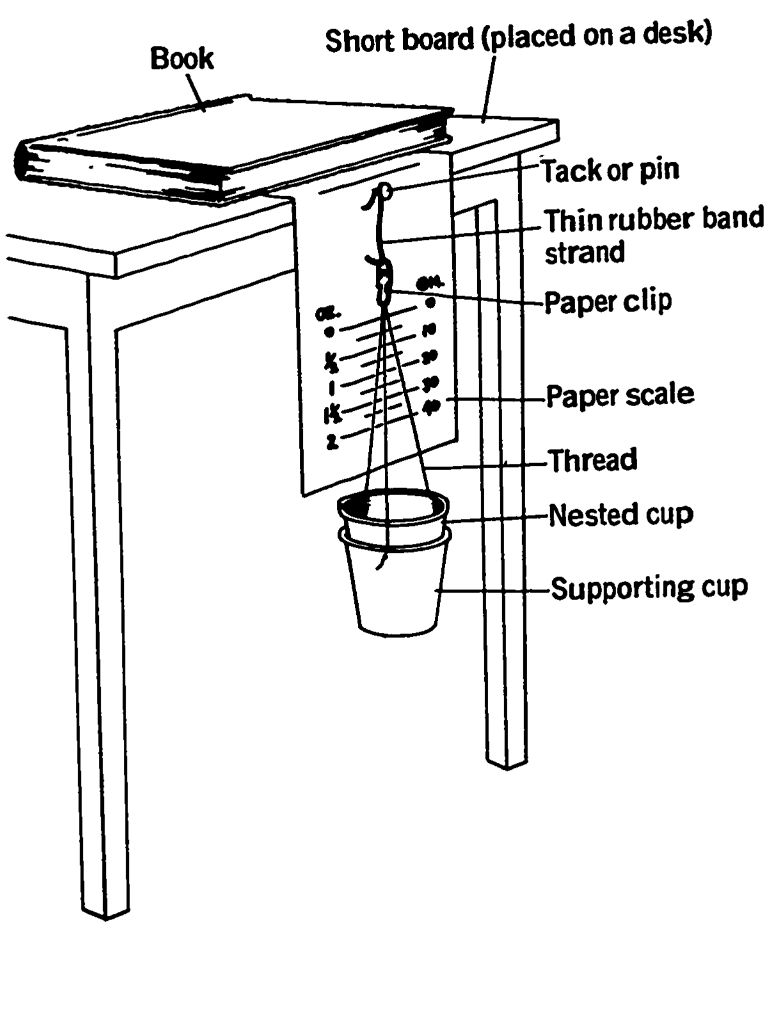
Concept to be developed: Equal quantities of different materials differ in weight.

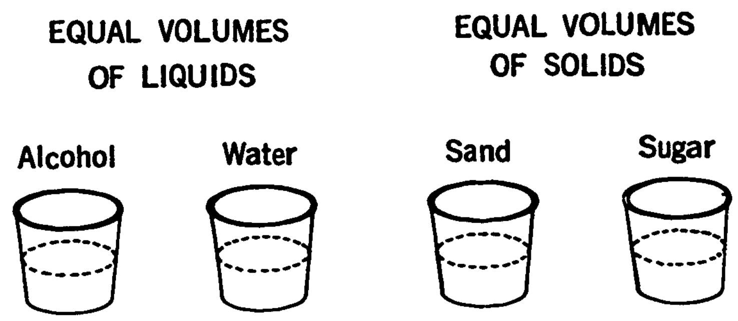
Materials needed:

- Sand
- Sugar
- Sawdust
- Water
- Tin cans or boxes
- Postage scale
- Small paper cups
- Rubber bands
- Paper clips
- Thread

INTRODUCTION: Point out to the children that there is another important property that varies in matter and that is weight. Encourage the children's theories as to how to test differences in weight. Point out that it would be helpful if there were a means of comparing the weights of equal quantities of various substances. What methods can the children suggest? Let them try their suggestions and then proceed with the following Activity.

The children can find out how equal quantities of materials compare in weight. Tin cans or boxes of the same size can be filled with sand, sugar, sawdust, water, and other substances and then weighed if a suitably sensitive scale is available. (A postage scale, or similar scale that can show differences of at least one ounce, will be suitable for weighing large quantities of materials in a box or a can.) If such a scale is not on hand, several simple yet sensitive scales can easily be made from small paper cups, a rubber band, a paper clip, and some thread. The illustration shows one type of scale that children can make.





Children can calibrate the scales in grams or fractions of an ounce by using dimes. Point out to them that a new dime weighs about 2½ grams, or a bit more than one tenth of an ounce. Have them mark a zero point on the scale where the threads join the paper clip. Be sure that *two* empty cups are nested and hanging freely for placing the zero mark. One dime at a time is then added, and the scale marked off in intervals of 2½ grams or tenths of an ounce.

Point out that small quantities of both liquids and solids can be measured out in equal amounts, and compared as to their relative weights. When children weigh samples, be sure that they fill each cup up to the same level. The filled cup is then set into the empty carrying cup of the scale and its weight noted. If the children weigh a cup of water and a cup of sugar, what do they discover? Does the water weigh more or less than the sugar? *(The sugar will be found to weigh 1.6 times as much as the equal amount of water.)* Ask the children to weigh other substances and make a list of their weights, as compared with that of an equal volume of water. Do they find any that are lighter than an equal amount of water? *(They might. Some lighter substances are alcohol and cork.)*

When the weight of a substance is compared with that of an equal volume of water the numerical ratio is called the *specific gravity* of that substance.

You may want to develop the following formula with some groups of children:

$$\frac{\text{Weight of substance}}{\text{Weight of equal volume of water}} = \text{Relative weight } \textit{(specific gravity)}$$

For example, in finding the specific gravity of table sugar,

$$\frac{\text{small paper cup half filled with sugar (48 grams)}}{\text{small paper cup half filled with water (30 grams)}} = 1.6$$

The specific gravity of sugar is 1.6; this means that any volume of sugar is 1.6 times as heavy as an equal volume of water.

Children can find out the specific gravities of other substances in the same way. As a check on their determinations, have them look up the specific gravities in a chemistry textbook.

Extending Ideas: After the children have completed the tests and Activities described thus far, it is important to help them draw some general conclusions from their findings by looking at their records. Point out that they were able to learn much about materials from their own efforts and observations, but that many other materials and properties were not studied.

What general statements can they now make about the number and variety of different substances around them? How many substances did they test or list? How many more can they suggest for further investigation?

There are many other questions that these Activities will have opened up for the children. They are often interested in extending an observation as far as possible. They might ask, "If a piece of iron wasn't the hardest substance we found, what is harder than iron? What is the hardest substance in the whole world? What is the softest? the heaviest? the lightest? Are iron and nickel the only magnetic substances?" Encourage them to continue these investigations further by testing and by consulting books and other authoritative sources of information.

On the basis of their experiences, ask the children to try to sort out the materials they have studied into groups having similar characteristics. Help them think carefully and critically about the problems of classifying so many different things. The categories they use could be based on particular properties of substances, such as hardness, magnetism, taste, origin (animal, vegetable, or mineral). It may be helpful to construct a chart to be used as a first step in organizing and then in summarizing their results.

You might ask such questions as, "Were many substances magnetic? How many had a definite taste? How many dissolved in water?" Moving in this way from particular observations to more general conclusions, the following generalizations can be developed:

1. There are many materials around us.
2. Materials may be pure substances, or made of more than one substance.
3. Substances have definite characteristics or properties.
4. We can discover what substances are like.
5. Substances can be sorted into categories according to their properties.

Learnings: The relative weights of materials are different. The weight of a substance compared with the weight of an equal volume of water is the specific gravity of that substance.

Summing Up Ideas: In this section the children were introduced to the idea that there is a vast variety of materials in nature. They learned of some of the physical properties that might be found in materials, such as color, odor, taste, texture, hardness, luster, form, magnetism, strength, electrical conductivity, and specific gravity. In addition, they learned that materials can be grouped into categories based upon these physical properties.

MATTER IN ITS SIMPLEST FORM — THE ELEMENTS

All the substances in the universe are composed of materials found in a single category of basic matter. We call the matter in this grouping the chemical elements.

All of the millions of substances we know, or all that are theoretically possible, can be built up from, or broken down to, these basic units. To date, man has discovered 103 of these fundamental building blocks of nature. Ninety-one have been found in nature, and the others have been produced in laboratories. According to present conceptions of the nature of matter, it appears that about a dozen more elements may eventually be discovered or produced.

ACTIVITY 5 (x,y)

DISCOVERING THE CHEMICAL ELEMENTS

Purpose: To introduce the elements as the fundamental building blocks of matter

Concept to be developed: All matter is composed of one or more of the 103 chemical elements.

Materials needed:

Set of wood building-blocks and/or other types of construction toys in which a set of basic units is used to assemble a complex structure (Tinker Toys, Erector Set, Lincoln Logs, etc.)
Dictionary

INTRODUCTION: Discuss with the children how they have used blocks to make play buildings, or other construction toys to build some larger assembly. Encourage them to consider the idea that all of the many substances around them might similarly be made of simpler units. What examples can they suggest from their own observations in which simple units are made into a bigger structure? Lead them to suggest such examples as the use of bricks in a building, steps in a staircase, paving blocks in a walk, etc.

The possibilities of building up very many large and complex structures from a few units can be illustrated by the "alphabet-dictionary" analogy. Tell the children that the letters of the alphabet represent the elements, and the words represent combinations of elements (compounds and mixtures). Stretching the analogy a bit further, sentences, paragraphs, and all the printing in a book represent larger and more complex aggregations of matter to form visible objects, such as people, buildings, television sets, and, in fact, the world.

Display a large dictionary, unabridged if possible. Look up the number of words (usually given in a preface). Some interesting counting experiences can be developed. Have some children count the number of words on about ten pages, find the average number of words per page, and then multiply this figure by the number of pages in the dictionary. When some appreciation of this large number has developed, point out that all these different words are composed of the 26 letters of the alphabet. The many possible ways of arranging a small set of units to yield a large number of different combinations might also be discussed. Such mathematical concepts as combinations, permutations, and probability are basic tools used in describing the atomic nature of matter. Children can gain a worthwhile awareness of mathematical concepts through such an experience.

A similar analogy could be worked out with the notes of a musical scale. Ask the children if they can visualize how this could be done. Here, too, the eight notes of an octave can be arranged into a great many chords, musical phrases, and entire compositions. Have the children use a xylophone, recorder, piano, or other instrument to "hear the music" of the "substances" they can prepare by arranging the eight "elements" of the musical scale.

Extending Ideas: Plan an "element hunt" with the children. Ask them where they think they can find out what elements are, and where elements can be found. Tell them that the objective of the hunt is to collect as many elements as possible and find out about their properties and uses. (Almost any chemistry or physics text will have a full list of the elements.) Ask the children to find out the names of as many elements as possible, and list these on a large wall chart. Allow space for adding information about each element as the children find out about it. Which elements are found in nature? What are some uses of pure elements? What are the chemical symbols used by scientists for each element?

Some elements can be obtained in a more or less pure form around the home, school, or neighborhood: silver and copper in coins; carbon as charcoal; aluminum as foil; iron in tools; copper as wire; lead in plumbing pipe; sulfur from the drug store; mercury in a thermometer; some of the gaseous elements sealed in glass containers, such as neon and argon in bulbs and xenon in strobe photoflash tubes; and tungsten in the filament of an incandescent light bulb. (*Safety Note:* To collect tungsten from a bulb, wrap the bulb in several thicknesses of cloth, and then break the glass with a hammer or other object. Wrap the glass splinters and dispose of them carefully.)

ATOMS AND MOLECULES

Learnings: All substances and objects known to our senses are composed of one or more of the 103 chemical elements. Few elements are found in a free form; most combine to form more complex substances.

ACTIVITY 6 (y,z)

IDENTIFYING ELEMENTS BY THE FLAME TEST

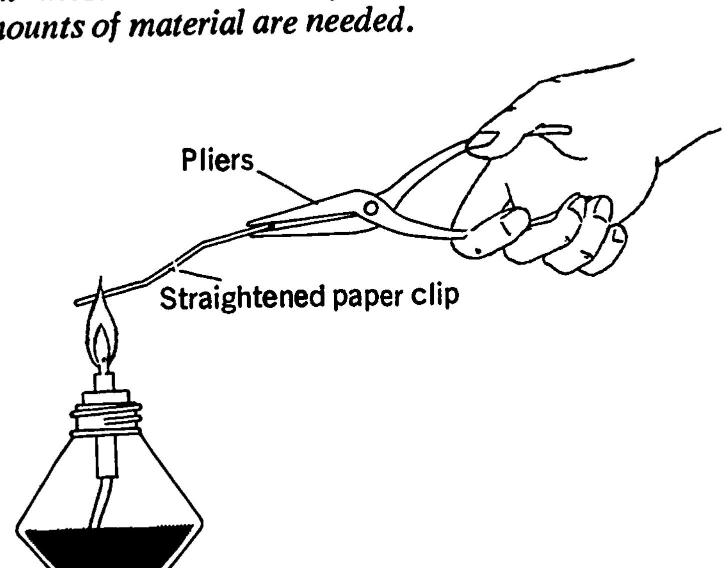
Purpose: To identify individual elements

Concept to be developed: Some elements, whether in an uncombined or combined state, give distinctive colors when heated in a flame.

Materials needed:

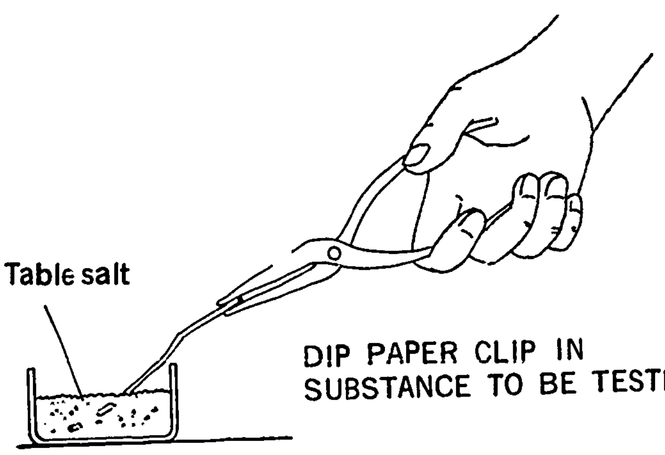
Table salt (sodium chloride)
Boric acid
Copper sulfate
Limewater (calcium hydroxide)
Other substances to test, such as lithium, strontium, or barium compounds (these may be obtained from the drugstore)
Portable propane torch
Bunsen burner, alcohol lamp, or can of Sterno fuel
Paper clips (steel)
Pliers

INTRODUCTION: Point out to children that it is possible to learn more about elements by testing them in various ways—by burning in a flame, by adding other things to them, and in other ways. By such techniques children can find out what elements a substance contains. For an example, mention that some elements have distinctive colors when heated in a flame, whether they are in a simple (uncombined) form or combined with other elements. For example, any substance containing sodium, such as table salt, will produce a bright yellow flame; boron in boric acid makes a green flame. Point out that these tests are very sensitive and only tiny amounts of material are needed.

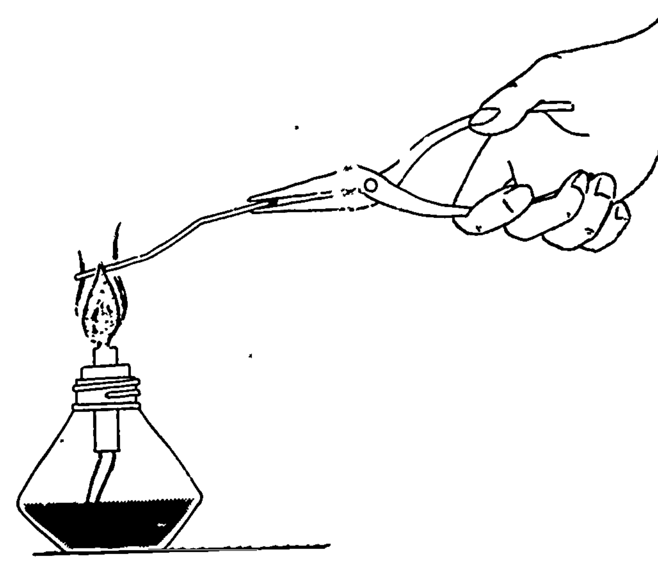


HOLDING A CLEAN PAPER CLIP IN THE FLAME PRODUCES NO COLORATION.

The flame tests are performed by dipping a straightened paper clip into the substance to be tested, and then holding it in the flame. Have



DIP PAPER CLIP IN SUBSTANCE TO BE TESTED.



SUBSTANCE ON PAPER CLIP COLORS THE FLAME.

the children use a pair of pliers or tongs to hold the clip. Be sure that a clean paper clip is held in the flame before each test to show that no color is produced until some particular substance is added. Have the children use a fresh clip for each test. A pinch of each powdered substance can be sprinkled into the flame to make the tests if extreme care is used. Have the children note the colors produced by each element. Their observations may be recorded on a chart similar to the one shown.

Substance Tested	Element Producing the Color	Color of Flame
table salt (sodium chloride)	sodium	bright yellow
boric acid	boron	green
copper sulfate	copper	emerald green
limewater (calcium hydroxide)	calcium	orange-red
lithium compounds	lithium	deep red
strontium compounds	strontium	red
barium compounds	barium	yellow-green

The children will find that only some of the elements produce colors when tested in a flame.

Point out that this is only one of the techniques a scientist might use to identify an element. Some children may wish to find out how small an amount of an element the flame test can detect. They may make up weaker and weaker solutions of table salt and test a drop from each.

Extending Ideas: How many substances contain sodium? How many contain other recognizable elements? Have the children try burning paper, washing soda, baking powder, eggshells, gypsum, and other substances of unknown composition to try to identify the elements in them.

Learnings: Some elements produce characteristic and identifying colors when heated in a flame. Flame tests are a simple means of identifying some elements.

ACTIVITY 7 (y)

PERFORMING THE TEST FOR IODINE

Purpose: To show one of the ways the element iodine can be detected

Concept to be developed: The reaction between starch and elemental iodine (that is, iodine not combined with any other element) produces a midnight-blue compound.

Materials needed:

Tincture of iodine
Cornstarch
Jars or drinking glasses
Water

INTRODUCTION: Mention to the children that some elements can be identified by their reaction with other elements or compounds. Iodine is an example of such an element, so is sulfur, and so is carbon. To see how this identification takes place, the children can perform this Activity and the two Activities that follow

To perform this Activity, the children will need two jars or drinking glasses, each filled with the same amount of water. A teaspoonful of cornstarch is added to only one of the jars. A few drops of tincture of iodine should now be added to each jar. Have the children note the color change in the jar containing starch. *(The starch solution turns dark blue.)* What happens in the other jar? *(Solution does not turn blue.)* Let the children use the jar containing the dark-blue solution as a comparison when they test other substances for iodine. Iodized salt and some sea foods may contain enough iodine to give a positive test.

Learning: When an unknown substance turns a starch solution midnight blue, it means the unknown contained the element iodine.

ACTIVITY 8 (y)

PERFORMING THE TEST FOR SULFUR

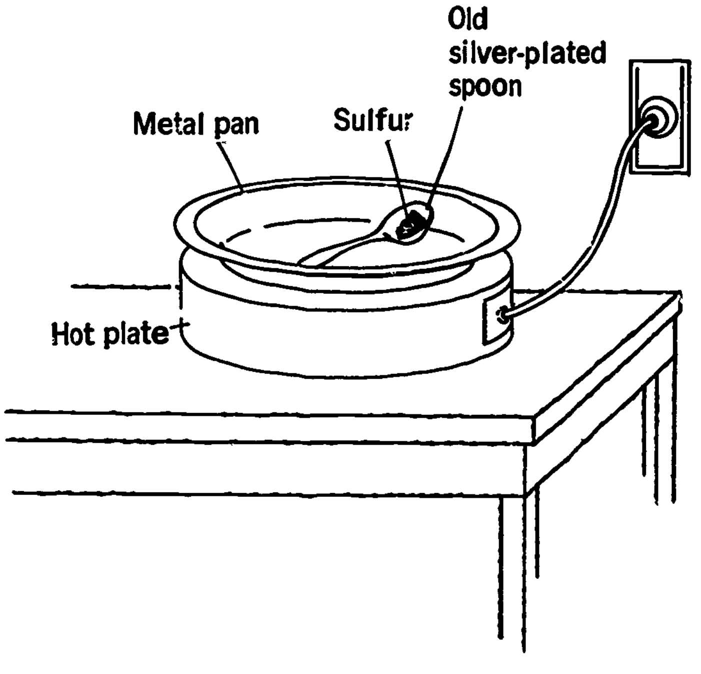
Purpose: To show one of the ways the element sulfur can be detected

Concept to be developed: The reaction between elemental sulfur and elemental silver produces a black compound.

Materials needed:

Sulfur
Plastic kitchen wrap
Piece of silver
Mustard
Eggs
Rubber bands
Electric hot plate
Pan
Silver polish

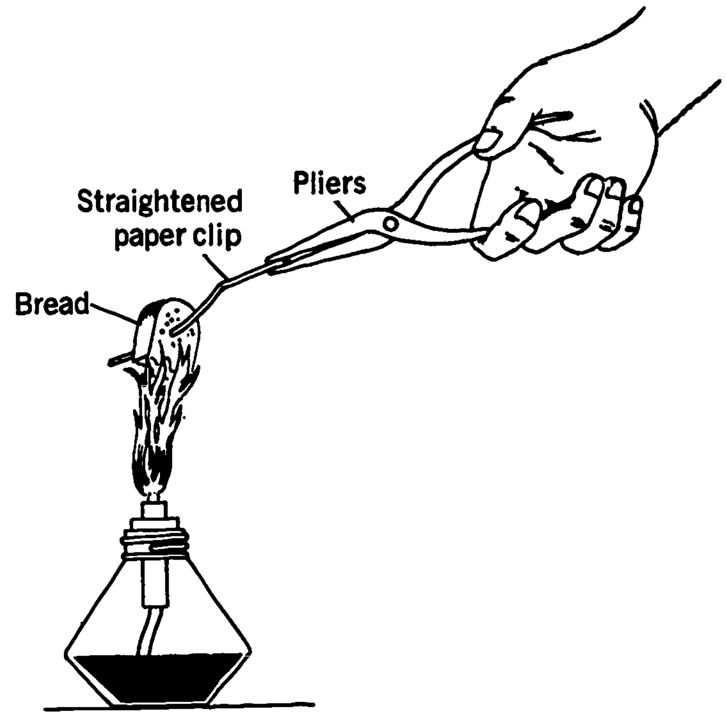
Have the children place a very small pinch of sulfur on a dime, quarter, or old piece of silverware. Put the coin into a pan, sulfur side up, and heat for 30 seconds over a hot plate or other heat source. What happens? *(The silver turns black.)*



Do this with another piece of silver without the sulfur and compare the results. What happens to the silver piece? *(Nothing.)* Have the children compare the color of the new substance with that of an untreated silver piece and with the sulfur. *(When silver comes into contact with sulfur, it is blackened by the formation of the black compound, silver sulfide.)* Try to remove the tarnish by washing and by using silver polish.

This tarnishing reaction can be used as a test for sulfur. Have the children place some food or other substance suspected of containing sulfur on some silver object. (Mustard, egg yolk, and rubber bands contain sulfur and can be used.) They should wrap the silver object and the sulfur-containing substance in plastic kitchen wrap so that it will not dry out. Another set of the same kinds of silver objects should be wrapped up, but without the sulfur-containing substance. These will serve as controls. Allow both sets to stand for several days, and observe them periodically for tarnishing. A variety of other materials should be tested for sulfur, such as butter, cheese, wax paper, salt, sugar, clay, wax. (Not all of these contain sulfur.) Have the children keep records of their findings.

Learning: When an unknown substance turns silver black, it means the unknown contained elemental sulfur.



IGNITING BREAD.

ACTIVITY 9 (y,z)

PERFORMING THE TEST FOR CARBON

Purpose: To show one of the ways the element carbon can be detected

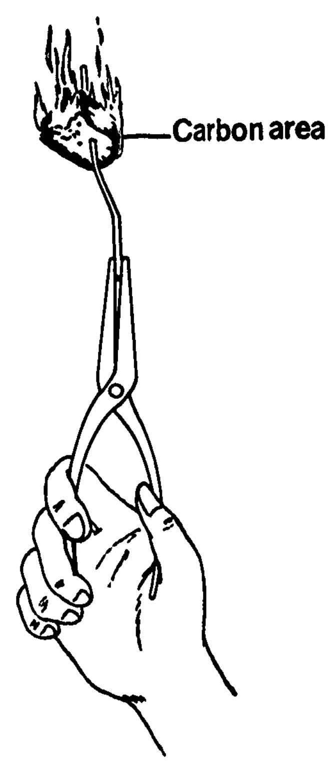
Concept to be developed: When a substance containing combined carbon is burned, some elemental carbon is left as a residue.

Materials needed:

Pencil lead
Coal
Charcoal
Candle
Paper
Bread
Walnut
Wood
Cotton cloth
Gas burner, alcohol lamp, or Sterno stove

Collect several samples of substances containing carbon, such as pencil lead (graphite), coal, charcoal, or the soot smudge from a candle flame on a piece of metal or a dish. Ask the children what characteristics these all have in common. *(They are black in color, have a slippery feeling, and make a mark on paper.)*

The children can test other materials for carbon, such as a small piece of wood, bread, walnut, paper, and cotton cloth, in the following way. Have a child place a small piece of the substance to be tested on a straightened paper clip, which is held with a pair of pliers. Burn the sample in the flame of a gas burner, alcohol lamp, or Sterno stove. What happens to the bread or the other materials burned? What color does it turn? *(Black.)* Now see if it makes marks on a piece of white paper. Is it the same color as the mark made with pencil lead? *(Yes.)* What kind of material is in the black mark? *(Carbon.)* Try all the materials listed. Children should discover that they all contain carbon. (*Note:* If a smoky yellow flame is used, carbon from the fuel used to make the flame may be deposited on the paper clip. This does not, of course, show that carbon is present in the bread, wood, or other substance being burned.)



BREAD BURNS, CARBON REMAINS.

Learnings: When a substance containing combined carbon is partially burned, elemental carbon is formed as a residue. This residue exhibits the properties of elemental carbon, that is, it leaves a black mark when rubbed on paper, has a slippery feeling, etc.

Summing Up Ideas: In this section the children were introduced to the idea that elements are the building blocks of matter, that is, that elements are the basic materials of which everything in the universe is composed. They also learned of some of the tests used to identify certain elements, such as the flame tests, the starch test for iodine, the test for sulfur using silver, and the test for carbon.

WHAT ARE MIXTURES AND COMPOUNDS?

When elements are combined, they can form either mixtures or compounds, depending upon the method used to combine them. If the combination does not involve a changing of the elements' properties, the result is a mixture. If the combination changes the properties of the elements, that is, if the result has a different set of properties, it is a compound.

Actually, mixtures may be combinations of elements and/or compounds. Typical mixtures are sugar and water, and salt and water, where the substances that have been combined retain their properties and can be easily separated.

Like the elements, most compounds show particular properties that are characteristic of the substance. Compounds therefore can be identified by their appearance or by performing certain tests. There are many compounds, such as sugar, salt, and water, that we can recognize because we are so familiar with their properties of taste, color, odor, form, and texture. However, we cannot be absolutely sure of the identity of such substances when we find them in an unfamiliar setting. It is most likely that a salty white powder in a container with holes in the top on the kitchen table is table salt, but the same substance in a jar on the teacher's desk is an "unknown" to the children. Besides, there are other white powders that taste salty besides salt. The chemist, as well, must test all substances before making a positive identification. Only if the "unknown" burns with a yellow flame, tastes salty, dissolves in water, forms crystals in the shape of little cubes, and shows some other characteristic properties will he feel confident about identifying it as sodium chloride, or table salt.

There are two ways to test a substance to see if it is made up of one element or of a combination of elements. (1) If the substance can be broken apart into two or more products, the original substance must have been complex, that is, a mixture or a compound. (2) If the substance can be built up from simpler units, then it must be complex. Both of these ideas are examined in the Activities that follow.

ACTIVITY 10 (y,z)

SEPARATING MIXTURES MECHANICALLY

Purpose: To discover that some mixtures may be separated mechanically

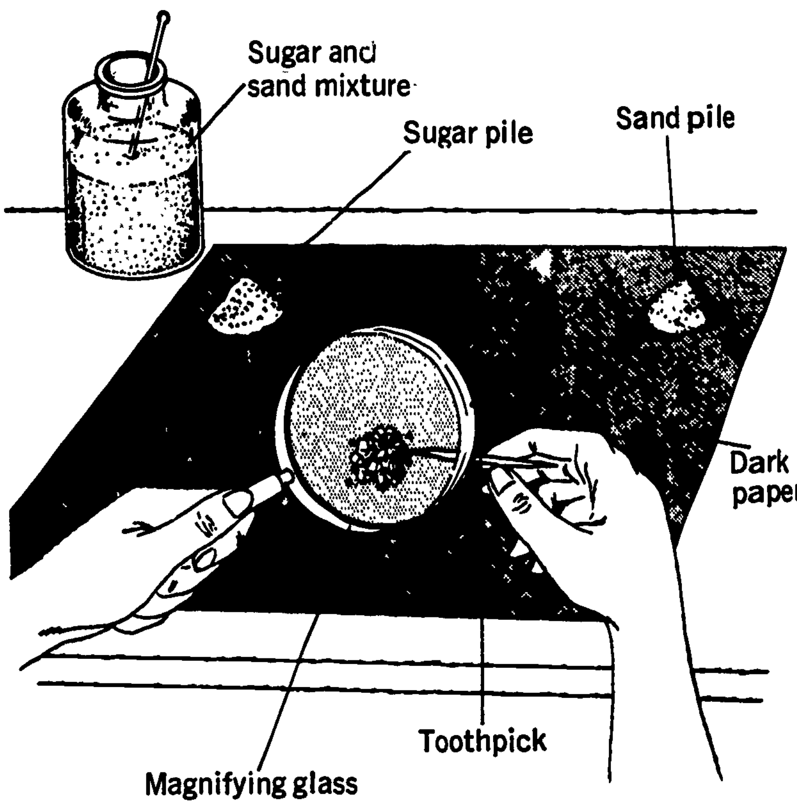
Concept to be developed: A mixture is merely an intermingling of the particles of two or more elements or compounds.

Materials needed:

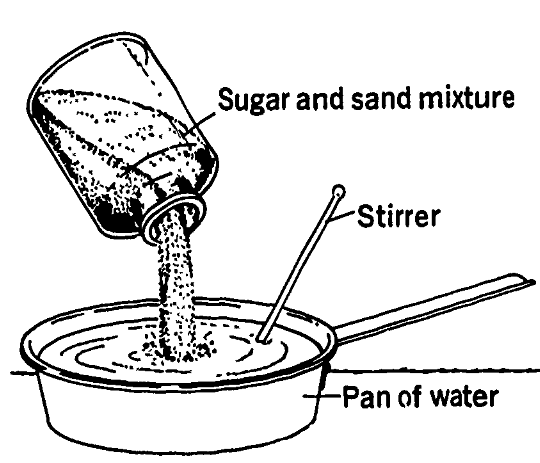
- Sugar
- Fine sand
- Jars or pans
- Iron filings
- Magnifiers
- Ink
- Soda pop
- Fruit juices
- Salt
- Toothpicks

INTRODUCTION: Bring out in preliminary discussion some information about mixtures and compounds. Emphasize that the difference between the two terms must be clearly understood in order to go on with the investigation of the properties of matter. Point out that in the past Activities the children have seen how the properties of various materials and elements differ. But how does one test a substance to find out whether it is an element or a mixture? Encourage the children's theories, and then proceed with the following Activity.

Have the children prepare a mixture of granulated sugar and fine sand by stirring equal amounts of each in a pan or glass jar. Distribute a small pinch of the mixture on a piece of dark-colored paper to each child and ask the child to examine it. Has a new substance been produced? *(No.)* Ask the class how the mixture might be separated so as to recover both ingredients. They may suggest picking apart the sand and sugar and separating the grains into two piles. If so, toothpicks and magnifying glasses will be useful, though not absolutely necessary.



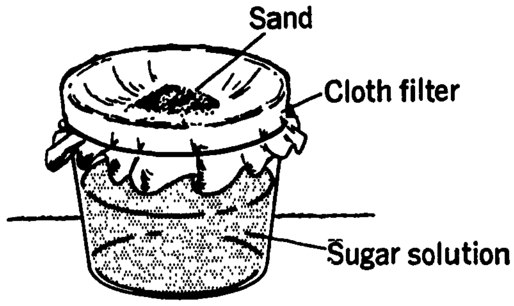
The children may suggest that another method would be to pour the mixture into water, stir it until all the sugar dissolves, and then filter out the sand through a cloth. The sugar solution may then be heated (or allowed to evaporate) in a flat dish to get the sugar back in its original form. Some of the sugar water may be given to a group of children so they can smell and taste it and watch it evaporate. Visible sugar crystals will appear in a few minutes. Have the children observe this process under a microscope if one is available.



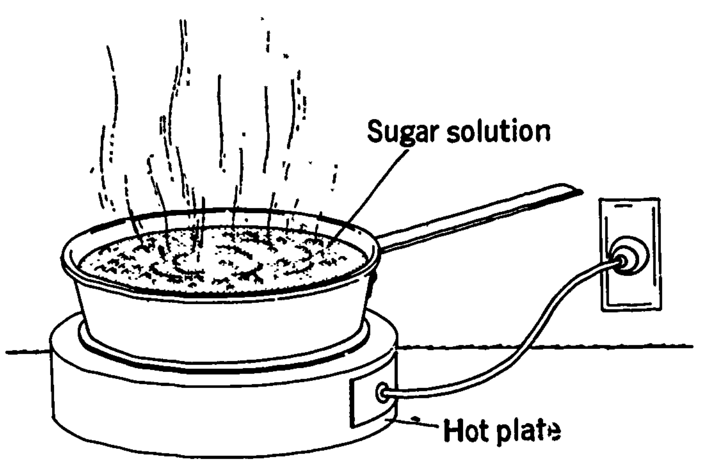
POUR THE MIXTURE INTO WATER AND STIR TO DISSOLVE THE SUGAR.

Extending Ideas: How would the children go about separating the ingredients of some other mixtures, such as a solution of salt in water? Have them try separating some of the ingredients in ink, soda pop, and fruit juices.

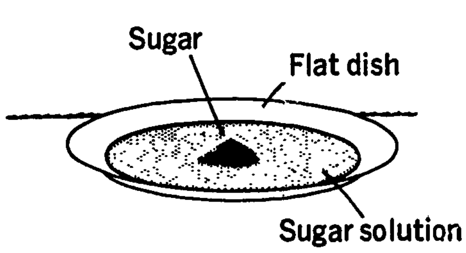
Another interesting mixture to separate is one made of fine iron filings and an equal quantity of sand, sugar, salt, or other powdered substance. What suggestions do the children have for separating these ingredients from each other? *(A magnet will be very useful.)*



POUR THE SOLUTION THROUGH A CLOTH TO FILTER OUT THE SAND.



BOIL OFF THE LIQUID TO RECOVER THE SOLID SUGAR OR...



...ALLOW THE SUGAR SOLUTION TO EVAPORATE.

Learnings: The combining of materials into a mixture does not involve the formation of a new substance. Some mixtures can be separated mechanically, that is, by nonchemical means.

ACTIVITY 11 (z)

SEPARATING MIXTURES BY CHROMATOGRAPHY

Purpose: To demonstrate another method by which mixtures can be separated

Concept to be developed: Chromatography is the technique of separating mixtures by allowing the mixture to seep through an adsorbent, such as paper, where each component is adsorbed at a different rate.

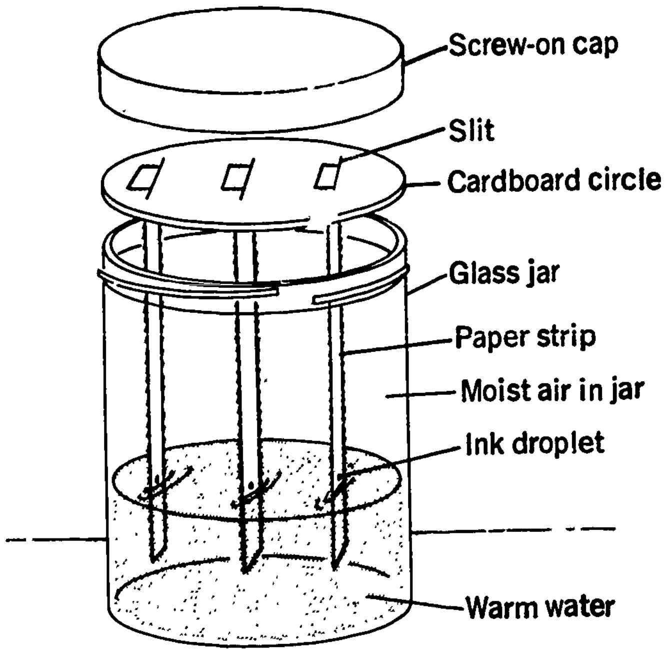
Materials needed:

Wide-mouthed jar with tight-fitting screw cap
Water
Cardboard circles
Facial tissues, newsprint, paper towels, or blotters
Cellophane tape
Various colored inks, tempera colors, and water paints
Various fruit and vegetable juices

INTRODUCT · Explain to the children that if a strip of adsorbent paper is suspended in a complex solution, the various substances of which the mixture is composed will move up the paper at different rates to form colored bands. Elicit children's theories as to why this might happen. Then explain that the rate of this movement depends upon several factors, two of which are the size and weight of the particles of the various substances. For example, a drop of black ink on a piece of facial tissue may appear as a black spot surrounded by green edges. If the paper is suspended in a jar of water, green bands will form above a black band. In a laboratory these strips would be cut apart to separate the bands, and each band would be analyzed. (Such techniques are beyond the scope of this book, but chromatography is an easy way to show that mixtures are made up of different substances.)

Explain to the class that the method works best if the adsorbent paper is suspended inside a closed container so that it is surrounded by moist air, and thus will not dry out. Mention to the children that this method is called chromatography. Put the term on the board and work out a definition with the children. Mention that many solutions can be used to demonstrate separability by chromatography, among them being inks, water colors and tempera paints, vegetable pigments (beet juice, mashed carrot, etc.), and food colors. Materials that may be used as adsorbent strips are facial tissues, clean newsprint, paper toweling, or blotters.

Using the mouth of the jar as a guide, have the children cut out circles of cardboard to serve as a support for the paper strips, and cut three slits in the circles. Then cut three strips of tissue paper (or towel, blotter, etc.) to a length that will touch the bottom of the jar when the strips are suspended. The upper end of each strip should be pushed into the slits in the cardboard, folded over, and held in place with cellophane tape. The circle carrying the strips can now be pressed into the screw cap.



To make the chromatograms, have the children pour warm water into the jar to a depth of one or two inches, and swirl it around to wet the walls and increase the amount of water vapor in the jar.

If the ingredients of different inks are being compared, one drop of black ink is put on one strip, one drop of blue ink on the second strip, and a drop of red ink on the third strip. The drops should be placed so that they are just above the water level when the paper is suspended from the cardboard circle that fits under the screw cap. The entire strip assembly is then lowered into the jar and the cover is screwed on tightly. Have the children make careful observations during the day. What happens as the water is adsorbed by the paper strips? *(It will travel upwards and carry with it the substances in the drops being tested. Since the substances differ in their rate of travel, they will separate and appear as bands of color along the strips.)*

Have the children experiment with different kinds of adsorbent paper to achieve the best results. Suggest that the children observe the chromatograms and answer the following questions: Do the similarly colored bands appear at the same level on different strips? *(Yes.)* What might this mean? *(That the same ingredient is present in different mixtures.)* If more than one band appears on a chromatographic strip, must the substance being tested be a mixture? *(Yes, because anything that is not a mixture will leave only a single band since all of its parts are of the same size and weight.)*

Extending Ideas: Ask the children whether the lower bands are composed of the larger, heavier ingredients or of the smaller, lighter ones? *(Larger, heavier ingredients.)* Will the darker-colored bands always be closer to the bottom of the strip than the lighter ones? *(Not always.)*

As a result of these Activities on making and separating mixtures, ask the children to give their ideas on what a mixture is like. Do the ingredients of a mixture change properties when they are mixed? *(No, most of the properties, such as taste, odor, and sometimes even form, remain.)* Are mixtures easy or difficult to separate? *(Most of those described here are easily made and separated, since they involved solutions—that is, liquid mixtures—or powdered dry solids. Some mixtures would be very difficult to separate, such as those made by dispersing two molten substances in one another and then allowing them to cool.)*

Learnings: Mixtures can be separated by using chromatography because their ingredients will be adsorbed at different rates to form bands of different colors. In mixtures, different substances are combined, but do not change most of their physical properties.

ACTIVITY 12 (x,y)

ILLUSTRATING CHEMICAL CHANGES

Purpose: To demonstrate that chemical change alters the properties of materials

Concept to be developed: A chemical change has taken place when a completely new substance, that is, one with different properties, is formed by the combination of two or more substances.

Materials needed:

Paper
Matches
Pan
Sand

INTRODUCTION: Explain to the children that in a compound, unlike a mixture, it is almost impossible to tell what elements are present merely from appearance. Could the children guess that the clear liquid, water, is a combination of two gases? Or that the same two colorless and tasteless gases are combined with carbon to form sweet, white, solid sugar? Point out to them that the appearance of such new properties is characteristic of a chemical change, *which occurs whenever a compound is formed or decomposed. Many other properties are affected when a substance undergoes chemical change, such as its odor, hardness, form, magnetic properties, and electrical conductivity.*

A piece of paper may be burned to produce smoke, ashes, charred fragments, light, and heat as an example of a chemical change. (*Safety Note:* Burn the paper in a dish or tray containing a layer of sand or other fireproof material. Have a bucket of water or a fire extinguisher on hand.)

Contrast this with tearing a piece of paper into bits as an example of a physical change. Ask the children to tell how these two changes in the paper are different. What differences do they notice in color, odor, and texture between the burned paper and the shredded paper? *(New properties have appeared after burning, but the torn paper still retains its identity as paper. Only the size of the pieces has changed.)* What kind of change takes place when sugar is dissolved in water? *(A physical change.)* How can the children tell? *(The sugar still retains its identity, as shown by the taste of the solution, and the sugar can easily be recovered by evaporating the water.)* What kind of change do they observe when milk sours? *(A chemical change.)* What evidence indicates this? *(New substances appear with new properties, such as curds and whey with assorted unpleasant odors.)*

Extending Ideas: Have the children consider other changes mentioned in this chapter, for example those dealing with iodine, sulfur, and carbon (Activities 7, 8, and 9). Are these chemical or physical changes? *(They are all chemical changes.)* How can the children tell? Have them discuss the physical properties of the components and the substances produced by each of the changes. You might also ask such questions as: Are chemical changes important to our welfare? What chemical changes does man produce to improve his welfare? *(Examples of cooking and the manufacture of materials for clothing and shelter, etc. can be pointed out.)* What chemical changes can they find occurring in nature? *(Suggest the growth and decay of animals and plants as an example.)*

Learnings: A chemical change has taken place when a completely new substance is formed by the combination of two or more substances.

Chemical changes are constantly occurring in nature, and many of these are of great significance to man.

ACTIVITY 13 (x,y)

MAKING A COMPOUND OF IRON AND OXYGEN

Purpose: To demonstrate how two elements can combine to form a compound

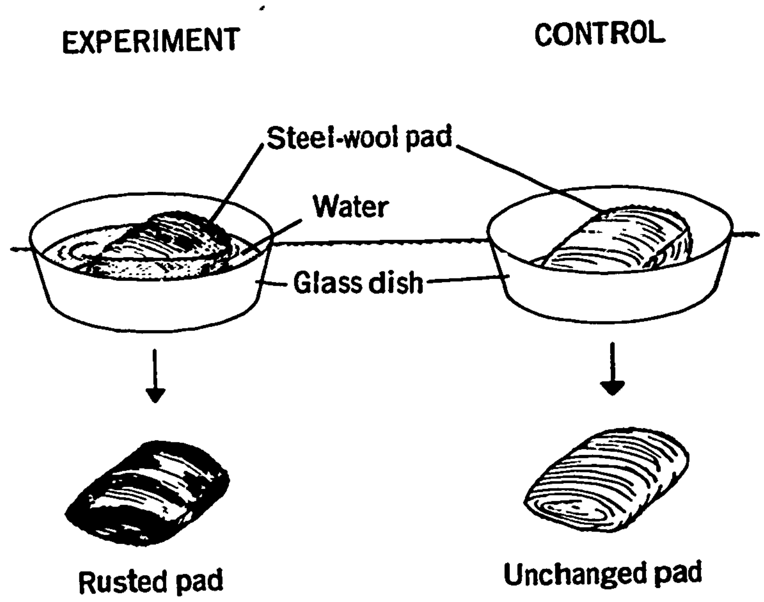
Concept to be developed: Iron and oxygen can combine to form red iron oxide.

Materials needed:

Steel-wool pads
Glass dishes
Tall jars

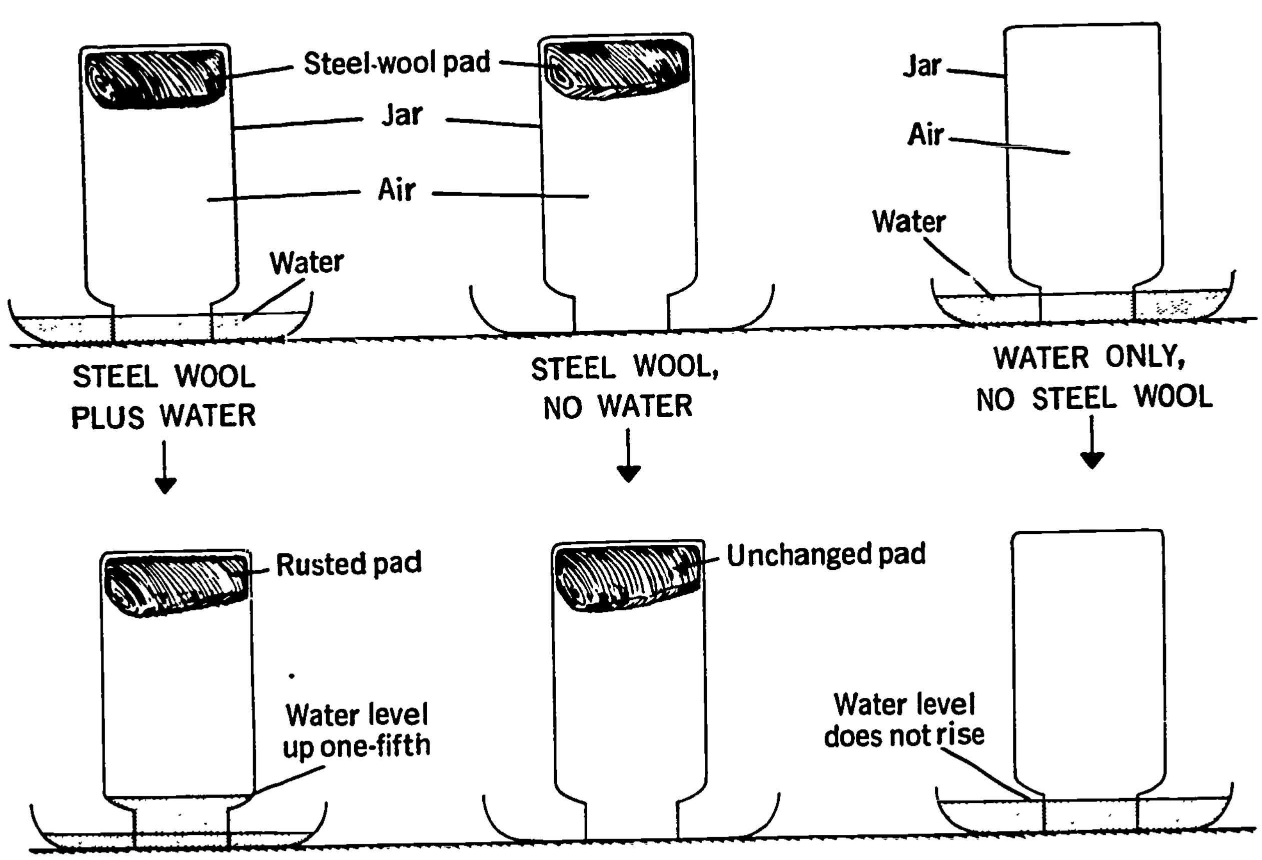
INTRODUCTION: Mention to the children that now they have studied some of the properties of elements and mixtures. Ask them to review what they learned about the definition of a compound. How are compounds formed? Is a physical change or a chemical change involved? The following Activity may answer their questions.

Point out to the children that steel-wool pads are made almost entirely of the element iron. Then have the children place a steel-wool pad in a dish of water so that it is half submerged. As a control, another pad should be placed in a dish containing no water. What do the children notice happening to the steel-wool pads over the period of a few days? *(The pad in the water will rust, but the dry one will not).* How does the appearance of the rusted pad differ from that of the unrusted steel wool? *(It differs in color, hardness, and texture).* Point out that these changes in properties show that a chemical change has taken place, for a new substance has appeared.



The iron in the steel wool and oxygen from the air have united to form the compound iron oxide, or rust.

Strictly speaking, it is not possible to tell from this Activity that it is oxygen that has combined with the iron to form rust. It is more accurate to conclude that something from the air, or perhaps from the water, has combined with the iron. However, the children can perform a refinement of this Activity which will provide them with more information about what takes place in the rusting of iron.



Have the children wet a pad of steel wool and wedge it loosely in the bottom of a tall jar. The jar should then be inverted and placed in a dish of water. A similar jar should be prepared and inverted in a dish with no water, and a third jar containing no steel wool should be inverted in a dish of water, these two acting as a control, or standard of comparison, for the series.

Have the children observe and compare each of the jars over the period of a week and try to explain what they see. *(In the jar containing the steel wool and placed over water, the water level will rise as the steel wool rusts. This occurs because the oxygen in the air inside the jar combines with the iron in the steel wool; this creates a lower pressure in the jar than the pressure outside in the surrounding air. The higher outside pressure pushes down on the water and forces some of it up into the jar.)* Does the jar fill up completely with water? *(Only partly.)*

Some children may wish to set up three or four jars containing steel wool over water to compare the height to which the water rises in each. They should discover that it will be about the same in each case; about one fifth of the jar will fill with water. Why might this be so? *(It indicates, but does not necessarily prove, that it is the oxygen in the air that has combined with the steel wool, since the proportion of oxygen in the air to other gases is about one fifth of any volume at the Earth's surface.)*

An interested child might be asked to make a brief report on the different kinds and amounts of gases in the atmosphere after consulting an encyclopedia or science text.

Extending Ideas: Ask the children to think of ways in which rusting might be prevented. The following question might be asked: How are iron and steel objects, such as bridges, fences, bicycles, and toys, protected from rusting? Let the children set up activities to test their ideas. Suggest that covering iron objects with some coating that excludes the air, such as petroleum jelly, paint, or oil, will work well. A steel-wool pad or some nails can be dipped in oil or painted, and placed on a wet sponge in a shallow dish of water, to test this idea. Be sure the children prepare, for comparison, a similar set of objects that have not been greased or painted.

Activity 8, in which silver and sulfur combine to form tarnish (silver sulfide), is another Activity they may wish to try to show the formation of a compound from two elements.

Learnings: Compounds are formed by the chemical combination of two or more substances. The properties of a compound are different from those of the substances that have combined to form it.

ACTIVITY 14 (x,y)

PERFORMING THE TEST FOR CARBON DIOXIDE

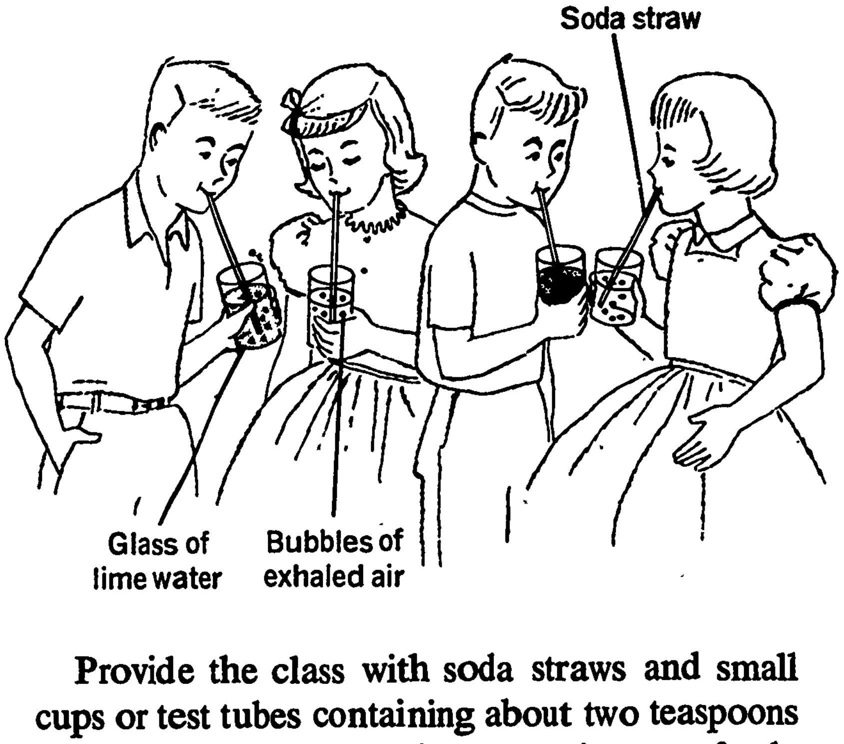
Purpose: To show one of the ways the compound carbon dioxide can be identified

Concept to be developed: Just as elements have specific properties that can be identified, so do compounds.

Materials needed:

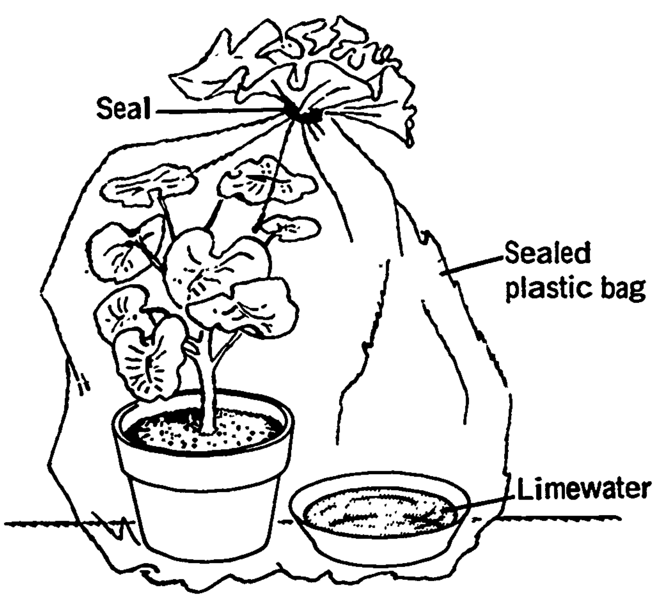
Limewater (obtainable from drugstore)
Soda straws
Paper cups or test tubes

INTRODUCTION: Point out to the children that compounds have specific properties that can be identified. For example, when carbon dioxide gas is mixed with limewater, a milky substance appears and settles to the bottom. This is the compound calcium carbonate, or precipitated chalk. Since carbon dioxide is the only odorless and colorless gas producing this result, the children may discover that it can be used as a test to identify the presence of the gas.



Provide the class with soda straws and small cups or test tubes containing about two teaspoons of limewater. *(Note:* Limewater is a perfectly harmless substance if swallowed. It was once widely used to provide additional calcium in the diet of children to prevent or treat rickets.) Have the children blow bubbles gently through the limewater. What changes do they see in the liquid? *(The carbon dioxide exhaled in breathing causes insoluble chalk to form, giving the water a milky appearance. If they continue blowing through the limewater, the cloudiness may disappear. This happens because an excess of carbon dioxide in the water forms carbonic acid, which dissolves the chalk.)*

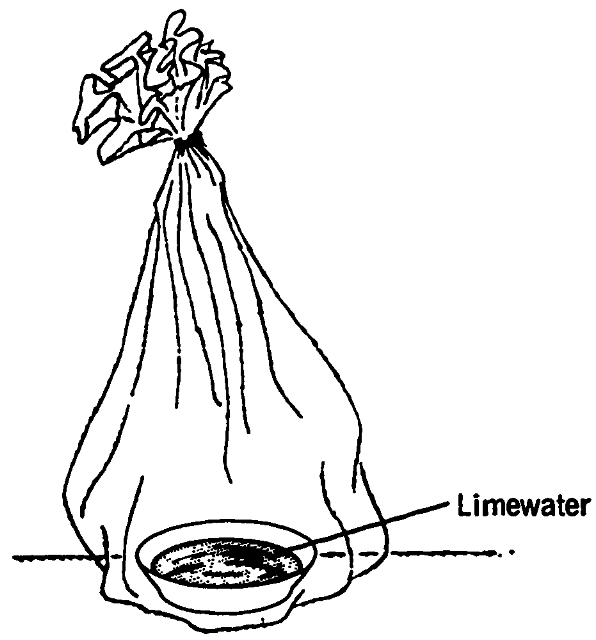
Let children discover what happens if a dish of limewater is left open to the air. Have them set up two dishes, one containing limewater and the other tap water, and observe these for a few days. The children will find that the limewater becomes clouded. Why? *(Because there is carbon dioxide in the atmosphere. For this reason, limewater should be stored in a tightly closed container that is kept full.)*



EXPERIMENT: POTTED PLANT AND LIMEWATER

Extending Ideas: Some children may wish to find out where the carbon dioxide in the air comes from.* Suggest that there are many sources, such as the burning of fuels, volcanic action, animal and plant respiration. An interested child may want to test for the production of carbon dioxide from these sources. For example, he can place a dish of limewater inside a sealed plastic bag containing a potted plant.

*For a further discussion of carbon dioxide in the atmosphere, see *The Earth*, by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).



CONTROL: LIMEWATER BUT NO PLANT

Learnings: Compounds have their own recognizable characteristics, just as elements do. One of the characteristics of carbon dioxide is that it reacts with limewater to form a white chalky substance that makes the limewater appear milky. This reaction with limewater can be used as a test for carbon dioxide.

ACTIVITY 15 (x,y)

PERFORMING THE TEST FOR WATER

Purpose: To show one of the ways the compound water can be identified

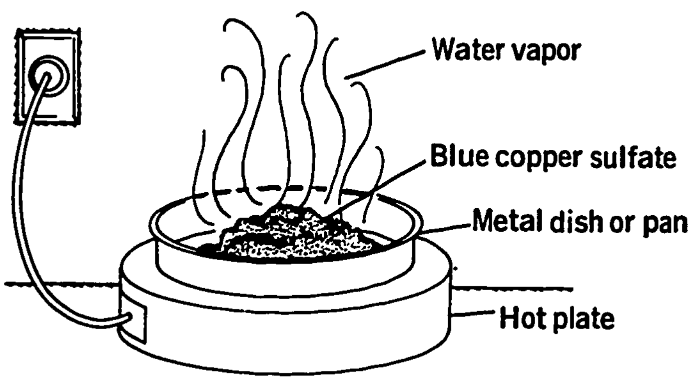
Concept to be developed: Just as elements have specific properties that can be identified, so do compounds.

Materials needed:

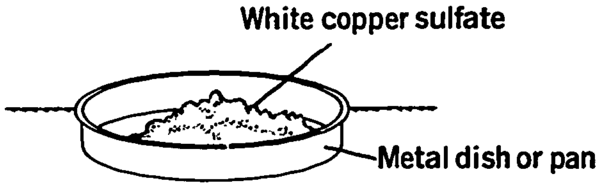
- Copper sulfate (**Safety Note:** Copper sulfate is a poisonous substance and should not be tasted. Have the children wash their hands after working with this compound.)
- Can
- Hot plate or other heat source
- Hardened plaster chips
- Paper scraps
- Chalk
- Wood scraps
- Shallow glass dish or plate
- Ice

INTRODUCTION: Point out to the children that, as they know, water is one of the most common and important substances on Earth. It is also a compound. Furthermore, many compounds such as wood, cereal grains, and plaster contain water even though they feel dry to the touch. Copper sulfate is another such compound. Moreover, copper sulfate is blue when it contains water and white when it does not. White copper sulfate can then be used *to test for the presence of water. If it cannot be bought in this white form, called anhydrous copper sulfate, it is easy to prepare from the blue form.*

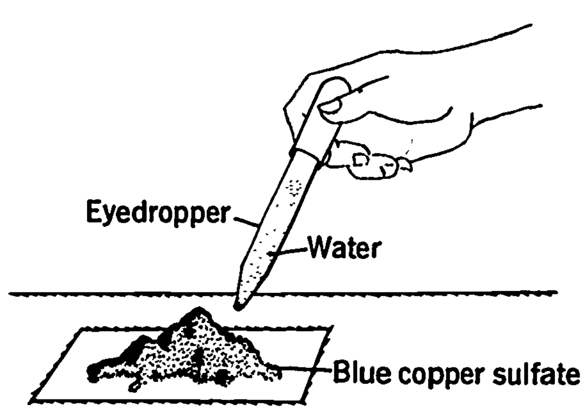
Place a teaspoonful of blue copper sulfate in a can and heat thoroughly. Its color will change to white as the water is driven off. Allow it to cool and store it in a tightly closed container.



HEATING BLUE COPPER SULFATE.

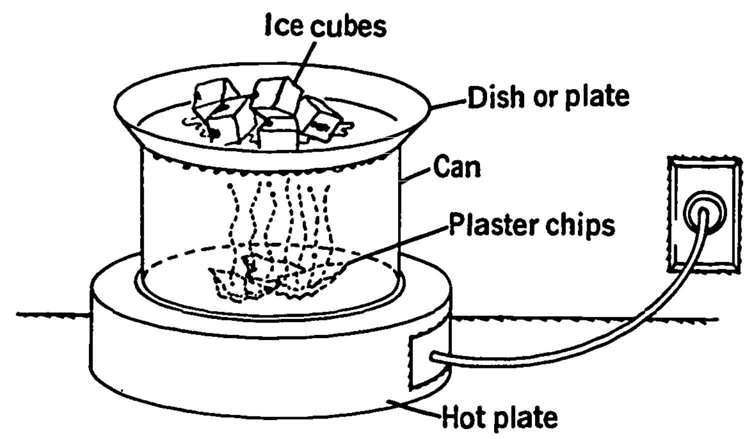


COPPER SULFATE TURNS WHITE AFTER WATER IS DRIVEN OFF.



WHITE COPPER SULFATE TURNS BLUE AFTER BEING WETTED.

Ask the children if they think there is water in the air. How can they tell? Leave some white copper sulfate in an open dish for several days and have the children watch it. What happens? *(It turns blue.)* Is there water in exhaled breath? *(Yes.)* How can the children find out? *(Have them breathe on a cold object, then place a pinch of white copper sulfate on it.)*



WATER VAPOR CONDENSES ON UNDERSIDE OF PLATE.

Since water is part of such materials as hardened plaster, wood, chalk, and cereal grains, when these substances are heated the water they contain will be driven off. If a cold plate is held above the heated materials, a mist of visible water will condense on the cold surface. Have the children arrange the equipment as shown in the illustration. Have them place some cereal flakes in the can and set it on the heat source. The cold glass plate is then placed over the top of the can. What do they see happening? *(Fine droplets of water will form on the underside of the plate).* They should repeat the same procedure with the other "dry" substances on the list, as well as with substances the children may suggest. Allow the glass plate to become cool again before the children try each substance, or have several plates on hand. An ice cube or two might be placed on the plate to keep it cool as it rests on the can over the heat source. Where did the water come from? How do the children know the liquid is water? Suggest using white copper sulfate as a test for water. Have them try the same procedure but without heating any substance in the can. Does water form on the plate? *(It does not; any water that appears can only have come from the "dry" substances.)*

What do the children find in the can after the substances have been thoroughly heated for a while? *(The paper, wood, and cereal will have become charred, showing the presence of carbon in them. Call attention to the familiar blackening and charring of food when it is burned.)*

Extending Ideas: There are many other tests that chemists can perform to find out what a substance is, but most of them are beyond the scope of this book. With some children, however, you may want to develop this topic further. One good source of information is the local pharmacist. He can supply materials that are used to test for the presence of several different compounds that are important in human diseases. One example is a specially treated paper or tablet used by diabetics. It will show the presence of simple sugar in a liquid by a color change. This test will not work for table sugar (sucrose), but will show the presence of the kinds of sugars found in fruit juices, milk, and other foods.

Learnings Some compounds can be identified by appropriate tests for their properties. Water can be identified by exposing white copper sulfate to the unknown—if the copper sulfate turns blue, the unknown substance contains water. Some apparently "dry" substances contain water.

ACTIVITY 16 (y,z)

DECOMPOSING A COMPOUND

Purpose: To show that a compound can be broken into its elements

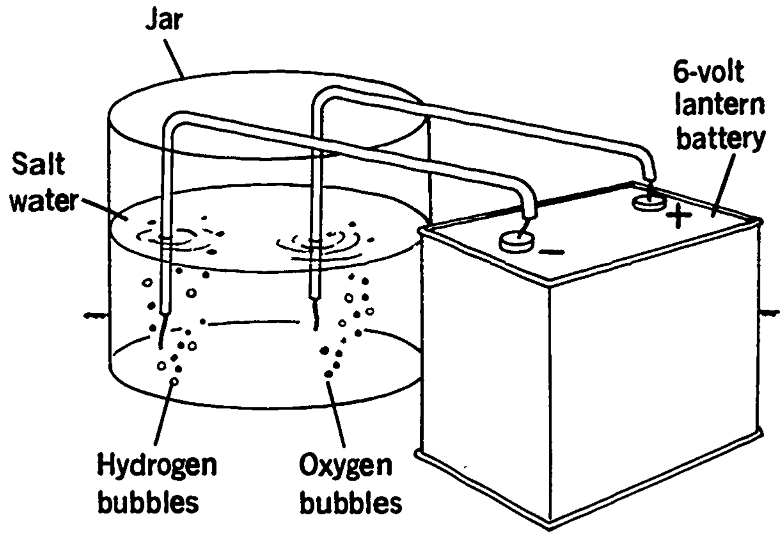
Concept to be developed: The decomposition of a compound into its elements is a chemical change.

Materials needed:

Salt water
6-volt lantern battery
Bell wire
Glass jar
Copper sulfate
Iron objects (tacks, nails, pins, paper clips)
Paper cups
Steel wool or sandpaper

INTRODUCTION: Explain to the children that electricity can be used to decompose some compounds. If a little table salt is added to a glass of water, the solution will be a better conductor of electricity than the pure water. An electric current will cause the water to decompose into the gases hydrogen and oxygen, which are the elements of which water is composed.

Have the children prepare two pieces of bell wire, each about 2 feet long. About 1 inch of the free ends of each wire should be stripped of insulation and scraped clean with the edge of a scissors or a knife. One wire is then attached to each post of the battery. The other end of each wire is now immersed in the salt water, and the current will begin to flow. What do the children notice happening? *(Bubbles of gas will rise up*



to the top of the water from each wire. If this does not happen, either the battery is too weak or there is not enough salt in the water and more must be added.) Have the children observe the bubbles very closely. Are there more bubbles coming from one wire than the other, or are there about equal amounts? *(About twice as many bubbles should be coming from the wire attached to the negative terminal of the battery as from the other wire.)* Ask the children to suggest an explanation for these bubbles and why they arise at different rates. *(They are bubbles of hydrogen and oxygen gas. Twice as much hydrogen is produced as oxygen, as might be expected from the formula for water—H_2O.)*

Here again, as in the case of iron and rust, this Activity suggests, but does not prove, that water is made of only two gases, nor does it show what these gases might be. However, this is a good occasion to point out the importance of research in the library. Write the word *electrolysis* on the board as the clue word to lead them to more information about the effects of electric current on water.

ACTIVITY 17 (z)

IDENTIFYING THE COMPONENTS OF AN UNKNOWN SUBSTANCE

Purpose: To use some of the methods of the analytical chemist in determining the composition of unknown substances

Concept to be developed: An unknown substance may be identified by finding out what its components are.

Materials needed:

All materials listed in the preceding Activities
Carbonated beverage

INTRODUCTION: As an example of how a complex mixture of substances is made up of simpler units, a carbonated beverage can be separated into its parts. However, the children should not be told what the sample is until they have made every effort to find out for themselves. It is essential that the beverage be transferred to a plain bottle or jar and labeled "UNKNOWN MIXTURE." Most soft drinks contain the same ingredients except for their flavoring. These are water, carbon dioxide, sugar, salt, and the various flavoring syrups. The following procedure will offer some guidance to the children in analyzing this "unknown" liquid. (Safety Note: *Do not ask the children to taste the "unknown." Although soft drinks are harmless, good safety practices demand that unknown materials not be tasted as they may be corrosive or poisonous.)*

Ask the children to describe and list the most obvious characteristics first, as follows:

Physical Properties:

1. What color is the liquid?
2. Does it have an odor?
3. Is it transparent, cloudy, or opaque?
4. Do you notice any other things about the liquid? *(Bubbles, for example.)*
5. Will the liquid boil? Have the children heat a sample of the unknown and a control sample of water in two different containers on the same hot plate. Do they both boil after the same amount of heating? (A wrist watch with a second hand may be used for the timing. The unknown may take a bit longer to boil since the boiling point of water is raised when a solid is dissolved in it.) How strong is this evidence that the unknown is, or contains, water? *(Suggestive, but not conclusive, since other liquids may have a boiling point near that of water.)*
6. Can the unknown be frozen in a refrigerator? Some children will enjoy carrying out this Activity at home if there is no refrigerator available in the school. Have them place a small paper cup about half-full of the unknown liquid in the freezer compartment of a refrigerator. Another cup filled with the same quantity of water should be placed alongside it as a control. The cups should be checked every 10 minutes to see if freezing occurs at about the same time for both. *(The unknown should take slightly longer to freeze, since it contains dissolved solids which will lower the freezing point of the mixture.)* When frozen, how are the two samples alike and different? *(Both will freeze to ice.)* How strong is this evidence that the unknown liquid contains water? *(It is very suggestive, but not yet conclusive; other liquids may have the same freezing point.)*
7. Will it conduct electricity? *(See Activity 16.)*
8. Is the sample a pure liquid or a solution? A few drops should be allowed to evaporate to dryness in a glass or porcelain dish. If some residue remains, the unknown contains dissolved solids. The children should compare this with the evaporation of the same amount of tap water.

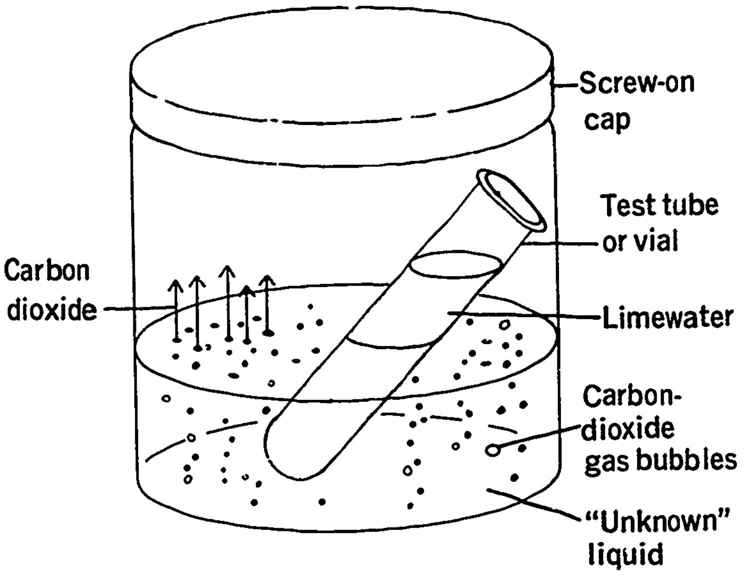
On the basis of these physical characteristics alone, can the children make some guesses as to what the unknown might be? *(Any such guesses must be considered hypotheses only, at this stage of the analysis, until confirmed by additional tests.)*

Chemical Properties:

1. Does the unknown burn? *(Since it does not burn, the unknown cannot contain a volatile liquid, such as oil or alcohol. Safety Note:* Following good safety practice, the children should place a small amount of the liquid in a dish before trying to ignite it.)
2. Examine the unknown for dissolved solids. The children can recover whatever solids are dissolved by heating about 2 ounces of the liquid in a pan until it boils and evaporates to dryness. What are the color, general appearance, and odor of the residue? *(It will be black, sticky, and smell like caramel.)* Have the children continue the heating and observe any further changes. *(In this case the residue contains mostly sugar, which will turn brown and then char with the characteristic odor of scorching sugar.)* As a control, they should dissolve some table sugar in water, heat in the same way, and note the similarities to the unknown liquid. *(The black color is a good indication that carbon is present, most likely as a component of sugar. See the test for carbon in Activity 9.)*
3. Is a gas dissolved in the liquid? A freshly opened bottle of pop will fizz; if the bottle is left open for more than a few hours, however, very few bubbles of gas will be seen. Suggest that the children stir or heat some of the liquid to see what happens. *(This will make it fizz slightly so that they can notice the presence of a gas.*

The gas in carbonated drinks is carbon dioxide, which can be identified by the limewater test. See Activity 14.)

If the unknown liquid is more or less transparent (ginger ale, lemon pop, etc.) the children can determine if the gas is carbon dioxide by mixing a few drops of the liquid with about an ounce of limewater. If the liquid is very dark in color, they should pour some into a wide-mouthed jar or drinking glass to a depth of one inch. Then,



a test tube, half-filled with limewater, should be lowered into the container. The whole assembly can then be sealed tightly by screwing the cap on the jar or placing the jar or glass inside a plastic bag. A similar set-up containing water instead of the unknown liquid should be prepared as a control. What do the children notice happening to the limewater as they observe this test over several hours? *(As the gas leaves the "unknown" liquid, it will react with the limewater to give it a cloudy appearance, indicating that the gas is carbon dioxide.)*

4. Does the liquid contain water? *(See the test for water, Activity 15.)* If the unknown liquid is more or less transparent, have the children add a few drops of it directly to white copper sulfate. What should happen if the liquid contains water? *(The white copper sulfate will turn blue.)* If the liquid is colored, how will the children be able to tell whether the copper sulfate changes color? *(The water will have to be separated from the mixture by boiling the mixture and condensing the vapor on a cold plate.)* Have them heat a sample of the liquid and test the droplets that condense with white copper sulfate.

5. What elements does the liquid contain? *(See the flame tests in Activity 6.)* Have the children dip a cleaned, straightened paper clip in the liquid and hold it in a flame. Does the flame glow with any particular color? *(Since salt is present in many carbonated drinks, the flame should burn with a yellow color, showing that a sodium compound is present.)* Do they think this test positively proves that salt is present? *(It does not, since all sodium compounds show a yellow flame, and a true unknown liquid may contain any of them. In soft drinks, however, sodium chloride, or table salt, is the sodium compound that is most likely to be found.)* How can they find out definitely which sodium compound is in the unknown liquid? *(This may be a good point at which to suggest that they consider all of their findings, and to list their ideas of what the unknown liquid is.)*

Learning: Unknown compounds are identified by analyzing them and identifying their components.

Summing Up Ideas: In this section the children learned about mixtures and compounds. They learned how compounds and mixtures can be broken apart into simpler components, and sometimes down to the elements of which they are composed. They have had some experiences with building up compounds and mixtures from the elements. They also learned some of the tests that are used in the identification of compounds.

IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the ideas with the most meaning or application are:

- There is a vast variety of materials in nature.
- The physical properties of different materials, such as their color, odor, taste, luster, form, texture, magnetism, strength, and hardness, vary.
- All matter is composed of one or more of the 103 chemical elements.
- Iodine turns a starch solution dark blue in color; this is the test for iodine.
- Silver and sulfur combine to form a black compound, silver sulfide.
- A mixture is the intermingling of the particles of two or more elements or compounds.
- A chemical change alters the properties of the substances involved in the change.
- The properties of a compound are different from those of its components.
- Compounds are formed by chemical change.

In the intermediate and upper grades the children should be led to develop concepts that are more complex and quantitative:

- Materials vary in their ability to conduct electricity; in general, metals are better conductors than nonmetals.
- The greater the conductivity of a material, the greater the quantity of electricity that can pass through it in any given time.
- The specific gravity of a substance is the ratio of its weight to that of an equal volume of water.
- Some elements, whether in a combined or uncombined state, give distinctive colors when heated in a flame.
- When a substance containing combined carbon is burned, some elemental carbon is left as a residue.
- Chromatography is the technique of separating mixtures by allowing the mixture to seep through an adsorbent, such as paper, where each component is adsorbed at a different rate.

3

INVESTIGATING THE ATOMIC THEORY

Many of the questions children ask involve the atomic theory of matter:

"What's the smallest piece of anything?"

"Why can't I see the salt in sea water?"

"Why do all the quartz crystals in my rock have the same shape?"

"How does water disappear from rain puddles?"

"Can you see atoms with a microscope?"

"If the world is made of elements, what are the elements made of?"

A good explanation of these phenomena is given by the atomic theory of matter. Literally millions of seemingly unrelated facts can be understood as examples of this broad general principle. The idea that matter is made up of small moving particles called atoms and molecules is perhaps the most fundamental and far-ranging concept of science.

Some of the evidence for this theory is developed through the Activities in this chapter. Answers to the questions given above can evolve out of experiences in which children make solutions, grow crystals, prepare compounds, and observe substances evaporate, condense, melt, boil, and freeze.

The first Activity with atomism is similar to that described by the Roman poet-philosopher Lucretius:

> Water dripping from the eaves hollows a stone; the bent plowshare of iron imperceptibly decreases in the fields. . . . These things then we see are lessened . . . but what bodies depart at any given time the nature of vision has jealously shut out of our seeing. . . . Nature therefore works by unseen bodies.

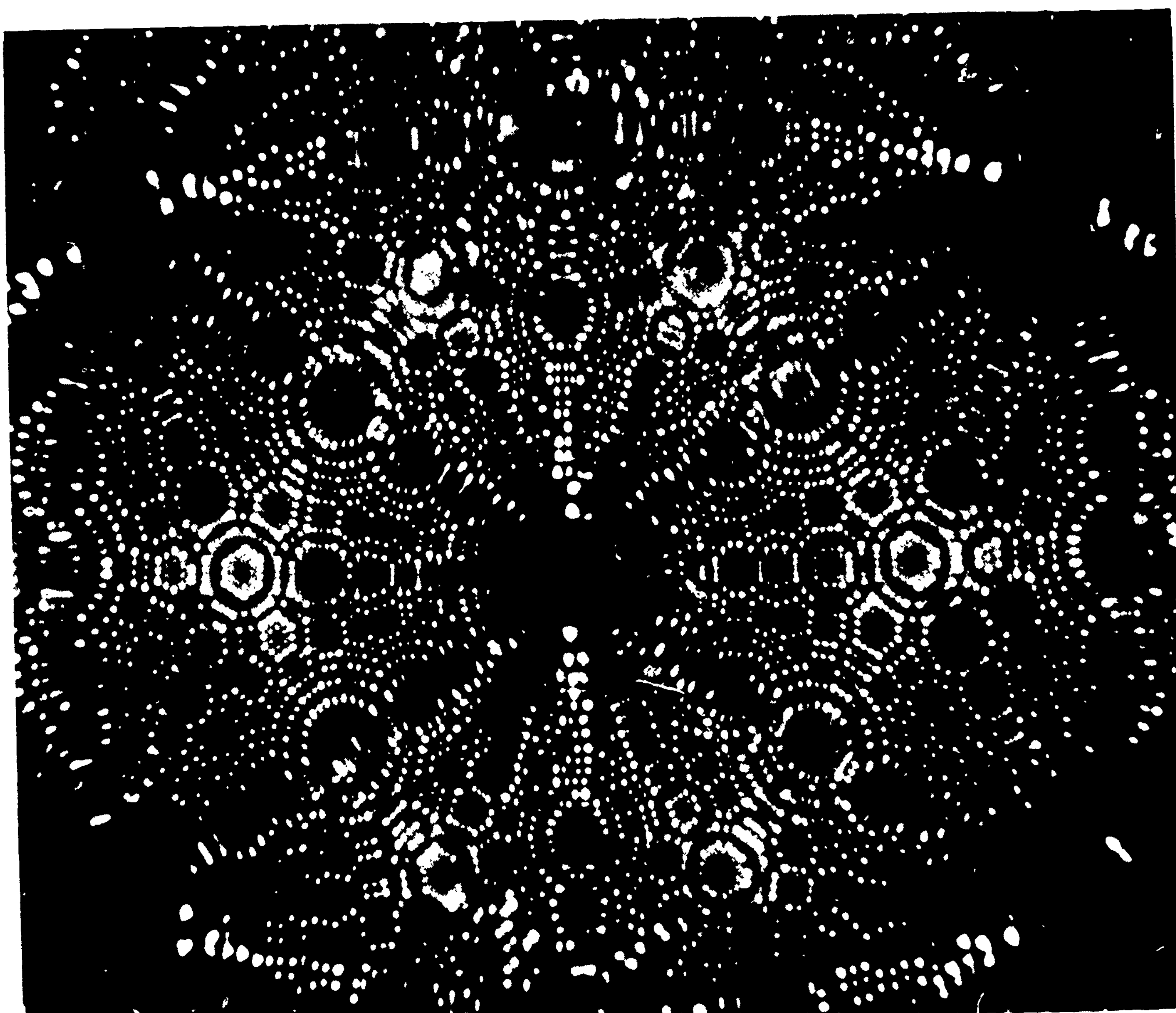
The observations of other everyday experiences, as presented here, can help children make similar commonsense interpretations about the behavior of various substances leading to an understanding of the particulate nature of matter. For example, the experiences in which liquids and solids seem to appear and disappear as they condense out of vapors or evaporate into the air can be understood as the coming together and separation of bits of matter too small to be visible individually.

As in Chapter 2, the approach taken is a commonsense, naked-eye observation of familiar materials and processes to help children consider what they see as being due to the behavior of large numbers of extremely small particles—atoms and molecules. Atoms are so small that none have ever been directly seen or directly measured. For this reason, the atomic theory is based almost entirely on indirect evidence. In this chapter, examples of this evidence are presented to support the idea that matter is made of atoms, or is particulate in nature. This idea is based on a line of reasoning first proposed by the ancient Greeks when they asked: What is the smallest bit of a substance? The elements, of which all matter is composed, are either infinitely divisible substances, or are, ultimately, particles that cannot themselves be divided. Many observations of the behavior of matter support the latter view that matter is ultimately made of indivisible particles, which these Greeks named atoms. We know today that atoms can be split in nuclear bombs and reactors, but not through ordinary chemical means. Apart from this most important exception, the more commonplace behavior of matter indicates the existence of atoms, and reveals some of their properties.

The first example of indirect evidence is that substances can be divided into smaller and smaller pieces. If a piece of iron or a sample of oxygen were halved over and over again in an imaginary experiment, there would finally remain one last tiny particle. It would be an atom of iron or an atom of oxygen. In theory at least, these atoms would still show some of their characteristic properties. The iron atom would be magnetic, or several iron and oxygen atoms could combine, or bond to each other, to form one particle of iron oxide, or rust. Actually, at the level of one atom, many of the physical properties of a substance have no meaning. Single atoms do not have color, nor are they solids or liquids; these are characteristics of large masses of atoms. Any visible sample of an element is composed of great numbers of its own kind of atoms.

Compounds are combinations of the atoms of different elements. They, too, can be theoretically divided and subdivided to a single smallest bit of the compound. This particle is called a molecule. However, if a molecule is taken apart any further, the compound loses its identity as a substance that is different from the elements making it up. For instance, when sugar is strongly heated it will decompose into elemental carbon and the compound water.

Indirect evidence for the existence of atoms and molecules is also given by such familiar processes as dissolving sugar in water, or the condensation of water vapor in the air to form rain. In the first case a visible substance seems to disappear in the water, yet it can still be tasted. The seen has become unseen. A reasonable explanation is that the compound sugar has divided into particles too tiny to be seen, that is, molecules. In the case of rain, invisible water-vapor molecules collect in sufficiently large numbers to become visible as raindrops. Here the unseen has become visible. Further evidence for the



Muller Field Ion Micrograph shows a tungsten cryst. magnified 2,700,000 times.

existence of atoms and molecules is provided by the formation of crystals from dissolved substances. In this process, regular geometric forms of the substance grow in a solution of some compound. The shape of a crystal seems to be due to the piling up of discrete invisible bits of the substance to form a regular structure.

Atoms and most molecules are indeed extremely small. On the average, an atom is about one hundred-millionth of an inch in diameter. There must be, therefore, billions of atoms in even a tiny speck of visible matter. Some idea of the very small sizes of atoms and molecules and their very large numbers in a sample of matter can be gained by dissolving certain substances in water. The color or taste of these compounds makes it possible to detect them even when diluted to many times less than their original concentration. A strong-tasting substance such as quinine can be detected even when there is only one part of the drug in 15 million parts of water! A molecule of quinine must, therefore, be smaller than one 15-millionth of a drop of water.

Much finer techniques or instruments are necessary to see or detect smaller particles. One such instrument is the Muller Field Ion Microscope. The accompanying photograph shows a crystal of the element tungsten magnified 2,700,000 times. (By comparison, a housefly magnified this many times would be about 12 miles long.) Each luminous spot seen in the photograph is a "shadow" cast on a screen by an individual atom.

It is on this kind of indirect but significant evidence that the atomic theory of matter is based. Indeed, since the idea of atoms was first conceived, all subsequent knowledge has supported the belief that atoms do in fact exist. Yet the Activities in this chapter should be developed as examples of how scientists evolve theories from observations to understand the world around them, *not* to prove that the atomic theory is the best final interpretation that will ever be made of the nature of matter.

WHAT ARE ELEMENTS AND COMPOUNDS MADE OF?

After learning that all substances are made of the chemical elements (Chapter 2), many children will wonder what the elements themselves may be made of. The following Activities will introduce them to the concept of the particulate nature of matter and the existence of atoms and molecules.

ACTIVITY 18 (x,y,z)

DISCOVERING THE PARTICULATE NATURE OF ELEMENTS

Purpose: To introduce the concept of atoms

Concept to be developed: The elements are composed of very small particles called atoms.

Materials needed:

Piece of sulfur
Stranded iron wire
Magnet
Scissors
Knife

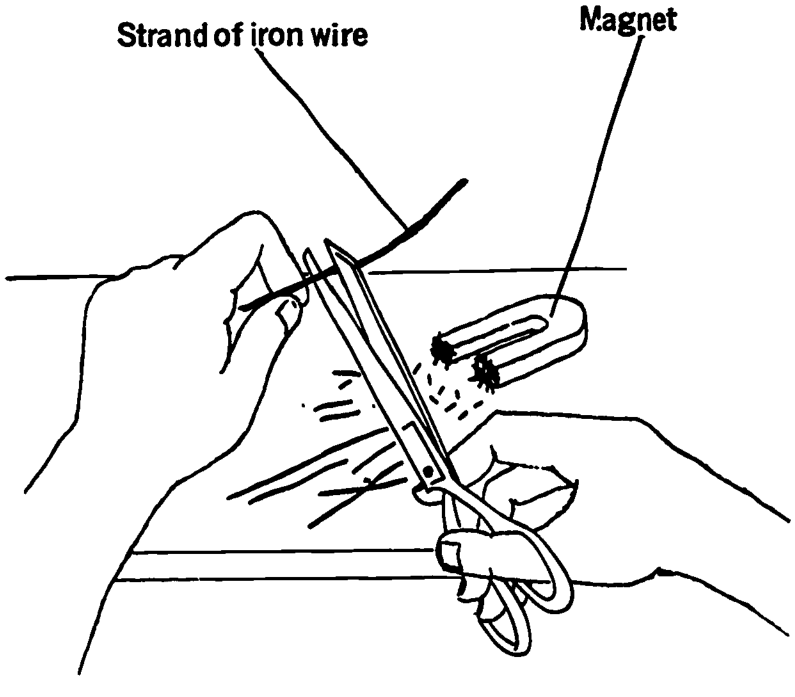
INTRODUCTION: Review with the children the concept that all matter is made of the chemical elements. Ask if anyone knows what the elements are made of. Help the children to discover the significance of the following clue.

Long ago it was noticed that substances such as the stone steps of a staircase could be worn away and hollowed out by the many years of hard usage. Yet no one could ever see the stone being removed. Ask the children to mention places they

know of which show wear. Perhaps they will think of stone or wooden steps, handrails where the paint has been rubbed off, spots on spoons and forks where the silver plating has worn off, bicycle tires, or the heels and soles of shoes. Discuss with them possible explanations of this wearing away. One might be that the material has been rubbed off these objects in very tiny bits, bits too small to see.

Have the children break the piece of sulfur in half. Put aside one of the halves. Break the other half in two and put aside one of these pieces. Continue this process until only a tiny speck remains. When the speck of sulfur is so small that it is impossible to break or cut with a knife, suggest that the children continue the breaking process in their imaginations. Ask them how far they think this process can be carried on. Bring out that eventually they will reach a small particle that is the limit of this breaking process. This particle is so tiny that if broken again (if this were possible) the fragment would no longer be an atom of sulfur. This process will illustrate to them the idea that matter is made of particles. Have them become familiar with the phrase, "the particulate nature of matter." Have them check the dictionary for the meaning of "particulate," after they have surmised its meaning on their own.

Continue this discussion by following the same procedure with a piece of stranded picture wire. This wire is usually made of fine iron or steel strands. Have the children untwist the wire and remove one of the strands. They should then test the



wire with a magnet to see if it is attracted. With scissors, cut the strand in half and test it with a magnet. Continue the halving and cutting process as far as possible. Show that even the smallest bit is still attracted to the magnet. (This bit of iron wire is still far bigger than any single atom of iron, but carrying on the halving process in the imagination helps the children visualize the possibility of arriving at a single atom of iron, or conversely, that there are many atoms, or particles, in a small piece of an element.) Ask what would happen if this smallest bit were halved. Would the resultant pieces still be iron? *(No.)* Bring out the fact that this smallest bit *that still retains the properties of the element* is called an atom.

Learnings: An element is particulate in nature, that is, it is composed of tiny bits, or particles, that have all the properties of the element. The smallest particle that still has these properties is called an atom.

ACTIVITY 19 (x,y,z)

DISCOVERING THE PARTICULATE NATURE OF COMPOUNDS

Purpose: To introduce the concept of molecules

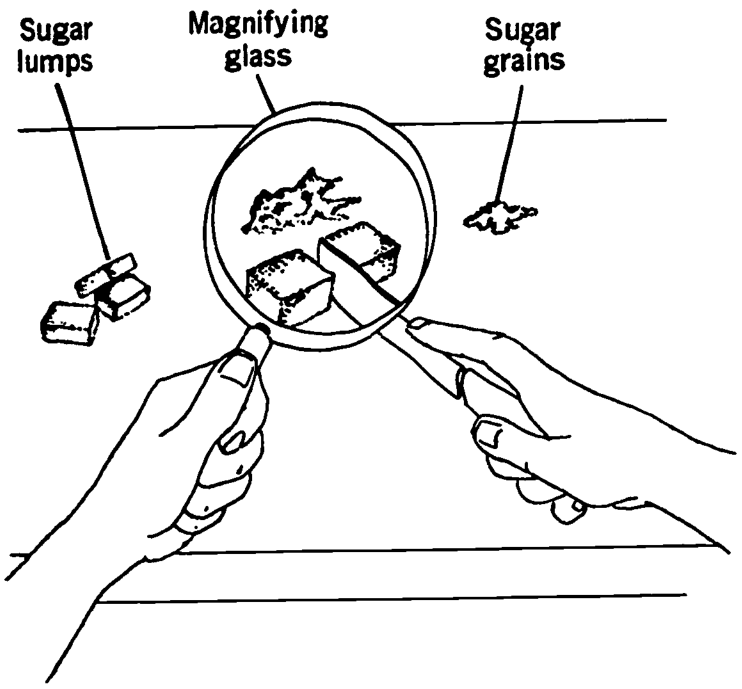
Concept to be developed: Compounds are composed of very small particles called molecules.

Materials needed:

Lump sugar
Water
Magnifying glass
Perfume atomizer or spray pump
Tall jar
Knife
Single-edge razor blade

INTRODUCTION: The children have already learned that substances composed of more than one element are compounds. Explain to them now that the smallest theoretical unit of a compound, composed of two or more atoms, is known as a molecule. The same demonstration used above, to indicate that an element is divisible into atoms, may be used to show that a compound can be reduced to its smallest particles—molecules.

Have the children break a lump of sugar in half and discard one piece. They should continue this subdividing process as far as possible with the remaining half. Suggest that they use such tools as a knife, then a razor blade. Smaller pieces of sugar may be put on a background of black paper to improve visibility, and may be viewed under a magnifying glass. Soon the speck of sugar will be too small to cut any further. Suggest to the class that this process be continued in their imaginations until only a very tiny bit of sugar is left. Point out to the children that this bit, the smallest



particle that still has the properties of sugar, is called a molecule. Ask the children what they think they would find if they divided this molecule. *(Since compounds are made of elements, and elements are made of atoms, molecules must be made up of atoms.)*

Next, suggest that water is another compound that can be divided to show that it is made of small particles. Water can be halved by filling a tall jar and pouring out half of it. Then pour out half of what is left, and continue this process as far as possible. To get water into even smaller particles, put some into a perfume atomizer or spray pump. Pump a fine spray of water into the air. Point out the very small size of the individual water droplets. Direct the spray at the chalkboard to show that the fine droplets in the mist recombine to form big drops of water.

Learnings: Compounds are particulate in nature, that is, each one is composed of tiny particles that have all the properties of the compound. The smallest particle that still has these properties is called a molecule. If a molecule is reduced still further, it will be found to consist of the atoms of the elements that are the components of the compound.

ACTIVITY 20 (x,y)

MAKING AN OIL AND WATER EMULSION

Purpose: To emphasize the particulate nature of matter in liquids

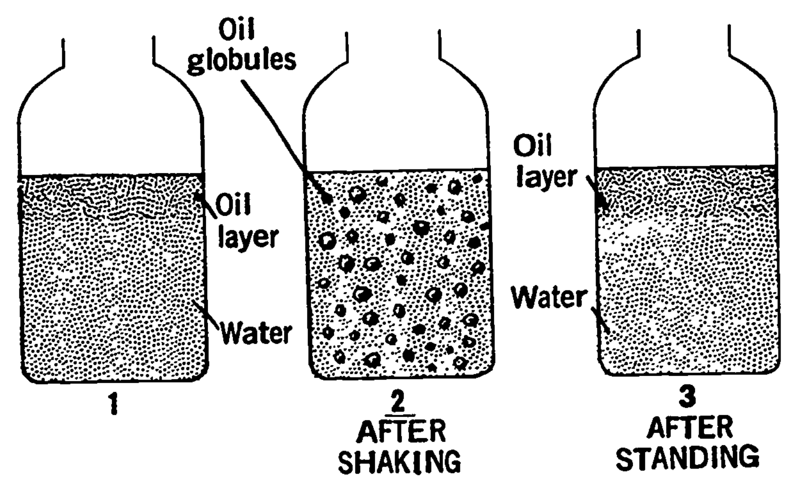
Concept to be developed: All matter is composed of tiny particles — atoms and molecules.

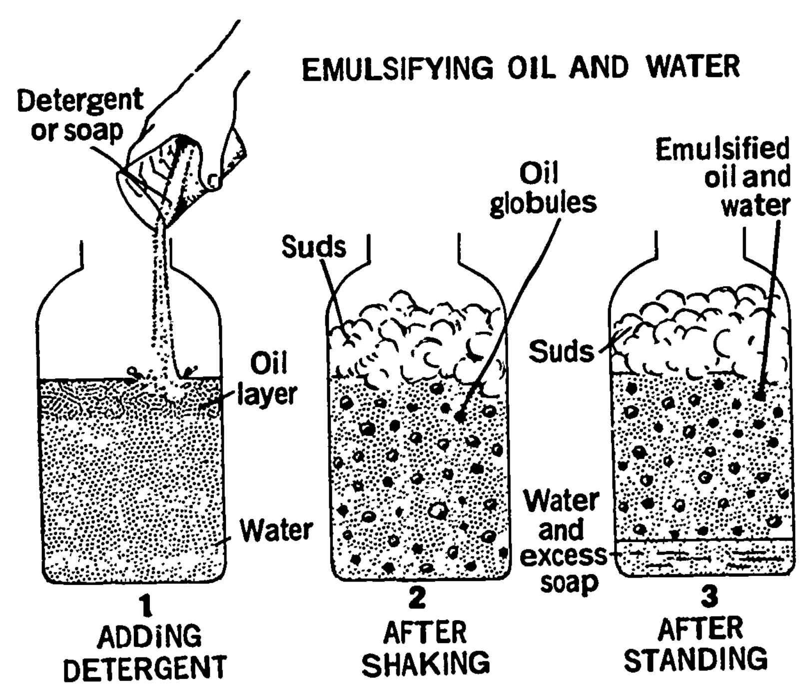
Materials needed:

2 one-quart milk bottles or glass jars
Olive oil or other cooking oil
Water
Low-sudsing detergent or soap
Microscope

INTRODUCTION: Point out to the children that the cutting of matter into the smallest possible bits soon reaches a point where tools and fingers can no longer be used. Although the grains of sugar or sulfur that were used in the preceding Activities can be cut into very tiny pieces, they would have to be further reduced in size many millions of times to become the size of a molecule or an atom. Suggest that other techniques and processes, however, make it possible to reduce these bits of matter to microscopic and even molecular dimensions. For example, fats and oils will separate into a distinct layer when we try to mix them with water. But they can be made to stay mixed by adding a substance that prevents the individual oil globules from flowing together. (In such a mixture, called an emulsion, the droplets of oil are microscopic in size.) Elicit children's theories as to how this might be possible and what kind of substance it would have to be. The children can perform the following Activity to see how this works.

OIL AND WATER DO NOT STAY MIXED





Have the children fill a bottle or jar about half-full of water and add about an ounce of cooking oil to it. Point out the two separate layers of oil and water. Can the children suggest how they might be mixed more intimately? If not, have a child hold his hand tightly over the bottle, or screw the cover on the jar, and shake the contents vigorously. What do the children see? *(The oil is broken into tiny globules and distributed throughout the water.)* Allow the mixture to stand for at least five minutes. What happens to the mixture now? *(The oil globules fuse together and float to the top of the water to form a layer just as at the start.)* Set this jar aside for use in comparing with another demonstration in which a detergent will change this behavior of water and oil.

Have the children prepare another bottle or jar with the same amounts of water and oil. Add a capful of a laundry or dishwashing detergent. Ask a child to shake this mixture vigorously, and have the class compare it with the first bottle in which no detergent was used. *(The oil now remains distributed through the water, and the solution looks like milk. Each oil globule has become surrounded by a thin layer of detergent that prevents it from touching the others and flowing together.)* Mention to the children that an emulsion has been formed. Print the word *emulsion* on the chalkboard and have a child check the exact meaning in the dictionary.

If a microscope is available, have a child put a drop of the emulsified oil on a glass slide and let the children examine it to see the numerous tiny droplets separated from each other. On another glass slide put a drop of the mixture without detergent. Be sure it has been shaken vigorously. The children will be able to watch the globules fuse together. Have them compare their observations of the two slides. Point out that any substance that will form films around globules of fat and prevent them from fusing is called an *emulsifying agent.*

Extending Ideas: To apply what the children have learned from these Activities, ask them, "If dirt is made of tiny particles of solid matter that are bound to our skin or clothing by a film of oil, how does a detergent help to remove the dirt particles?" *(By making the oil mix easily with water so that it can be washed away.)*

Learnings: Matter is particulate in nature. An emulsion is a mixture of two substances that do not ordinarily mix. In an emulsion one substance is suspended within the other, and its particles are prevented from flowing together by an emulsifying agent.

ACTIVITY 21 (y,z)

STUDYING HOMOGENIZED LIQUIDS

Purpose: To emphasize the particulate nature of matter

Concept to be developed: All matter is composed of tiny particles—atoms and molecules.

Materials needed:

1 quart of homogenized milk
1 quart of unhomogenized milk

INTRODUCTION: Point out to the children that fats, oil, and grease can also be made to mix with water without separating if the size of the individual fat droplets can be made small enough. The class can understand that the forces holding the atoms or molecules of a single small droplet together will then be stronger than the attraction between the droplets themselves and the particles will not fuse together into a separate layer. Mention that reducing the size of fat droplets by a mechanical method is called homogenization. Ask the children what foods they know of in which the homogenization process is used.

Obtain samples of the two kinds of milk. Ask the children how they think these two kinds of milk are different. *(They differ only in that the cream will separate in one and not in the other.)* Have the children compare the two and observe how the cream (fatty portion) rises to the top of the unhomogenized milk even after it has been shaken. Have the children examine a drop of each kind of milk under the microscope and compare the sizes of the fat globules in each case. Ask them to predict which kind of milk will have the smaller globules of cream. At the dairy, milk is homogenized by being forced through a metal filter that is pierced with many extremely fine holes. It may be possible to borrow one of these filters from a local dairy for the class to see.

Extending Ideas: As a result of the last two Activities, the children will note that some substances can be reduced to droplets of microscopic size—too small to see with the unaided eye. The size of a fat globule in an emulsion or in homogenized milk, however, is still far larger than that of a single molecule in a true solution, but such observations can add more meaning to children's concepts of how matter can exist as very fine bits.

Learning: Matter is particulate in nature.

ACTIVITY 22 (x,y)

MAKING SUBSTANCES INVISIBLE BY DISSOLVING THEM

Purpose: To emphasize the concept that matter is particulate in nature

Concept to be developed: All matter is composed of tiny particles—atoms and molecules.

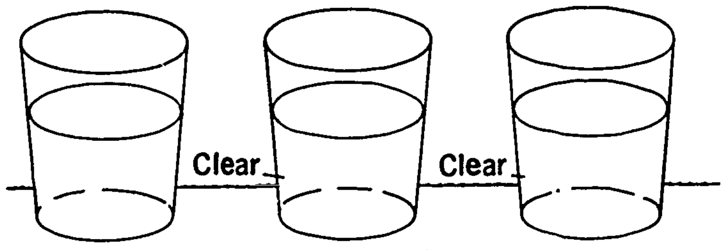
Materials needed:

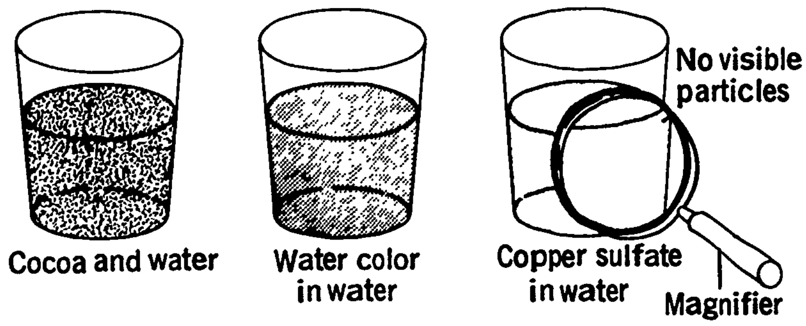
Salt
Sugar
Instant cocoa powder
Copper sulfate
Powdered water-color paints
Water
Drinking glasses or jars
Magnifying glasses
Cloth (handkerchief)
Teaspoon
Cotton batting
Filter paper (coffee-maker type)

INTRODUCTION: Discuss with the children that making solutions in water is an excellent way to show that visible amounts of a substance may be reduced to invisible molecules and distributed throughout a solvent. Ask the children how it can be proved that the substance is still there. Elicit their theories. No doubt some child will immediately say that the color or taste indicates that the substance is still present, but not in "pieces" big enough to see.

Have the children dissolve a teaspoonful of each of the substances listed above in separate drinking glasses almost filled with warm water, and stir thoroughly. How do the children account for the apparent disappearance of the salt and sugar? How can they tell whether these substances are still present? *(By tasting the solutions.)* How do they know the other substances haven't really disappeared? *(By the color of the solutions.)* Ask them to compare all of the solutions with a glass of tap water. Is there any difference in the appearance of the tap water and the clear solutions of salt and sugar? *(No.)*

Conceal the glasses of salt water, sugar water, and tap water behind a paper screen, or by standing in front of them, and switch the positions of the glasses to some random arrangement. Ask

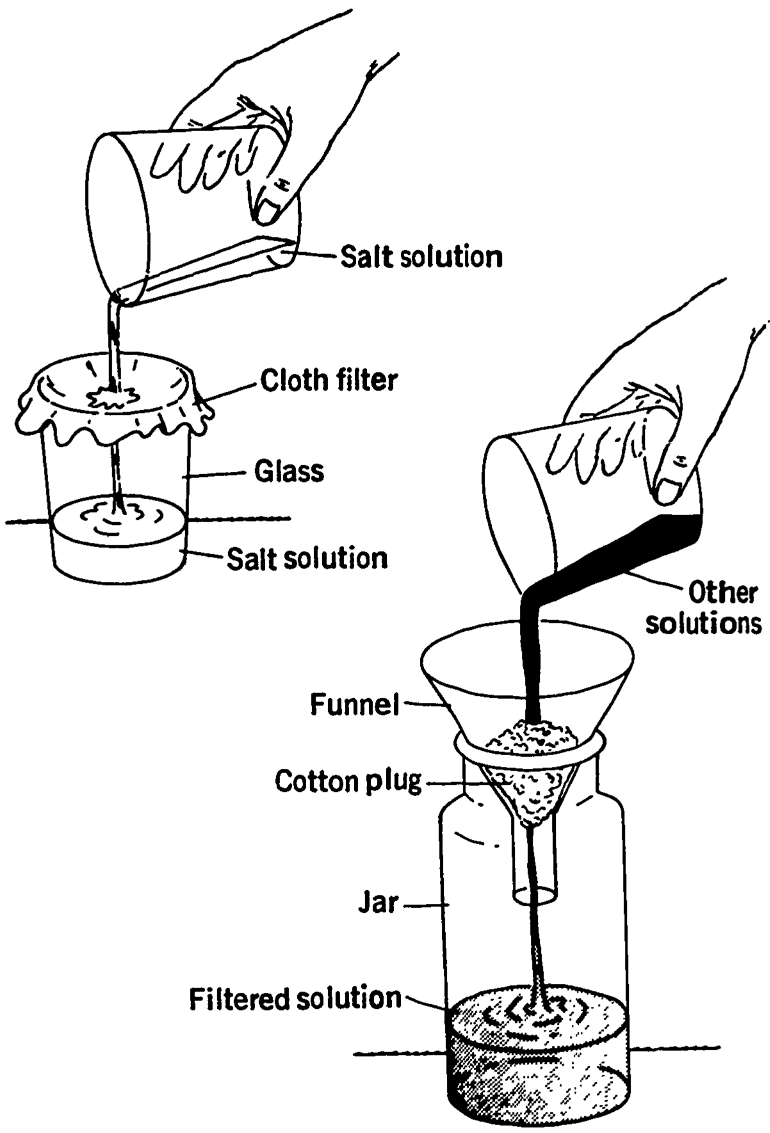




the children to taste each solution and identify which substance each glass contains. Bring out that they can tell that the salt and sugar are present throughout the water, even though no sugar or salt grains can be seen.

It is easy for children to see that the cocoa, paint, and copper sulfate are present because the water is colored by them. Can they see any particles in the clear upper portion of each solution? *(No.)* Can they see any particles with a magnifying glass? *(No.)* Do they think using a microscope can reveal particles that are too small to be seen with the unaided eye? *(If a microscope is available, they should examine a drop of the clear portion of each solution to see whether higher magnification will show visible particles. None will be seen since the substances, if completely dissolved, are now divided into "bits" the size of molecules.)*

Some appreciation of the size of these dissolved particles can be gained by attempting to filter them. Have the children hold up a handkerchief to the light and note the fine holes formed between the woven threads. Do they think that these holes will be small enough to separate the tiny particles from the water? Have them fold a handkerchief or piece of cloth twice and drape it over the mouth of a drinking glass as a filter. They should try tap water first to see that it will flow through the filter. Do they think that the solutions will flow through, or will the dissolved substances be left behind on the cloth? *(The solutions will flow through unchanged.)*



How can the children determine this? Ask some children to taste the salt and sugar water after it has been filtered. Divide the colored liquids into paper cups and have them filter these. *(Safety Note:* The solutions of the colored substances should not be tasted.) The glass and cloth should be washed after each trial. *(All of the dissolved substances will pass through the pores of the cloth filter.)*

Extending Ideas: Some children may wish to experiment further with filters that have finer pores. They may wish to try a loose plug of cotton batting in a funnel, or the kind of filter paper that is used in making coffee. Do these filter out the dissolved particles? *(None of these filters have fine enough pores to separate the dissolved substances from the water.)*

The class may also wish to try making other substances invisible by dissolving them in water. The various powdered dyes sold for tinting clothing can be used to show how large grains of substances are subdivided into molecular dimensions by dissolving them in water, but are still detectable by their colors.

Learnings Matter is particulate in nature. When one substance is dissolved in another it breaks up into particles so small that they cannot even be seen with a microscope.

ACTIVITY 23 (x,y)

MAKING SUBSTANCES DISAPPEAR BY EVAPORATION

Purpose: To emphasize the particulate nature of matter

Concept to be developed: All matter is composed of tiny particles—atoms and molecules.

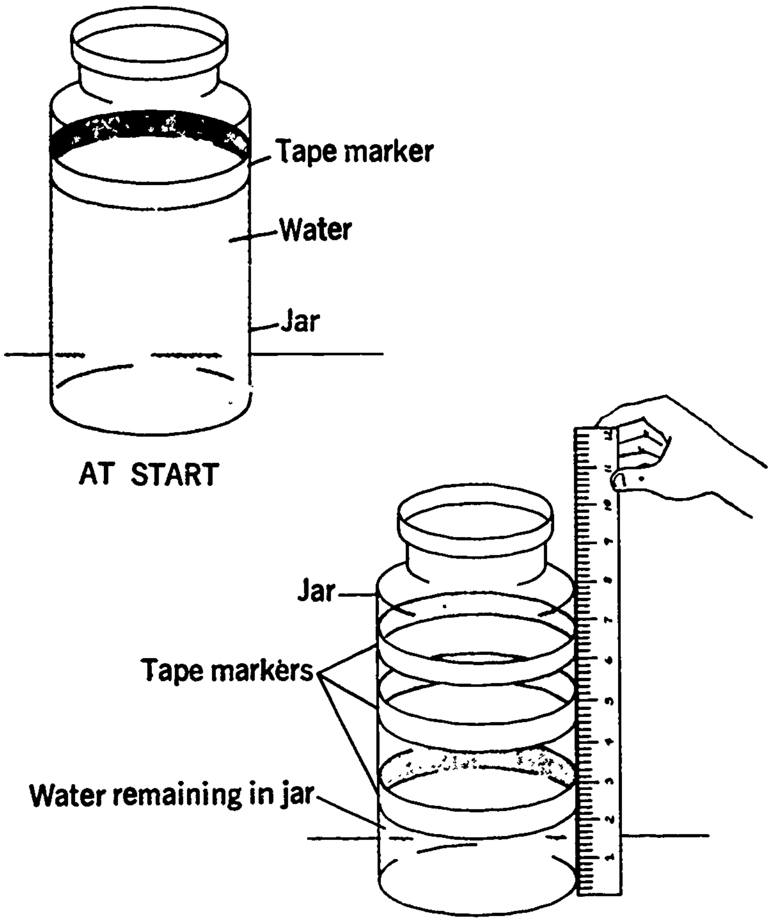
Materials needed:

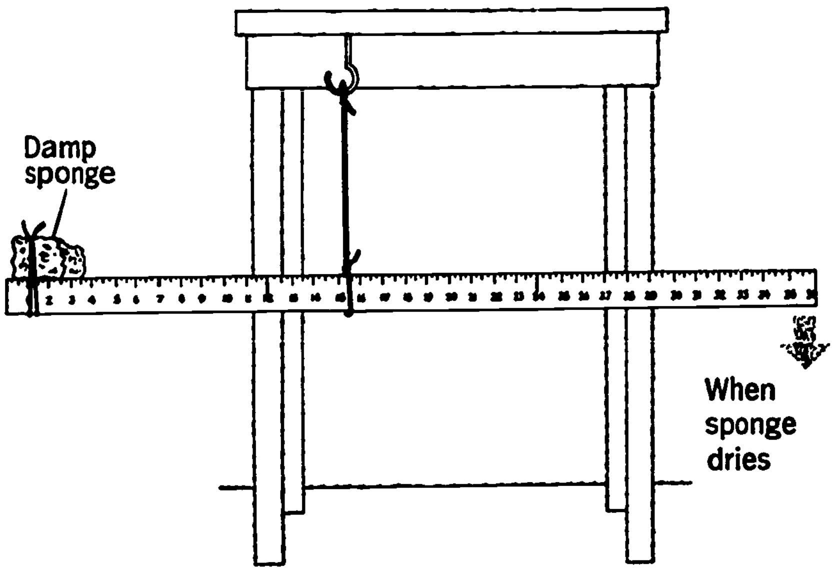
- Cloth
- Sponge
- Yardstick
- String
- Jars or drinking glasses
- Masking tape
- Rubbing alcohol
- Mineral oil

INTRODUCTION: Discuss these questions with the class: How does water disappear from rain puddles? Where does it go? Point out to the children that it has been estimated that each cubic mile of air on a clear hot summer day may hold as much as 1,500,000 barrels of water. Yet we may see no evidence of a single drop of this vast amount of water as it hangs over our heads. Ask the children why they think this may be. Perhaps one will say that the water is in the form of invisible water vapor mixed with the air. Explain further that at other times some of the water may be seen in various types of clouds. Of course, it becomes visible when it falls as rain, snow, sleet, or hail, or appears in the form of dew, fog, and frost. Point out that the change from visible water droplets to invisible water-vapor molecules is another piece of evidence that matter is made up of small particles. The following Activity will help the children to see this.

Moisten a large spot on the chalkboard with a wet sponge. Ask the children to describe what happens as the spot dries. Discuss where the water has gone and why we cannot see it leaving. *(The water is moving into the air as particles too small to see.)*

Then fill a large wide-mouthed jar with water and mark the level with a piece of masking tape. Ask the children to observe what takes place over a period of several days, and have them place a new marker at the water level each day. What do they predict will happen to the water? Why do they think the amount of water decreases? Does the same amount of water disappear each day? *(If the classroom is not air-*





conditioned, the rate of evaporation will vary depending on several factors: the higher the temperature, the faster the water will evaporate; when the amount of water vapor in the air (humidity) is already high, the rate of evaporation will be less; the more circulation of air there is in the room to carry away the vapor-laden air over the jar, the faster will be the evaporation.)

Do other liquids also "disappear" through evaporation? Have the children set up three jars to observe water and other liquids, such as mineral oil and alcohol, to see whether they evaporate, and how quickly as compared with water and with each other. *(The alcohol will evaporate more rapidly than the oil.)*

As an additional demonstration of evaporation, have the children tie a damp sponge to one end of a yardstick. From a shelf bracket or other support in the room, suspend the yardstick by a string so that it hangs level. What do the children predict will happen as the sponge dries? *(The end with the sponge will lose weight and slant upward.)* The children can clearly see the loss in weight as the water evaporates, yet the water vapor cannot be directly observed because it is a colorless substance with no smell or taste.

Extending Ideas: On the basis of the preceding experiences with evaporation, let the children give their explanations of how water disappears from rain puddles, and where it goes. Help them to think in terms of the explanation that evaporation takes place when very tiny particles of water leave the liquid and move into the air. Let the children suggest how their observations of evaporation might be applied to the disappearance of water when it is boiled.

Learnings: All matter is particulate in nature. Evaporation takes place when small particles of a liquid pass into the atmosphere.

ACTIVITY 24 (y,z)

MAKING SUBSTANCES DISAPPEAR BY SUBLIMATION

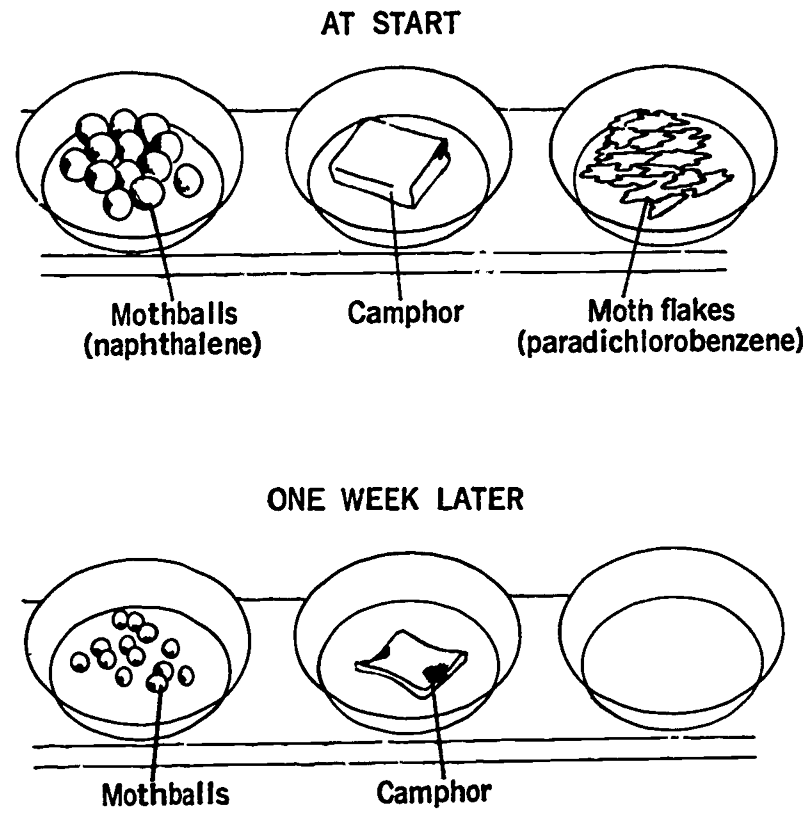
Purpose: To emphasize the particulate nature of matter

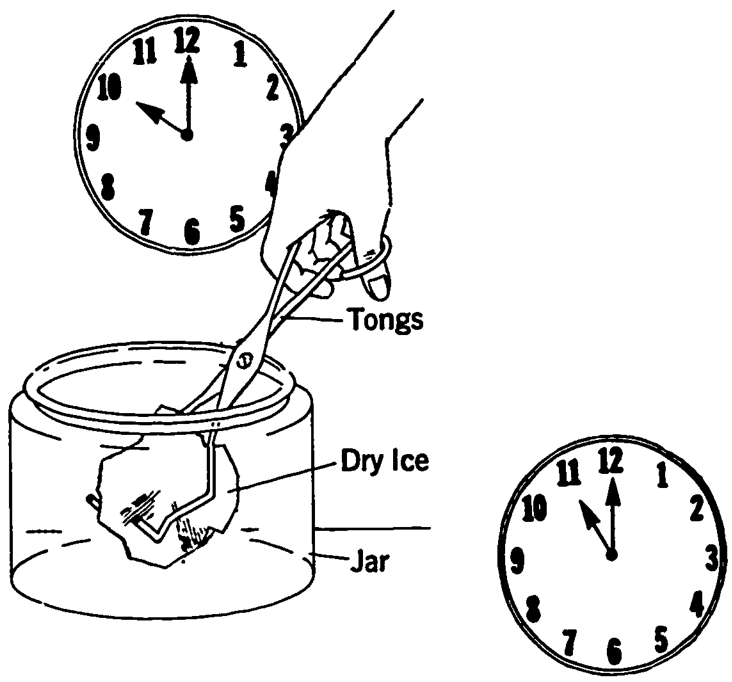
Concept to be developed: All matter is composed of tiny particles, which are called atoms and molecules.

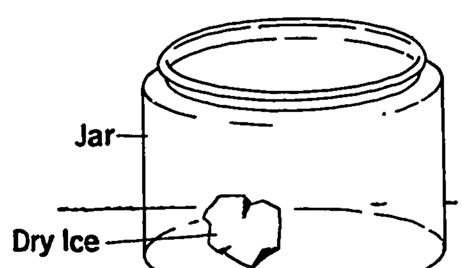
Materials needed:

- Solid carbon dioxide (Dry Ice)
- Moth flakes (paradichlorobenzene)
- Mothballs (naphthalene)
- Camphor
- Tin can
- Small glass dishes or Pyrex nursing bottles
- Tongs or gloves
- Iodine

INTRODUCTION: Although the children may be familiar with the evaporation and boiling of water and other liquids, they may not be aware that solids can evaporate too, but usually at an unnoticeable and extremely slow rate. Point out to them that some solid substances can change directly from the solid state to vapors in a brief period of time by a process called sublimation. *For example, in the winter time, in climates where the temperature falls below freezing, wet laundry hung out to dry will freeze, but the ice will sublimate and the clothing* *will become dry. In the following Activity, the children will have an opportunity to observe how various solids sublimate.*

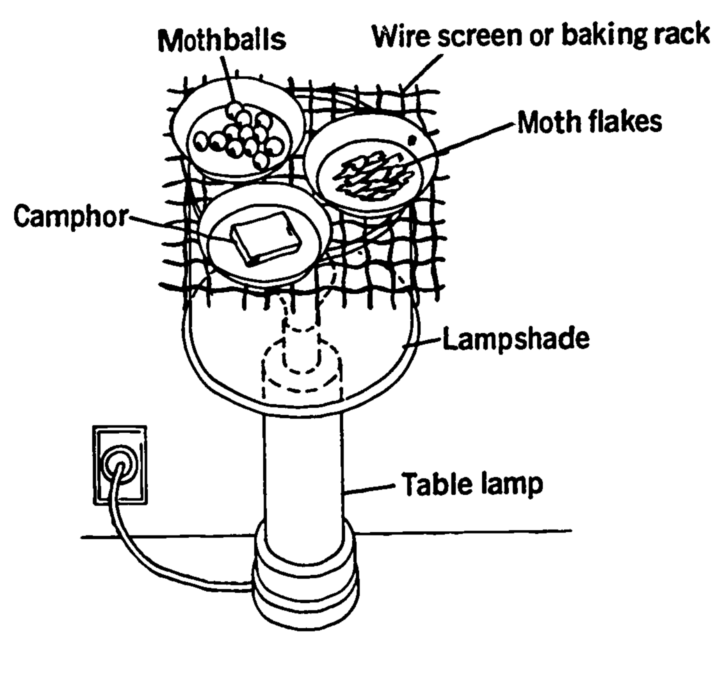


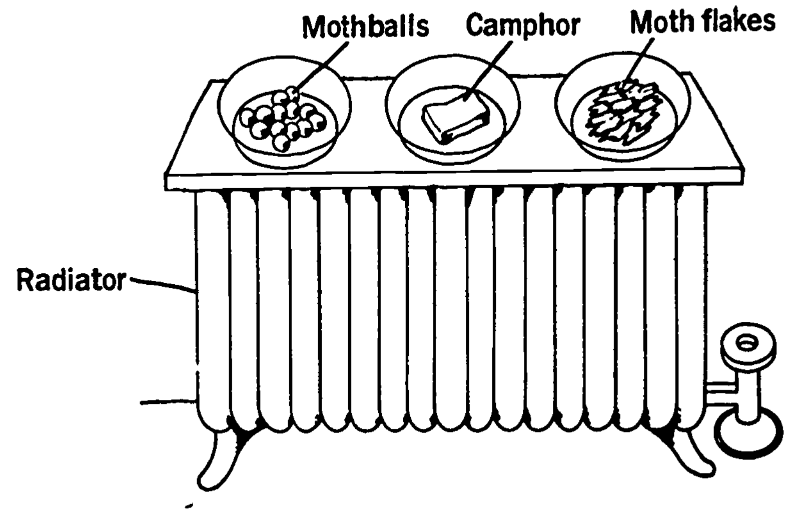




Have a child place small pieces of Dry Ice in a dish for the class to observe at 15-minute intervals. (A small piece of Dry Ice will sublimate in less than an hour at room temperature. It sublimates to gaseous carbon dioxide. *Safety Note:* Handle Dry Ice only with tongs or gloves, as its extremely cold temperature can cause frostbite.) To demonstrate the sublimation of the other solids on the list, put about 1 teaspoonful of each in open containers and have the children observe them every few days. (The samples should be weighed every few days to detect the sublimation as a loss in weight. The scale shown in Activity 4 may be used.)

The rate of evaporation can be greatly speeded by a little heating. *(Safety Note:* Do not use an open flame as a source of heat for the moth repellents or camphor, as they may catch fire. Also, iodine is a poisonous substance and large amounts of fumes will be produced if it is heated too strongly. Do this demonstration in a well-ventilated room or out of doors.) Place only one or two crystals or flakes of these solids in





glass dishes or Pyrex baby bottles, and warm them, using a radiator or light bulb as the heat source. What happens? *(As in the case of liquids, the solids will disappear from the container.)*

The apparent disappearance of substances when they are dissolved, evaporated, or boiled indicates that they have been divided into particles too small to be seen. This is strong, but indirect, evidence that visible samples of matter are composed of aggregations of many small particles, or atoms and molecules.

Learnings: Matter is particulate in nature. When matter is changed directly from the solid to the gaseous state, without passing through the liquid state, the process is called sublimation.

Summing Up Ideas In this section the children were introduced to the concept that all matter is particulate in nature by observing and interpreting various everyday phenomena. First they were introduced to the possibility of the existence of minuscule particles, called atoms and molecules, by the process of imaginary halving. Once this idea was established, it was used to explain the mechanism of solution, evaporation, and sublimation in terms of these atoms and molecules. The children learned that an atom is the smallest unit of an element that still exhibits all the properties of that element, and that a molecule is the smallest unit of a compound that can still exhibit all the properties of that compound.

HOW DO ATOMS AND MOLECULES FORM VISIBLE MATTER?

More indirect evidence for the particulate nature of matter can be gained by causing the invisible atoms and molecules of vapors and solutions to come together into amounts large enough to be seen. This occurs in the condensation of steam to water and in the growth of crystals in the solutions of substances such as sugar.

ACTIVITY 25 (y,z)

OBSERVING THE CONDENSATION OF WATER-VAPOR MOLECULES

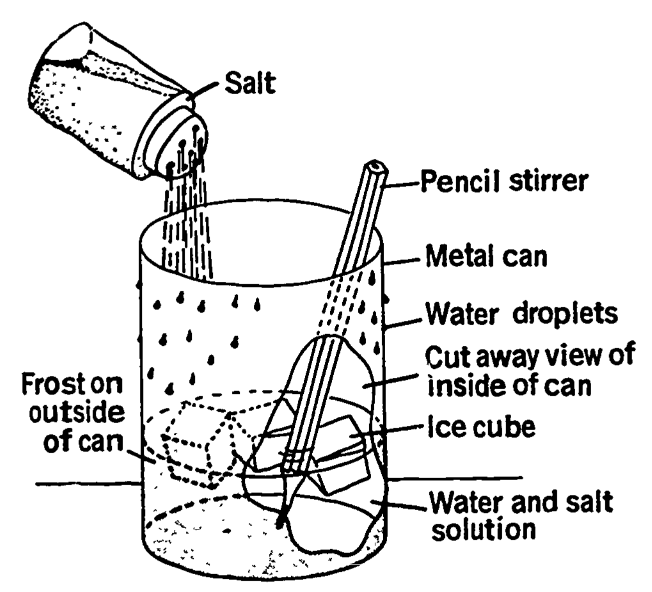
Purpose: To show that under proper conditions atoms and molecules can be made to collect into visible matter

Concept to be developed: The invisible water-vapor molecules in the air can be collected by condensation to appear as visible droplets of water and crystals of ice.

Materials needed:
Empty food cans
Salt
Ice cubes or snow
Pencils or small sticks

INTRODUCTION: Tell the children that another way in which the atomic theory can be supported by indirect evidence is to make something visible appear where it had not appeared before. How is this possible? Have the children suggest some situations in which water, for example, appears where it had never appeared before. Suggest that they think about how water droplets appear on a cold plumbing fixture after someone has taken a hot shower, how the frost or dew is formed, how water droplets appear on the outside of a cold-drink bottle on a summer day. Then introduce the following Activity to help them understand this process and its relationship to the particulate nature of matter.

Have the children bring to school empty food cans with the tops and labels completely removed. Have them fill the cans about one-third full of water, and add two teaspoonfuls of salt and an ice cube to each. Have the children stir the salt water and ice mixture with pencils or small sticks.



What happens? *(In a few minutes a layer of frost will form on the outside of the can.)* Ask the children where it might have come from? *(Water vapor in the air condenses on the can's cold surface.)* Can they suggest how water gets into the air, and from what sources? *(By evaporation from lakes, oceans, rivers, in the exhaled breath of animals, and from the respiration of plants.)* Point out to them that the entire water cycle from water to vapor and back to water is an excellent illustration of the particulate theory of matter. In the water cycle, visible amounts of liquid water evaporate to invisible molecules of water vapor, which in turn condense to form visible liquid water once again.*

Extending Ideas: By observing the behavior of water as a liquid, solid, and gas, the children can discover that unseen water molecules become visible when large numbers of molecules are condensed or made to come together. Point out that this interpretation may be correct only for water. Do the children think this conclusion can be applied to other substances? *(Any substance that exists as an invisible gas can be made to condense to form a visible quantity of matter.)* Some children may wish to find out about the condensation of other substances in an encyclopedia or science book, or by asking a science teacher or scientist.

Learnings: The invisible molecules of water vapor present in the air can be condensed to form visible droplets of water. The condensation of water vapor is a familiar phenomenon, and it is an important factor in the water cycle.

ACTIVITY 26 (y,z)

LEARNING ABOUT CRYSTALS

Purpose: To familiarize the children with the shapes of crystals in preparation for the Activity dealing with crystal growth

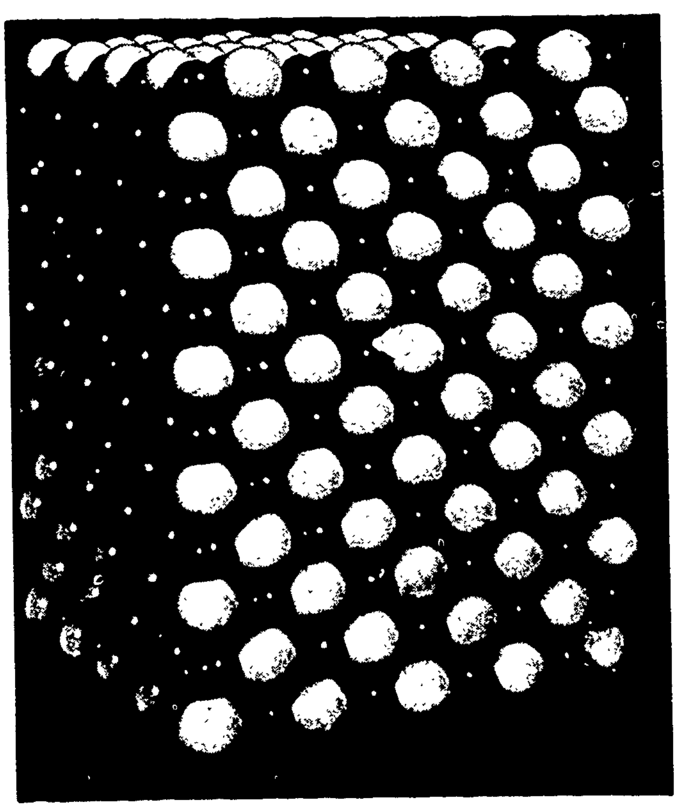
Concept to be developed: Many solids have crystalline shapes.

Materials needed:

- Magnifying glasses
- Boric acid
- Rock salt (sodium chloride)
- Epsom salts (magnesium sulfate)
- Rock candy (sugar)
- Rocks and minerals

Much knowledge about the molecular structure of matter has come out of the study of crystalline substances. The key fact is that all crystals of a particular substance have the same geometric shape, whether the crystals are large or small. The regular geometric shape indicates that such solids are built up of layer upon layer of many small crystal-building blocks arranged in a regular pattern.

The crystal-building blocks are the individual atoms or molecules of the substances. Strictly speaking, the particles of many crystals are modified atoms or molecules called *ions,* which are atoms and molecules that have an electric charge. The attraction between differently charged ions is the force holding a crystal together. For example, in table salt (sodium chloride) sodium ions (positively charged) are attracted to chloride ions (negatively charged); the strength of the attractive forces and the directions in which they are exerted determine the pattern by which the ions join together to form a cube-shaped crystal of salt. In the same way, the ions of other substances build up to form other crystal shapes. When salt crystals are dissolved in water, the cubical network of ions in the crystal is pulled apart by the greater attraction of the ions making up the water. A solution of salt contains, therefore, many separate ions of sodium, chlorine, hydrogen, and oxygen (the latter two being the ions of water).



Model of a cube-shaped salt crystal.

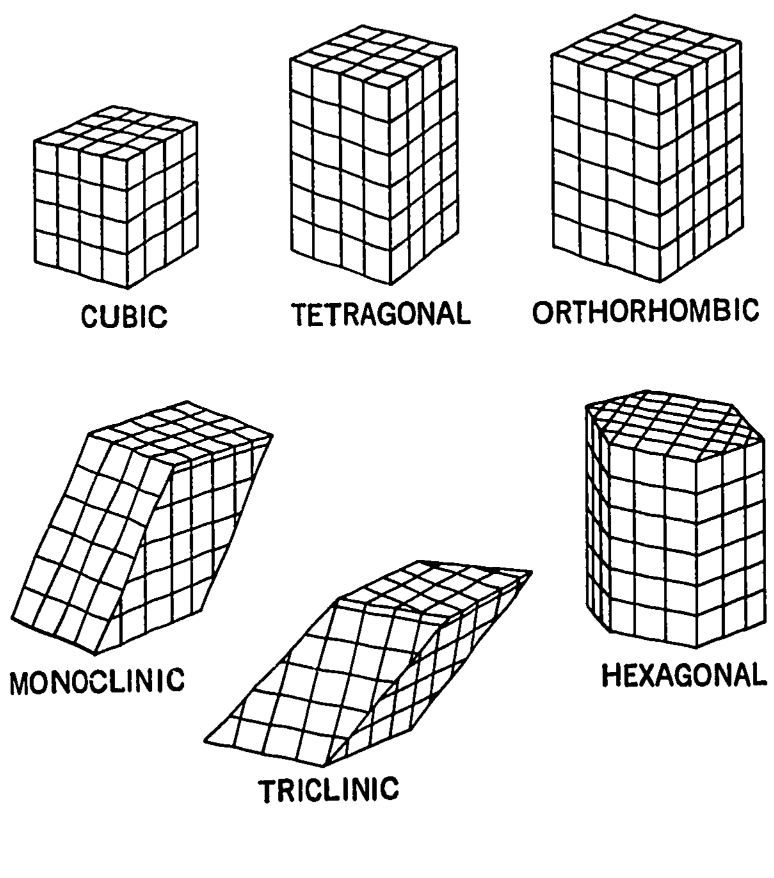
In nature, some crystals are formed from water solutions that have evaporated, but most are formed from the cooling of substances dissolved in molten lava. Crystals form when water evaporates from a solution containing dissol- material. As the water evaporates, some of the dissolved material comes out of solution and deposits itself on a speck of dust, a "seed" crystal (a crystal that acts as a base for the dissolved

*For a thorough discussion of the water cycle and Activities with which to demonstrate it, see *The Earth,* by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

substance to deposit on), or some other nucleus of condensation. The crystals grow larger with further evaporation, but the shape remains the same. The faces of a crystal are usually as smooth as glass, and the edges sharp, as if ground and polished.

INTRODUCTION: Mention to the children that one way to determine whether matter is made of atoms and molecules is to examine the way in which the particles combine to form crystals of the substance. The study of substances made up of crystals has shed much light on the molecular theory. Do the children know of anything in their own experience that would be made up of similar small units arranged in a regular pattern? Encourage their theories and ideas. What about a brick wall, for example? Have children draw a pattern of a brick wall on the board. Point out that the bricks are usually the same size and are usually arranged in a specific pattern to make the wall stronger. Mention that when one looks at a crystalline substance through a microscope, he can see that all crystals have the same geometric shape, whether they are large or small. They are also arranged in a specific pattern, layer upon layer, like the bricks in the wall. The following Activity will show the children how this situation gives evidence of the theory that matter is particulate.

Have the children look at some crystalline substances with a magnifying glass. Point out the appearance of each. *(The pieces of each sample seem to have the same general shape, such as the cubic crystals of table salt and the long needles of Epsom salts.)* What other shapes can the children find among other household substances? If any of the children have rock and mineral collections at home, ask them to bring these in for the class to see.

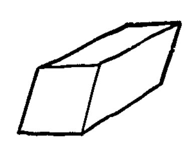


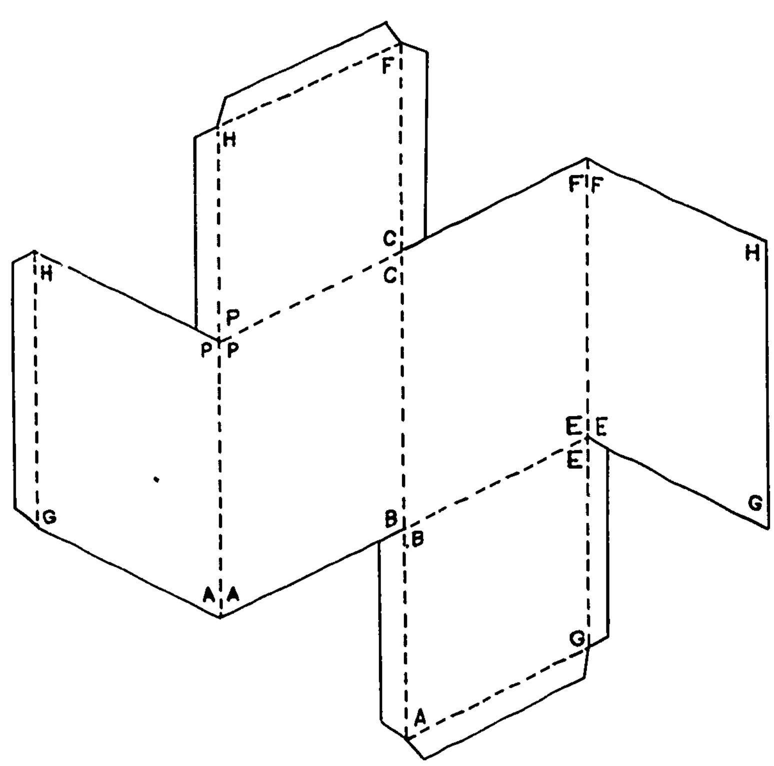
Three-dimensional models, which are easily made of paper, can help children visualize the different geometric shapes of crystals.

Have a child trace the pattern shown in the illustration on a duplicating stencil and make copies for each child on heavy paper. The patterns may then be cut and glued together to form a model of the crystal shape. Any fast-drying adhesive, such as rubber cement or contact cement, will be suitable. Copper sulfate and boric acid are two compounds whose crystals are of this shape. Other patterns may be found in some of the books listed in the bibliography.

TO FORM THIS TRICLINIC MODEL:

Cut on solid lines,
fold on broken lines, and
paste tabs to undersides
of edges with
matching letters.





Extending Ideas: Some children will be interested in all of the six basic crystal shapes. They might look up the meanings of the following names for these basic shapes, and make paper models: cubic, monoclinic, triclinic, orthorhombic, tetragonal, and hexagonal.

Learnings: Many solids have crystalline structures. There are six basic crystalline structures.*

ACTIVITY 27 (y,z)

GROWING CRYSTALS FROM SOLUTIONS

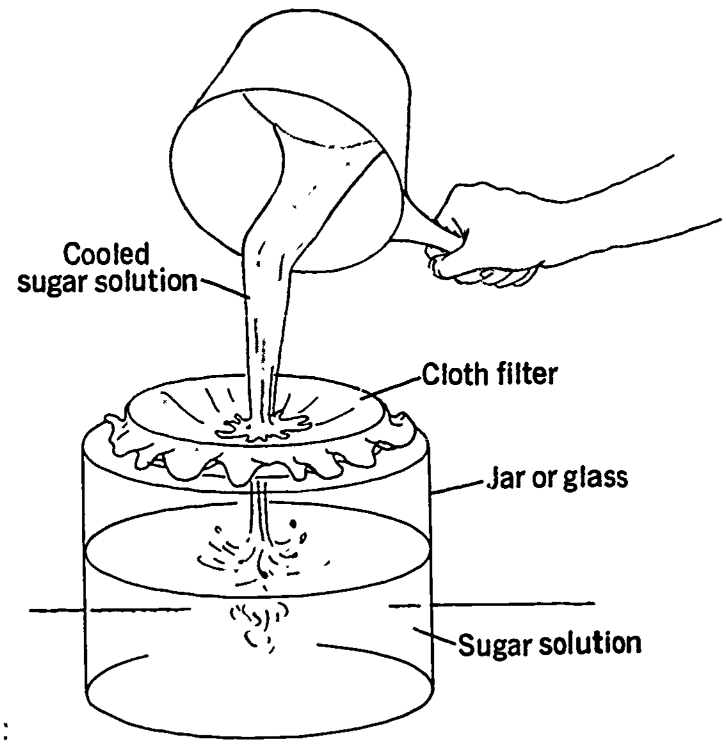
Purpose: To demonstrate how atoms and molecules are attracted to each other to build up visible crystals

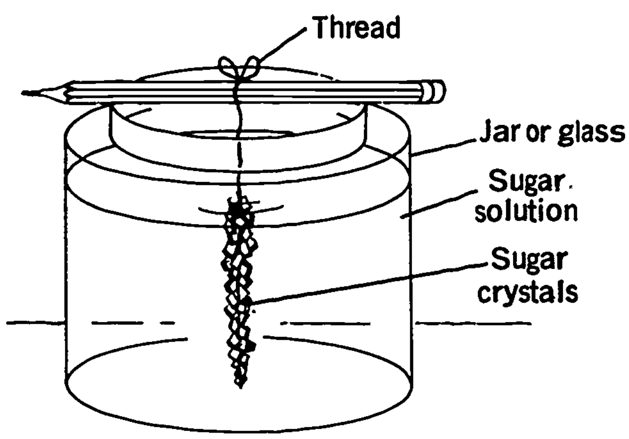
Concept to be developed: Crystals can be grown by depositing individual atoms or molecules on a nucleus until the desired size is reached.

Materials needed:

- Sugar
- Pan
- Electric hot plate
- Cloth (handkerchief)
- Magnifying glasses
- Small jars
- String
- Table salt
- Alum (potassium aluminum sulfate)
- Copper sulfate
- Rochelle salt (potassium sodium tartrate)
- Photographer's hypo (sodium thiosulfate)

INTRODUCTION: Now that the children understand how a substance is formed by the addition of crystal to crystal in a regular pattern, perhaps they would like to grow their own crystals. Mention to them that it will be possible to grow a variety of types. Have them suggest substances that they would like to grow crystals of, and then proceed with the following Activity.



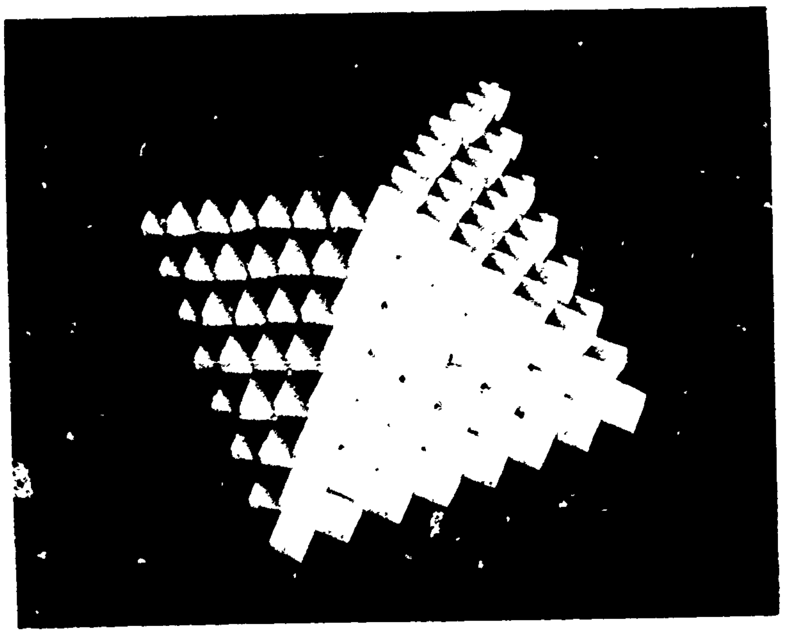


To make sugar crystals or rock candy, add about 1¾ cups of sugar to one cup of boiling water in a pan. Stir until the sugar dissolves and allow the solution to cool. When it is cool, pour it into several small glasses or jars, using a folded cloth as a filter. The children can see that the sugar has disappeared from view, but that its presence is still shown by the solution's taste. Hang a piece of clean string in the solution in each jar by fastening it to a pencil which is laid across the top of the jar. Tie a small piece of a sugar cube or a paper clip to the end of the string to keep it from floating up. Explain that the string forms a nucleus, or center, around which the crystals will form as the water evaporates. In a few hours small crystals will form on the string. (Sometimes a "crust" of sugar crystals forms on the surface of the liquid. Break this up with a clean pair of tweezers and remove the pieces as often as necessary.) In a few days the crystals will have grown quite large. They may then be handed out to the class and eaten. Have the children note their color and shape, and make other observations with a magnifying glass before eating them.

Additional strings may be suspended in the solution and more crystals will grow as the water evaporates. Place the jars in an undisturbed location, where they will not be exposed to extremes of hot and cold. The children will discover that the longer the process continues, the larger the crystals grow.

Point out to the children that crystals of many other substances can be grown by the same procedure as that for rock candy. Have the children try crystal-growing with table salt (sodium chloride), photographer's hypo (sodium thiosulfate), copper sulfate, alum (potassium aluminum sulfate), and Rochelle salt (potassium sodium tartrate). (These materials may be

*For a further discussion of crystals, see *The Earth* by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).



Packing model of cubic salt crystals.

ordered through drug stores or from scientific supply houses.) Have the children dissolve as much of each substance as possible in about 6 ounces of almost boiling water. Caution them not to use too much water, since surprisingly large amounts of many solids can be dissolved in a small amount of water. If crystals do not start to grow within two days, the children may "seed" the solution by adding a very few tiny particles of the solid to the solution. When the children observe some of the crystals they have grown, they will see that the crystals have a regular and orderly pattern of structure.

Extending Ideas: The growth of poorly shaped crystals is another way of showing that crystals are built of small units. Have the children remove some crystals from their solutions and dry them on a piece of blotting paper. Have them look at these crystals under a magnifying glass to find "defective" crystals. *(For example, crystals that have been lying on the bottom of the jar will be flattened on that surface, and appear lopsided and not perfectly shaped. A properly grown crystal will have an almost perfect geometric shape, such as a cube, a hexagon, or two pyramids joined base to base, depending on the substance making it up.)*

Have the children select some imperfect crystals and return them to the jar so that the flat side or other defect is now facing up into the solution. Or they may suspend each crystal in the solution from a piece of string. The crystal now becomes a nucleus for regular growth. Over a period of several days, have the children look at the crystals and see how the flattened crystal faces become "repaired" or "healed" as other particles in the solution deposit themselves on it so that a balanced shape is achieved.

An interested group may experiment further with crystal "healing" by breaking or cutting off a small corner or piece of a crystal, and returning it to its solution. Have them observe what happens. Do they think the crystal will grow unevenly? *(Again, growth will take place so as to restore the regular shape of the crystal.)*

What do the children think will happen if a crystal of one substance is placed in a solution of another substance? Have the children try some of these exchanges. *(If the "foreign" crystal does not dissolve, it will become a nucleus of condensation for the substance in the solution, and a differently shaped crystal will grow, according to the characteristic pattern of the substance in solution.)*

Learnings: Crystals may be grown from a solution. The crystals grow when atoms or molecules of the substance dissolved in the solution are deposited on a nucleus. Each substance grows a crystal in its own characteristic pattern.

ACTIVITY 28 (y,z)

GROWING CRYSTALS FROM A MOLTEN SUBSTANCE

Purpose: To demonstrate another manner in which crystals may be grown

Concept to be developed: Some molten materials form crystals when they are cooled; the longer the cooling takes, the larger will be the crystals.

Materials needed:

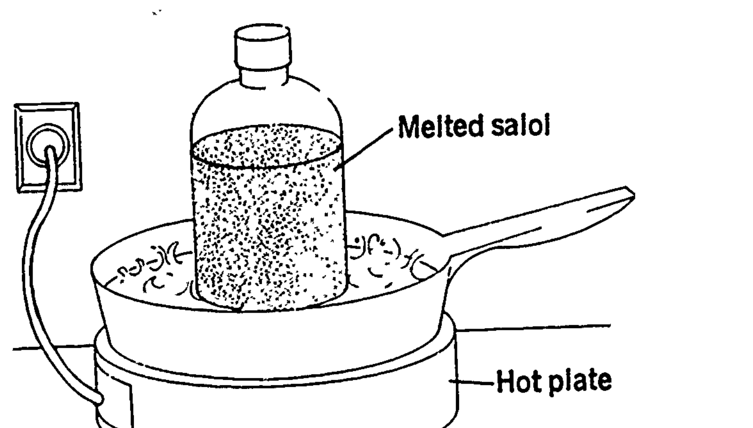
Salol (phenyl salicylate)
Glass or plastic pillbox or test tube
Pan
Child's mineral collection or pictures of mineral crystals

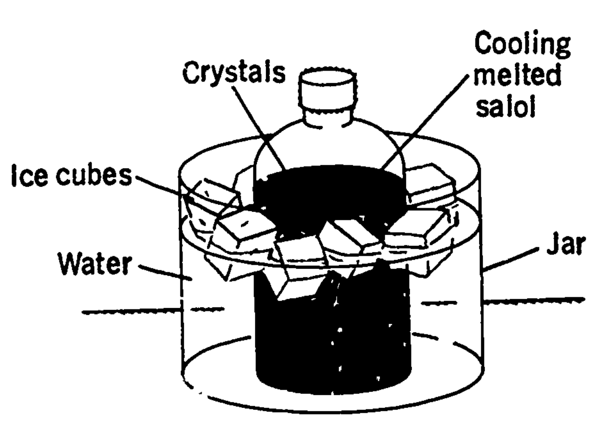
INTRODUCTION: Mention to the children that there is another process by which crystals may be formed. Can the children guess what it might be? Elicit their ideas. Have they ever seen pictures of an area after a volcano erupted? What is lava? How is it formed? Does it look the same way after it has cooled? Have children bring in pictures of volcanic rock to determine the answers to this question. Then proceed with the following Activity, which will illustrate what happens to lava when it cools and show another process by which crystals are formed.

The appearance of visible crystals from unseen molecules can easily be demonstrated by using salol, or phenyl salicylate, a compound that will melt in hot water. It may be ordered through drug stores. (*Safety Note:* Salol is poisonous and should not be tasted.)

Have the children put a small bottle of salol in hot water. When it has melted into a clear liquid, they should remove it from the water. As it cools down to its freezing point, the crystals grow slowly enough for the children to observe the process. Can they see how this process is similar to the formation of mineral crystals from molten lava in nature? *(The lava from volcanoes is a mixture of substances dissolved in very hot melted rock. Crystals of some of the substances form as the lava cools.)* Have the children compare the size of the salol crystals with those of some natural mineral samples, such as quartz. *(The size of the quartz crystals will vary from one rock specimen to another. They may all be very small, very large, or some size in between. The size of a crystal is determined by the time it takes the substance to cool down. This process can be investigated by using the salol.)*

Ask the children to design an experiment in which a bottle of melted salol can be cooled very quickly, as well as very slowly. *(The bottle might be plunged quickly into ice water after the compound has been melted, or left in the hot water bath and allowed to come to room temperature very slowly.)* Ask the children to think of a process of crystal formation that would account for the different sizes of crystals formed. *(If the molten material hardens quickly, the crystals will only be able to grow to a small size. If it cools slowly, more growth can take place and larger crystals can form.)*





Extending Ideas: Some children may wish to experiment further by freezing water to crystals of ice both slowly and quickly. Have them try this at home and report to class. A tray of hot water and one of cold are placed in a refrigerator's ice cube compartment. Does one tray freeze sooner than the other? Do they find any difference in the clearness of the ice cubes? Can they explain this by the size of ice crystals formed? *(The ice cubes can be brought to school in an insulated ice cream bag for the rest of the class to observe.)*

Learning: After the crystals of a material are melted, large crystals may form if it is allowed to cool slowly.

ACTIVITY 29 (y,z)

BREAKING CRYSTALS APART

Purpose: To discover that crystals result from the orderly arrangement of small units

Concept to be developed: Crystals are built up from individual atoms or molecules.

Materials needed:

Mica pieces or mica-bearing rocks
Straight pins
Spoons
Hammer

INTRODUCTION: Explain to the children that there is another way to support the theory that matter is made of an orderly arrangement of small units. Ask them to advance ideas as to what this might be. What other things could be done to crystalline substances to prove that they are made of small, regularly arranged bits? Perhaps someone will suggest that a crystal could be broken apart. Ask for the children's suggestions as to what sort of crystalline substance would be best for this. Then proceed with the following Activity.

Mention to the children that the mineral mica is an excellent illustration of the way a crystalline substance is built up in layers. Small pieces of mica can be seen in granite and other rocks. Have the children look for, and bring in, such "glitter" rocks. Some of them may have mica rocks in their rock collections. The small flakes of mica can usually be dug out with the edge of a dull knife or spoon. Larger pieces can be removed by breaking up the rock with a hammer. (*Safety Note:* To avoid danger from any flying particles, wrap the rock in cloth before breaking it with a hammer.)

Explain that the structure of mica is like that of a book in which the pages are glued together with a weak glue. Distribute the pieces of mica to a group of children and ask them to try to get the thinnest sheet possible. The sheets can be peeled apart by inserting a pin or the edge of one's fingernail between the layers. One of these layers can then be separated further into even thinner sheets. The only limit to their thinness is the children's skill in picking them apart. (Soaking the mica in water for a few minutes will make it easier to separate the layers.) Have the children imagine that they can continue this splitting process until they arrive at a layer of mica that is one molecule in thickness.

Mica can be separated into thin sheets.

Have the children try to bend a piece of mica or break it. What difference in strength do they find between bending it and peeling the layers apart horizontally? *(The children will find that mica is flexible and quite strong when they attempt to bend it or break it; however, the mica can more easily be separated into layers.)* Explain that many crystals can be more easily split in one direction than another because of natural lines of weakness. These lines of weakness are called *cleavage planes*. Have the children check the dictionary definition of the terms *cleavage* and *plane*. Mention that diamond cutters really split a rough diamond crystal along its *cleavage planes* to shape it into a many-faceted gem stone. Help the children to picture how the molecules might be arranged in a piece of mica in a way that explains their experiences with it, that is, the ease with which they can peel the layers apart and the difficulty they have in breaking or bending the mica.

Learnings: Crystals can be split along lines of weakness, called cleavage planes. The cleavage planes of a crystal help to show that the crystal is composed of small particles.

Summing Up Ideas: In this section the children reinforced their understanding of the concept that all matter is particulate in nature by working with the building up of invisible particles into visible substances. They learned about condensation and how the invisible water-vapor molecules in the air condense t[illegible] water droplets. They also learned about c[illegible]d the ways in which these can be grown from [illegible]le particles. In addition, they learned how the cleavage planes in crystals help to show us the particulate nature of matter.

HOW BIG ARE ATOMS AND MOLECULES?

An ordinary drop of water contains more than 1,000,000,000,000,000,000,000 (one sextillion) water molecules. Such a large number is so much beyond our experience that we can scarcely form any adequate idea of it. A few "word pictures" may help children enlarge their understanding of concepts dealing with very large quantities.

- A quantity of air about as big as a pencil eraser contains fifteen billion times as many molecules as there are people on the Earth.
- If a small raindrop evaporated by losing one million molecules per second, it would still take about three million years to evaporate completely.
- If the molecules in a glass of water were changed to grains of sand, the entire United States would be covered with a layer of sand 100 feet deep.
- If all the children in the class cooperated to count the number of iron atoms in a pinhead—and they counted every day, all day, at full speed

—by the end of two years the number of atoms they would have counted would equal only the total number of people in the world (about 3 billion). It would take all of these three billion people—counting for their whole lifetimes, and doing nothing else—to reach the total number of atoms in a pinhead of iron.

ACTIVITY 30 (z)

ESTIMATING THE NUMBER OF MOLECULES IN A SOLUTION

Purpose: To develop the concept of the minuscule size of atoms and molecules

Concept to be developed: The number of molecules in a solution can be estimated by observing their color or taste after a large number of dilutions.

Materials needed:

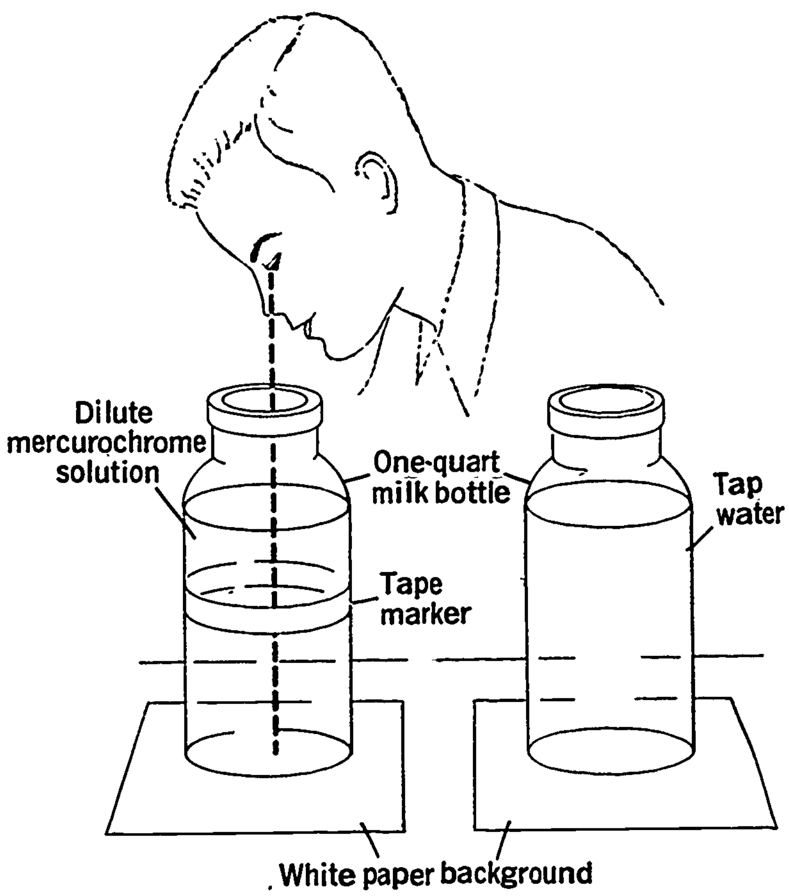
Mercurochrome or other dye
2 one-quart bottles
Masking or adhesive tape
Sugar, salt, or vinegar

INTRODUCTION: Explain to the children that although no one has ever directly observed the molecules of water, iron, the gases in air, or most other substances, their numbers and size have been determined by calculations based on certain experiments. It is possible to detect substances even when they are present in molecule-sized particles because of the color, odor, or taste of the substance. Ask children if they can figure out how such small amounts could be detected. Then explain that by diluting the substances in solutions to the point where their characteristics of color, odor, or taste can no longer be detected, some estimation of the number and size of molecules involved can be made. Mention that the children can use the same methods to gain some appreciation of the vast numbers and small size of molecules that even a tiny quantity of matter contains.

Have a child make a very dark solution by adding one ounce of mercurochrome (or other strong dye) to a quart bottle of water. Have him shake or stir the water to distribute the color evenly. Point out that the uniform color shows that the molecules of mercurochrome are now scattered evenly throughout the water. Have another child fill another bottle with tap water for purposes of comparison.

Let the children estimate the number of molecules of mercurochrome added to the water. Ask them what is the biggest number they can imagine. *(Hundreds? Thousands? Millions? As many as all the people in the world? As many as all the drops of water in the ocean? Or do they feel there is not enough information to make an estimate?)*

Explain that they will get some idea of the number of molecules present in an ounce of dye by mixing it with a large quantity of water. Help them to see that as long as the color is present, this means that some molecules of the dye are present. If some color remains even after large quantities of water have been added then there must have been large numbers of molecules present originally.



Have a child put a tape marker around the quart bottle containing the dye at the halfway point and pour out half the liquid. Fill the bottle to the top once again. Have the children note the change in the depth of the color. Have the children repeat this several times.

Can the children determine by how much the dye is being reduced with each dilution? *(Each time half the solution is poured off and an equal amount of water is added, the remaining quantity of mercurochrome is cut in half.)* Have the children continue to make dilutions. Depending on the strength of the dye stuff being used, this process can be repeated at least ten or more times before the color becomes too pale to be seen. The chart shows how much dye is left after various dilutions.

Dilutions	Proportion of Dye Left
1	1 ounce
2	½ ounce
3	¼ ounce
8	about 1/100 ounce
11	about 1/1,000 ounce
15	about 1/10,000 ounce
18	about 1/100,000 ounce
20	about 1/500,000 ounce

For best results, place a sheet of unlined white paper under the bottle and have the children look downward through the solution to see how much color is visible after each dilution. They should also compare the color after each dilution with the bottle of tap water.

What sort of estimate can the children make now about the "order of magnitude" of the number of molecules present in this colored solution? Hundreds? Thousands? Millions? Billions? Ask them to recall the deep color of the solution at the start and its gradual lightening with each dilution. What do they think this indicated about the number of molecules present? *(There were very many at the start and fewer toward the end of the dilution.)* Since only one half-millionth of the amount of dye was left after twenty dilutions, the number of dye molecules at the start must have been at least several millions. *(The actual number of molecules in the quart of liquid, is, of course, many more than several millions. In the case of this experience, the technique can only indicate the degree of largeness of the numbers involved, not the actual number of molecules.)*

Extending Ideas: To have the children estimate the number of molecules in a solution by taste rather than color, use the same procedure as given above; however, use one ounce of sugar, salt, or vinegar in place of the dye. Pour a little of the solution into cups and have a number of children taste it. After each dilution, have the same children taste the solution again. Do they find the taste as strong as before? How many dilutions can be made of each of these substances before its taste is undetectable? Is the number of dilutions the same for each? *(About four dilutions for sugar and vinegar, about eight for salt.)*

Some children may be interested in experimenting with stronger tasting substances, such as the synthetic sweeteners saccharine and Sucaryl, or bitter quinine. Do they find that much higher dilutions can be made with these than with sugar? *(Saccharine is about 700 times as strong tasting as sugar, and quinine is more than 10 million times stronger than sugar. Only very small amounts of these substances should be used in making the initial solutions.)*

Ask the children to give their ideas about the number of molecules present, based on the fact that these substances can still be tasted after being diluted with so much water.

Learnings: Some idea of the number of molecules in a solution may be obtained by observing the color or taste of the solution after a number of dilutions. A single drop of a liquid contains millions upon millions of molecules.

ACTIVITY 31 (y,z)

DEMONSTRATING THE SMALL SIZE OF ATOMS AND MOLECULES

Purpose: To investigate the relationship between the sizes of objects and the space they fill

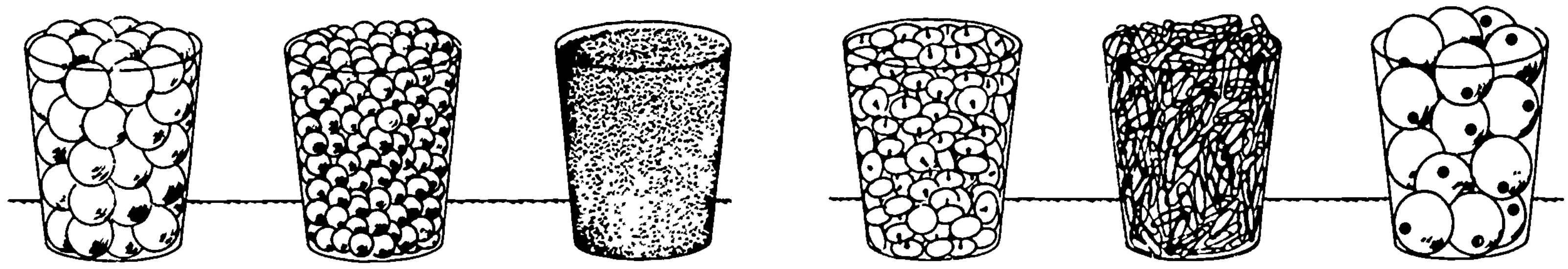
Concept to be developed: Atoms and molecules are extremely small.

Materials needed:

Marbles
Beads
BB shot
Thumbtacks
Paper clips
Gravel or sand
One-ounce paper cups

INTRODUCTION: Since there are vast numbers of molecules in even a speck of matter, as the children saw in the previous Activity, the individual molecules must be extremely small. The following Activity will show the relationship between sizes of objects and the space they fill.

Ask the children to fill separate cups with each of the materials listed above. Which cup do they find contains the greatest number of objects? *(The cup containing sand.)* Are these the smallest or the largest objects? *(The smallest.)* Do they see that the smaller the size of an object, the more objects of that size can be packed into a given space?



MARBLES B-B SHOT SAND THUMBTACKS PAPER CLIPS BEADS

Help the children apply this relationship to the fac: that molecules must be extremely small if a very large number of them are contained in a speck of matter. The following "word pictures" dealing with the sizes of molecules and atoms can help children visualize the numerical concepts involved:

- On the average, an atom is about one hundred-millionth of an inch in diameter.
- If atoms were as large as golf balls, the number of atoms in an inch would then stretch from New York to San Francisco.
- If a piece of rock, or anything else, one inch in diameter were enlarged to the size of the Earth, its atoms would become about the size of tennis balls.

Learnings: There is a relationship between the size of objects and the quantity of those objects that will fit into a given space: the smaller the object, the greater the number that will fit in. Since large numbers of atoms and molecules can occupy very small spaces, atoms and molecules must be very small.

IMPORTANT IDEAS IN THIS CHAPTER

For kindergarten, primary, and intermediate grade children the kinds of ideas with the most application and meaning are:

- Elements are composed of very small particles called atoms.
- Compounds are composed of very small particles called molecules.
- Matter is particulate in nature.
- An emulsion is a mixture of two substances that do not ordinarily mix together; one substance is suspended within the other and its molecules prevented from flowing together by an emulsifying agent.
- When one substance is dissolved in another, it breaks up into particles so small that they cannot be seen even with a microscope.
- Evaporation takes place when small particles of a liquid enter the gaseous state and pass into the atmosphere.
- Crystals may be grown from a solution.
- Crystals can be split along lines of weakness, called cleavage planes.
- Atoms and molecules are very small.
- There are millions upon millions of atoms in any small amount of any form of matter.

In the intermediate and upper grades, the children should be led to develop concepts that are more complex and quantitative:

- Some substances change directly from the solid form to the gaseous form without first becoming liquid.
- Invisible molecules of water vapor present in the air can be condensed to form visible droplets of water.
- Crystals grow from a solution when atoms or molecules of the substance dissolved in the solution are deposited upon a nucleus.
- The crystals of a substance have a characteristic structure.

4

INVESTIGATING THE ARRANGEMENT OF ATOMS AND MOLECULES IN MATTER

"What makes the rain fall in drops?"

"Why does a rubber ball bounce?"

"If I am made of millions of separate little molecules, why don't I fall apart like a heap of marbles?"

"What do atoms and molecules really look like?"

"Why are plastics called man-made?"

"How do we get electricity from batteries?"

The experiences in this chapter will help the children apply their knowledge of atoms and molecules to understand how some of the properties of matter are traceable to its molecular structure. For example, the elasticity of a rubber ball or the solidity of a wooden table depends on the way their molecules are arranged and held together. A mental picture of a table in terms of its molecular structure is totally different from our "commonsense" perceptions; when considered in this way, a table consists mostly of empty space in which enormous numbers of atoms and molecules are located. Yet, despite this strange construction, the table does not fall apart; it supports things lying on it and prevents them from falling through the empty spaces. This "molecular table" may seem "unreal," but such a molecular view is important since it makes it possible to reach deeper understandings about the nature of matter.

The preceding chapters have introduced and developed the generalization that all matter is composed of atoms and molecules, and that when large numbers of these "particles" come together we have matter that can be seen, tasted, smelled, felt, and otherwise experienced by our senses. However, another idea is needed at this point: if matter is made up of tiny particles, or bits, there must be empty spaces between them. In fact, matter is literally full of holes—the spaces between the molecules that make up the solids, liquids, and gases of the world. (There is also space within each of the atoms that make up a molecule, but the Activities in this chapter deal only with the spaces between the "particles" of a substance; the empty space within a single atom is one of the topics in Chapter 5.)

The porosity of matter is the first major concept presented in this chapter. Simple Activities are described to challenge children's thinking about solids as being impenetrable, and to deepen their concepts about the particulate structure of all other states of matter.

For example, children may have noticed that within a few days after a balloon has been inflated, it will have shrunk in size. How has the air been lost? If there are no tiny holes in the balloon and if it has been tightly sealed, it seems reasonable to assume that the air has somehow seeped out through the "solid" rubber. This assumption is tested by other Activities in which children discover that gases and liquids can indeed pass into and out of seemingly solid containers, because, at the molecular level, these solids are porous. What happens when substances are dissolved in water can similarly be explained as being a consequence of the porosity of matter. The molecules of the dissolved substance become dispersed in the spaces between the molecules of the solvent.

The next major idea presented is: what do atoms and molecules really look like? The quickest answer to this question is that no one really knows! However, scientists have formed some very good ideas of what they probably look like. (Only some of the very largest molecules, containing thousands of atoms, are big enough to be seen with an electron microscope.) A mental picture of the appearance of smaller molecules has been built up indirectly from countless observations and experiments over many years. Most of the Activities in this section can lead children to form similar conceptual models or mental pictures of what molecules may look like, and will provide some experience with the use of such models in scientific thinking. When a model helps us to understand how certain things happen, such as how water dissolves salt, or iron rusts, we say the model works. A truly successful model also helps us make predictions and can lead to new knowledge. On the basis of one such model, in which all the known elements were arranged in a table according to their relative weights, chemists were able to deduce that some elements were missing from their places. A search for these unknown elements led to their discovery. The models described here, whether they be made of thoughts or objects, should be similarly developed with the children as tentative constructions that help us explain and predict the behavior of matter, and not as direct representations of reality.

Another main section of the chapter deals with the forces that hold molecules together and give them their shapes. When atoms combine to form molecules they do so in some regular way so that all the molecules of a substance are identical in size, shape, and behavior. Atoms act this way because each atom has a definite combining power, or capacity, that determines the number and kind of other atoms with which it can join. Directions are given for making a variety of models to help children visualize how atoms and molecules are thought to be arranged and held together in different substances.

A long time ago it was thought that an atom had tiny hooks or spines attached to it, the number of hooks being equal to its combining power. Molecules would then be built up by the hooks of some atoms fastening onto the hooks of other atoms to form drops of rain, to hold us together, or to make glue sticky. However, this model does not explain enough; it does not indicate, for example, why different substances should melt, freeze, and boil at different temperatures. Today, it is certain that the bonds between atoms are not such simple mechanical links, although this "hook model" may sometimes be a useful way to think of the different combining powers of various kinds of atoms.

What then holds atoms and molecules together? The answer to this question is known, but only in a general way. It is contained in a single word—electricity. Electrical forces hold atoms together to form molecules, and hold molecules to each other to form large visible amounts of matter. All molecules exert a weak electrical attraction upon one another. This attraction is thought to be due to the fact that the atoms themselves are composed of electrically charged particles (electrons and protons) that attract or repel each other depending on their charge and number. (The electrical nature of the atom is developed more fully in Chapter 5.) There are many experiences and observations to indicate that electricity is somehow deeply involved in the structure of matter. Some of these Activities include producing electricity from various substances, electroplating metals, decomposing compounds by electric current, and charging objects with static electricity.

As a whole, the Activities of this chapter will show children how powerful the abstract concepts of the scientist can be in illuminating many commonsense observations of matter. Equal importance should be placed on helping the children practice the processes and techniques used by scientists in arriving at these powerful ideas.

HOW DO WE KNOW THERE IS SPACE BETWEEN MOLECULES?

Since visible amounts of matter are built up by the aggregation of many atoms or molecules, it is logical to expect that the spaces between these particles would give substances a porous quality. It might also be predicted that if the atoms or molecules of one substance are small enough, they can pass right through the larger spaces of another substance. Actually, substances differ greatly in the size of the spaces between their molecules and in the ease with which other substances can pass through the molecular "pores." The following Activities provide experiences in which children can discover, and then test, the validity of this concept.

ACTIVITY 32 (x,y,z)

SEEING THAT MATTER IS POROUS (variation a)

Purpose: To show that gaseous matter can pass through other matter that is apparently "solid"

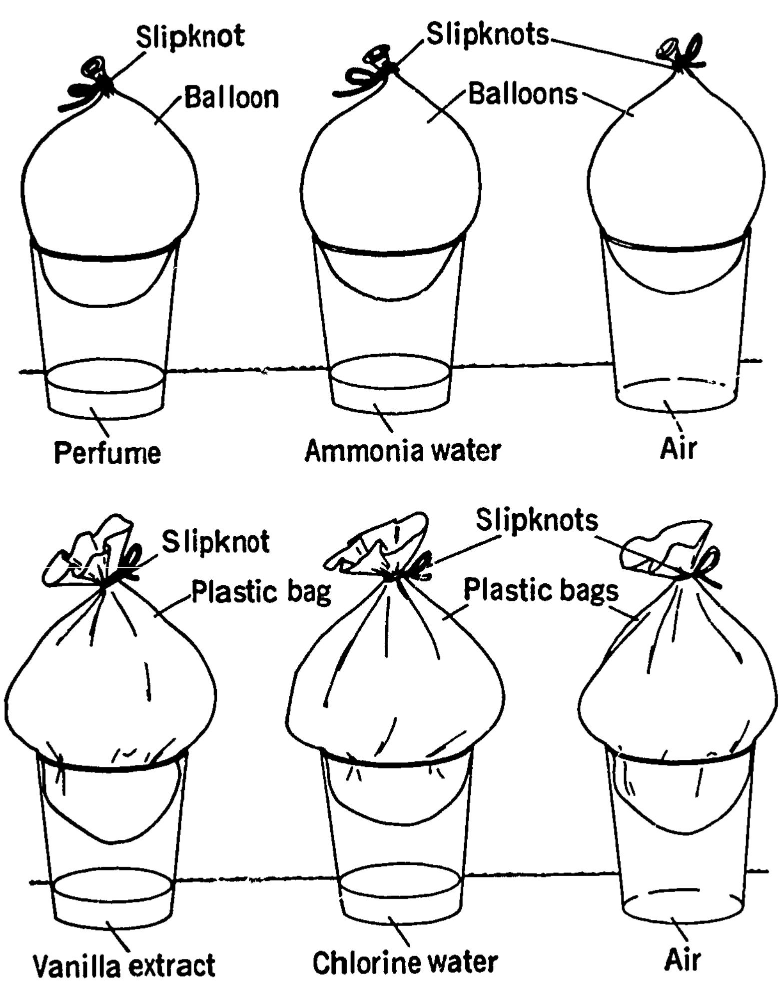
Concept to be developed: There are spaces between the molecules that make up a substance.

Materials needed:

Rubber balloons or plastic bags
Drinking glasses or wide-mouthed jars
String
Perfume
Household ammonia
Vanilla extract
Chlorine water
Other strong-smelling substances

INTRODUCTION: Ask the children if they have noticed that within a few days after a balloon has been inflated it seems to shrink in size. Ask them to theorize as to why this happens. Ask them if they think that the air could have passed out through the "solid" walls of the balloon. After they have expressed their opinions, tell them that the following two Activities will help the children to find out whether the air could have passed through the walls of the balloon.

Have the children pour a spoonful or two of each odoriferous substance into a separate glass. Then have them insert a balloon or plastic bag about one-third of the way into each glass or



jar, and inflate the balloon so that it is wedged tightly in the opening to prevent the odors from escaping. The balloons should be tied with string, using a slip knot that can be easily opened later in the experiment. For controls, remind the children to place one or more of each kind of inflated object into empty jars that contain no strong-smelling substances. Allow the jars to stand for two or three days. Then have the children unseal each balloon and bag, and smell the air as it escapes. How did the odors get inside? *(As the substances evaporated, some of their molecules seeped through the walls of the inflated object and mixed with the air inside.)* What conclusions can the children draw about the porosity of different substances? *(There are spaces between the molecules of rubber that are large enough so that some gases can pass through them. The plastic bags will show much less "porosity," the actual amount depending on the type of plastic.)*

Learnings: Matter is porous. There are spaces between the molecules of substances through which small molecules may pass.

ACTIVITY 33 (x,y,z)

SEEING THAT MATTER IS POROUS (variation b)

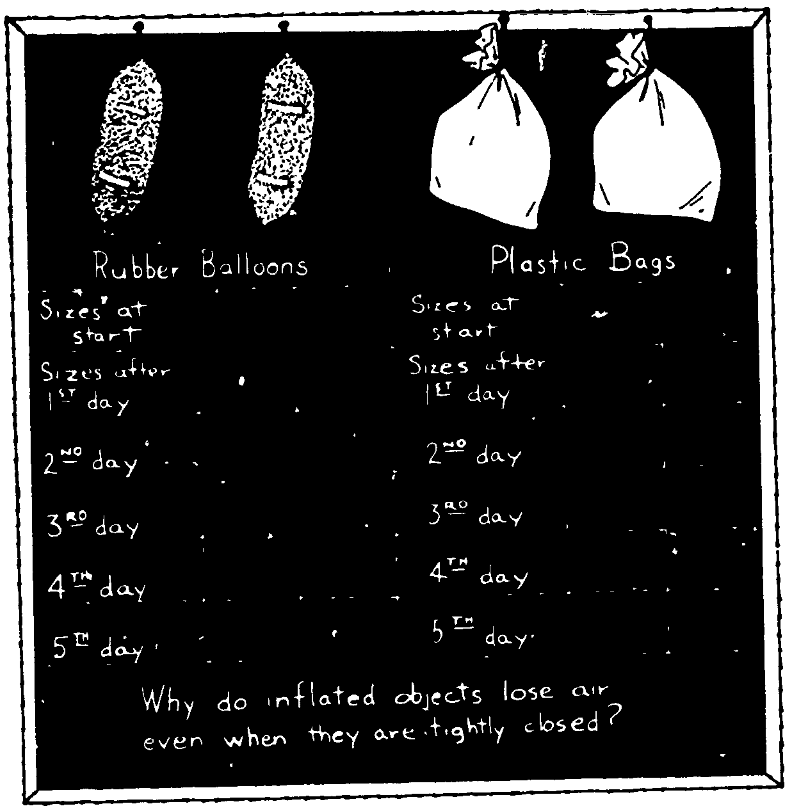
Purpose: To show that gaseous matter can pass through other matter that is apparently "solid"

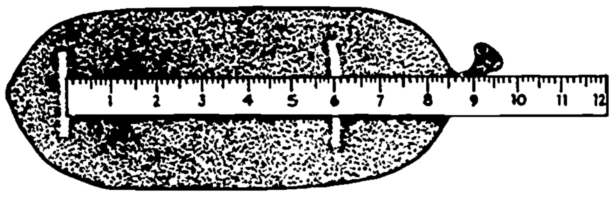
Concept to be developed: There are spaces between the molecules that make up a substance.

Materials needed:

Rubber balloons
Plastic bags
Ball-point pen
String
Ruler

Have the children inflate a number of balloons and plastic bags and knot or seal the openings tightly. They should then hang them on a chalkboard or bulletin board as shown in the illustration. Any loss of air in the inflated objects can be detected in the following way: Have the children make two marks 6 inches apart on one side of the inflated object. The distance between these two marks will decrease as the inflated objects lose air. Measurements should be taken at the same time each day. A record of any changes can be written on the chalkboard in the spaces under each balloon and bag.





What predictions can the children make about each case? Make a list of their predictions and have them check the accuracy of their predictions when results become noticeable. *(The air should escape more quickly through the rubber balloons, and slowly through the plastic bags, if at all, since the "pores" of the balloons are the larger.)*

Sometimes it is possible to buy helium-filled balloons at places like an amusement park. Have the children compare the gas seepage rate of such a balloon with one filled with air. Will the kind of gas used be important? *(The helium-filled balloon will shrink faster because helium atoms are smaller than those of the gases in the air.)*

Learnings: Matter is porous. There are spaces between the molecules of substances through which small molecules may pass.

ACTIVITY 34 (y,z)

SEEING THAT MATTER IS POROUS (variation c)

Purpose: To show that liquid matter can pass through other matter that is apparently "solid"

Concept to be developed: There are spaces between the molecules of a substance.

Materials needed:

- 3 small plastic bags
- 3 large, wide-mouthed jars
- Ammonia water
- Alkali indicator (red litmus, 0.1 percent solution of phenolphthalein, or other indicator dye, available at drugstores)

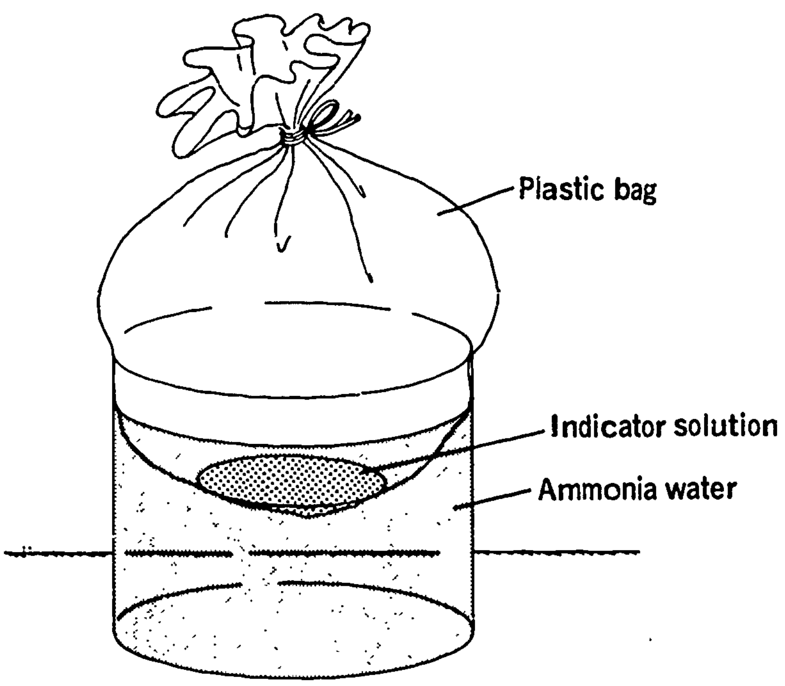
INTRODUCTION: Mention to the children that the porosity of matter is also evidenced by the fact that water, and substances dissolved in it, can pass through thin sheets (membranes) of some solid substances. Can children devise a way of proving this? What "thin sheet" could they use? Suggest that the plastic bag be used again. In what liquids might it be immersed? Elicit their theories, and then proceed with the following Activity.

First explain the necessity of having an "indicator" solution. An indicator solution changes color under certain conditions.* Alkali indicators, such as red litmus and phenolphthalein, are one color in acid solutions and another color in alkali solutions. The reason for using them in this Activity is to detect the presence of ammonia water, which is an alkali, in determining whether it passes through a plastic bag. Demonstrate the reaction of the indicator to the ammonia water by adding a drop or two of ammonia water to an ounce of the indicator solution. *(The solution will turn a wine color if the indicator is phenolphthalein, or blue if the indicator is litmus.)* Show that no color change results when ammonia or indicator is added to tap water.

After testing a small plastic bag for leaks by filling it with water, fill it half-full of indicator solution and place it into a large jar containing the ammonia water. Have the children observe what happens after a short interval. *(The indicator changes color.)* How do they explain this? *(Some molecules of ammonia have passed through*

*For a more complete discussion of indicators, see *The Earth*, by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

the plastic as shown by the change in the color of the indicator solution. Therefore, there must be very tiny spaces between the molecules making up the plastic.)



Learnings: Matter is porous. There are spaces between the molecules of substances through which small molecules may pass.

ACTIVITY 35 (z)

DISCOVERING THAT THERE ARE SPACES BETWEEN MOLECULES

Purpose: To discover that there are spaces between water molecules

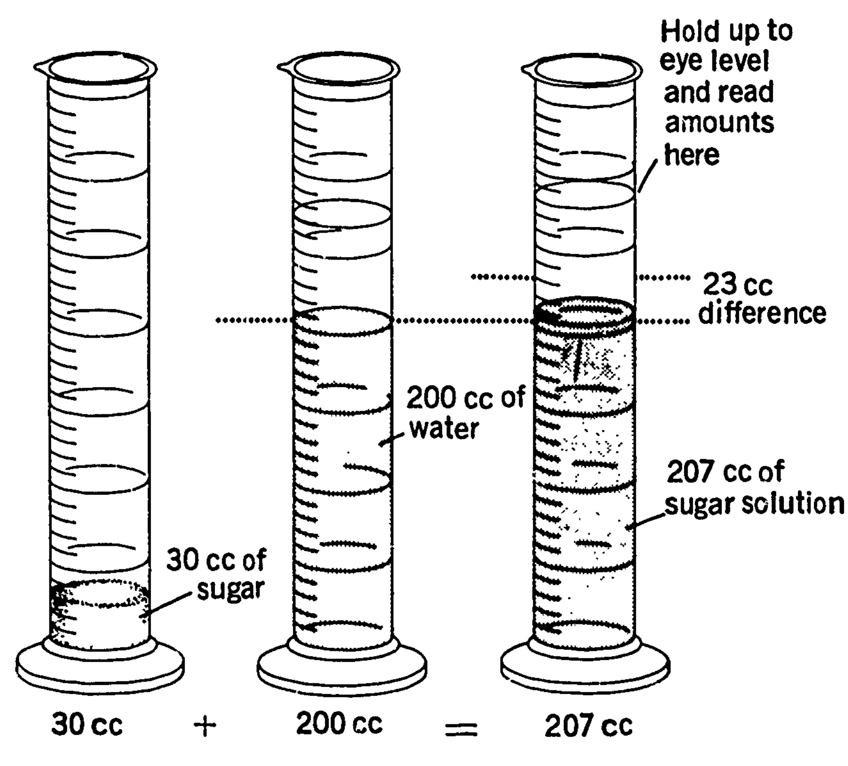
Concept to be developed: When solids dissolve, their particles enter into the spaces between the molecules of the liquid in which they are dissolved.

Materials needed:

Sugar
Salt
Baking soda
Copper sulfate
Tablespoon
Drinking glasses
Masking tape
2 graduated cylinders (250 cc) or tall narrow olive jars

INTRODUCTION: Ask the children what they think would happen to the molecules of a solid if the molecules were dissolved in a liquid. Can they devise a procedure that would help them find out? Suggest that since the children know that liquid and solid substances take up space, perhaps they could try measuring them before and after making the solution to see what results are obtained. Perhaps such a process would help them answer the question of what happens to the molecules of a solid when it is dissolved in a liquid. The following Activity will show them how to carry out this investigation.

Have the children measure out about 2 tablespoons of sugar into a graduated cylinder. (If a graduated cylinder is not available, an olive jar can be converted into one as follows: Place a strip of masking tape down the side of the jar from top to bottom. With a ruler, mark off ¼-inch intervals on the tape. Quantities of material can now be measured in terms of height in inches—using quantities of materials proportional to those given in cc's.) The sugar should be tamped or shaken down gently to eliminate as much air as possible between the grains. More sugar should then be added and tamped until the cylinder is filled to the 30-cc mark (about 1 ounce). This quantity of sugar should then be transferred to a drinking glass, and 200 cc of warm water measured in the cylinder.



Now have the children add the water to the sugar in the glass and mix until the sugar has dissolved completely. Ask the children what they think the combined total of the sugar and water should be. Have them pour the solution back into the graduated cylinder and see if they are correct. *(Although they might expect 30 cc of sugar and 200 cc of water to add up to 230 cc of solution, the total will actually be about 207 cc, or 10 percent less.)*

Have them try the same experiment using salt, baking soda, and other soluble substances. What results do they find? *(In most cases the actual total is about 10 percent less than would be expected.)* Give the children a chance to hypothesize as to why this happens. *(The Activity actually points to two conclusions. First, apparently continuous matter has empty spaces in it; in other words, matter consists of particles. Second, in some solutions, the particles of the two substances are so intimately mingled that the particles of each substance enter the spaces between the particles of the other.)*

Extending Ideas: Point out to the children the possibility that even when as much sugar as possible has been dissolved in water (a saturated solution), there may still be room between the molecules in the solution for other substances to enter. Suggest that this may be tested in the following manner.

Have the children prepare a saturated sugar solution by adding teaspoons of sugar to a glass half-filled with warm water, and stirring vigorously. When no more sugar dissolves—that is, when there is some undissolved sugar at the bottom of the glass—the solution is saturated. They may now add one more teaspoon of powdered copper sulfate, and stir it into the solution. What happens to the colorless solution? *(It takes on a blue color, which indicates that some molecules of copper sulfate have dissolved by fitting into the spaces between the molecules of sugar and water.)*

Review with the children that various solids, liquids, and gases are porous because of the spaces that exist between the atoms or molecules of which they are made. Have them restate their learnings as follows: in mixtures of substances, the extent to which their molecules enter the spaces between each other may vary from almost not at all to very much. A solution of equal parts of alcohol and water, for example, will actually add up to a smaller volume than the arithmetical sum of the two starting quantities. The solutions of sugar, salt, and other substances made by children in this chapter show similar results, although to a much lesser degree. The "porosity" explanation of the movement of gases and liquids through solids is of additional help in understanding the nature of matter.

It may be interesting to have the children think about how small these molecular spaces might be, and about the even smaller size of other atoms and molecules that can fit between them. Some children may wish to examine pieces of rubber or plastic with a microscope to see if the molecular "pores" are visible. They should be encouraged to do so, even though the results will be negative; the molecular spaces are far too small to be seen. Of course, children will not be able to estimate the sizes involved in any numerical way, yet these experiences with the porosity of matter can nevertheless enrich their understanding of the generalization: There is space between the molecules of substances.

This concept is not only helpful in appreciating the atomic-molecular nature of matter but is also of great importance in understanding the functioning of living things. The intermolecular spaces of substances make it possible for dissolved nutrients and gases to pass into and out of the cells of plants and animals.*

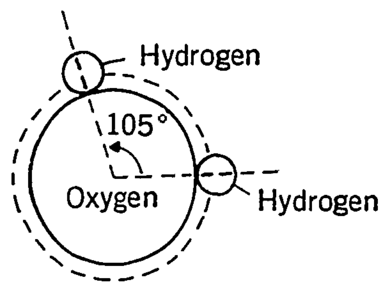
Learnings: There are spaces between the molecules of a substance. When a solid is dissolved in a liquid, the molecules of the solid fit into the spaces between the molecules of the liquid.

Summing Up Ideas: In this section the children were introduced to the concept that space exists between the molecules that make up substances. They learned how this accounts for the fact that liquids and gases can pass through seemingly solid materials. They also learned about the mechanism of solutions, that is, how the molecules of one substance could occupy the spaces between the molecules of another substance, thus lowering the total volume to a size below that which might be expected.

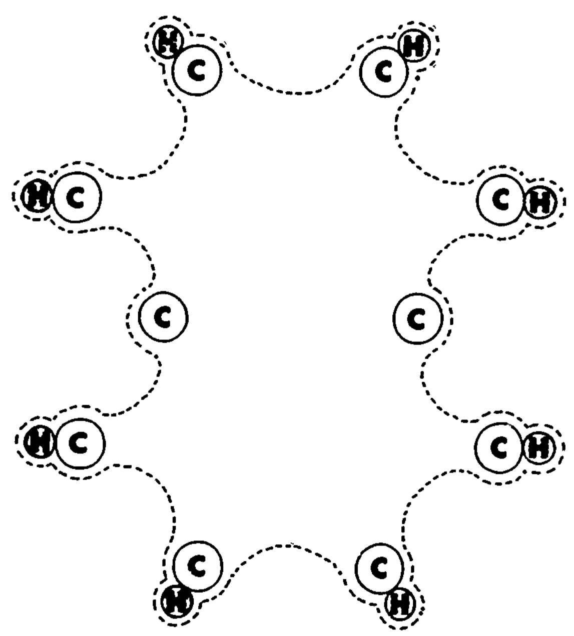
WHAT DO MOLECULES LOOK LIKE?

The actual appearance of any one molecule is not known, except in a most general way. It is known, however, that a single molecule of a substance has a particular size and shape. For example, as the accompanying illustrations show, in a molecule of water, two atoms of hydrogen are

*For additional information on the applications of this concept in the life processes, see *Living Things*, by James Wailes (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964) linked to one larger atom of oxygen at an angle of 105 degrees; in a molecule of naphthalene, ten carbon atoms are arranged to form two joined hexagons (called rings), with a single atom of hydrogen attached to each of eight of these carbon atoms.



WATER MOLECULE (H_2O)



NAPHTHALENE MOLECULE ($C_{10}H_8$)

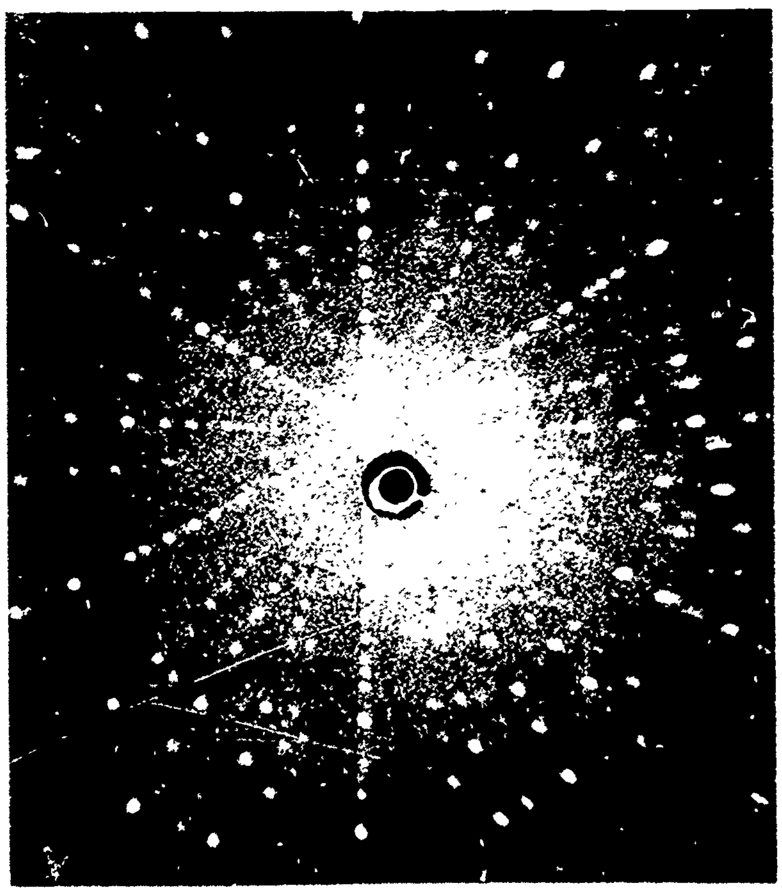
Scientists are able to draw such diagrams, not because they have ever seen these molecules directly, but because they have been able to piece together many clues gained from observing the behavior and properties of matter. The same approach to building up a mental picture of what some molecules may look like in a general way is followed in this section.

Children often ask about the techniques used by scientists to "see" what molecules really look like. The electron microscope is one device by which unusually large molecules have been observed. The accompanying photograph may be shown to the class with an opaque projector.

The structure of many other smaller molecules has been determined by the technique of shooting a beam of X rays through a thin slice of a substance, usually a crystal. This results in a

Collagen molecules magnified 100,000 times.

kind of shadow being cast on a screen or film. The pattern of the shadow is usually an array of dots, or spots. These dots are caused by a scattering of the rays striking the atoms or molecules in the substance and by rays that passed through the crystal without contacting these particles. By studying the arrangement of the dots, scientists can figure out how the atoms and molecules are arranged in the crystal. The accompanying photograph shows such a shadow picture made by X rays passing through crystals.



X-ray photograph of a quartz crystal.

The large spot in the middle of the picture was made by the unscattered part of the beam.

ACTIVITY 36 (z)

DEMONSTRATING HOW SHADOW PICTURES SHOW THE ARRANGEMENT OF MOLECULES IN A SUBSTANCE

Purpose: To demonstrate the methods by which shadow pictures are produced and interpreted

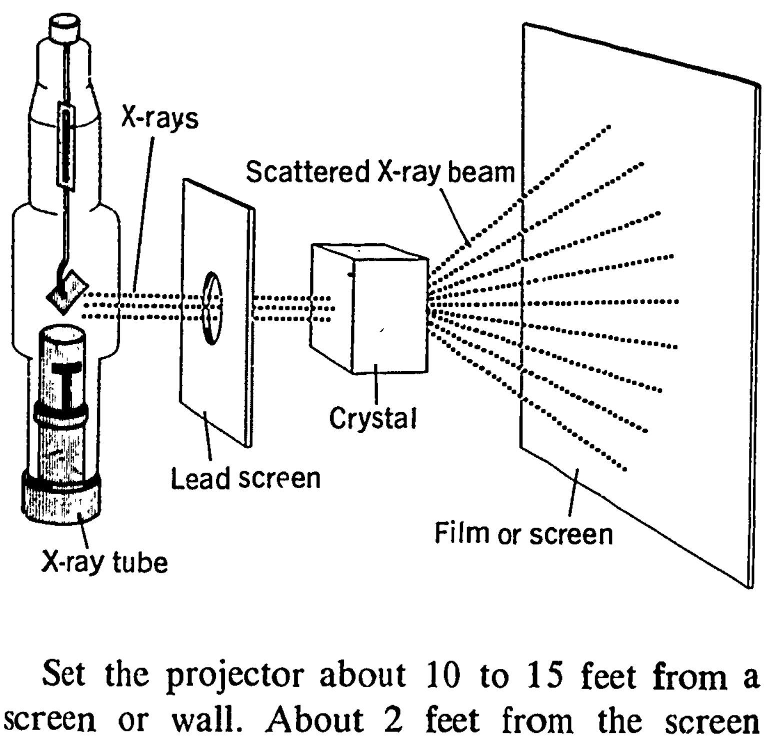
Concept to be developed: A study of the shadow pictures produced by X-ray techniques enables scientists to understand the structure of molecules.

Materials needed:

Filmstrip or slide projector
Cardboard carton
Crystal models made of gumdrops and toothpicks
Screen (optional)

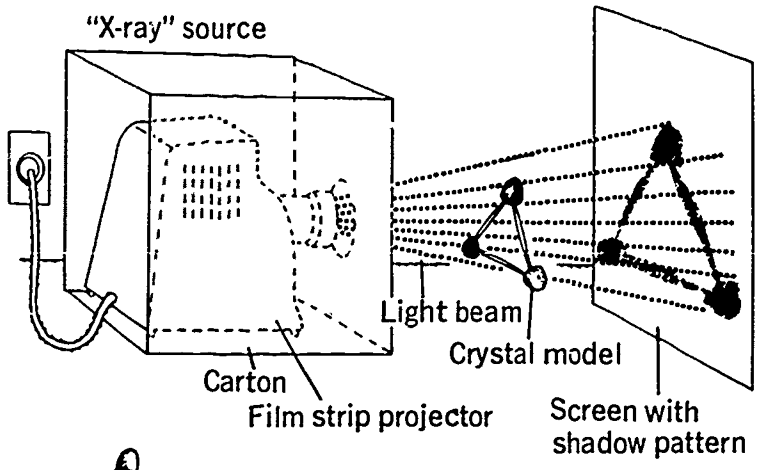
INTRODUCTION: Discuss shadow pictures with the children, and if possible, show them some. Then ask them to devise a method of illustrating the shadow technique. A working model of the shadow technique can be easily made in the classroom and used by the children to investigate the arrangement of "molecules" in a large three-dimensional model of a crystal. Sketch a diagram of the scientists' equipment on the board and explain how its operation will be imitated by the classroom model. A beam of light from the projector takes the place of the X rays. The lead shield or screen is imitated by placing the projector inside a cardboard carton, which has had a hole cut in it through which the light can shine. The crystal models shown in the illustration can be made of gumdrops and toothpicks, or the model shown in Activity 39 may be used.

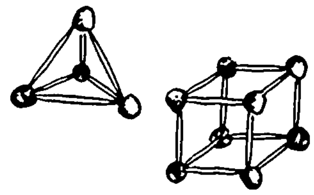
THE SCIENTIST'S EQUIPMENT



Set the projector about 10 to 15 feet from a screen or wall. About 2 feet from the screen place a book, vase, or any object of similiar size so that a shadow is cast. Adjust the lens until a

CLASSROOM MODEL OF THE SCIENTIST'S EQUIPMENT





OTHER GUMDROP AND TOOTHPICK CRYSTAL MODELS TO TRY

clear shadow with sharp outlines appears on the screen. Now replace the object with the crystal model and have the class observe the pattern on the screen.

Point out how the shadow is an enlargement of the model, but that it has only two dimensions —length and width—while the crystal has three dimensions. (Shadows will also be cast by the toothpicks or other links used to join the atoms in the model, but these should be disregarded.) Rotate the crystal model to different positions to show that other patterns appear. Help the children to see how the shadow can be used to determine the shape of the object that cast it.

Can the children deduce the shape of another crystal model by using these shadow patterns? Ask the children to face the rear of the room while you place a different model into the light beam. Set up a barrier of books between the model and the class so as to block their view of it. With the new shadow pattern now projected on the screen, have the children tell you how to turn the model and position it, while they try to infer its shape in three dimensions.

The X-ray shadow technique is limited since it shows the molecules only as dots, indicating where they are located in a sample of matter. In general, however, the technique gives direct evidence that there are spaces between the molecules in matter.

Learnings: Shadow pictures help to determine the relative positions of molecules in a substance. Shadow techniques demonstrate the fact that spaces exist between the molecules of a substance.

ACTIVITY 37 (y,z)

MAKING MODELS OF MOLECULES

Purpose: To discover the arrangements that atoms may have within molecules

Concept to be devel..ed: Atoms are joined together in definite configurations to form molecules.

Materials needed:

For atoms: plastic clay, sponge rubber balls, pop-it beads, gum drops, Tinker Toy disks, or styrofoam balls
For links: wire, pipe cleaners, toothpicks, or Tinker Toy sticks
Long wire or string

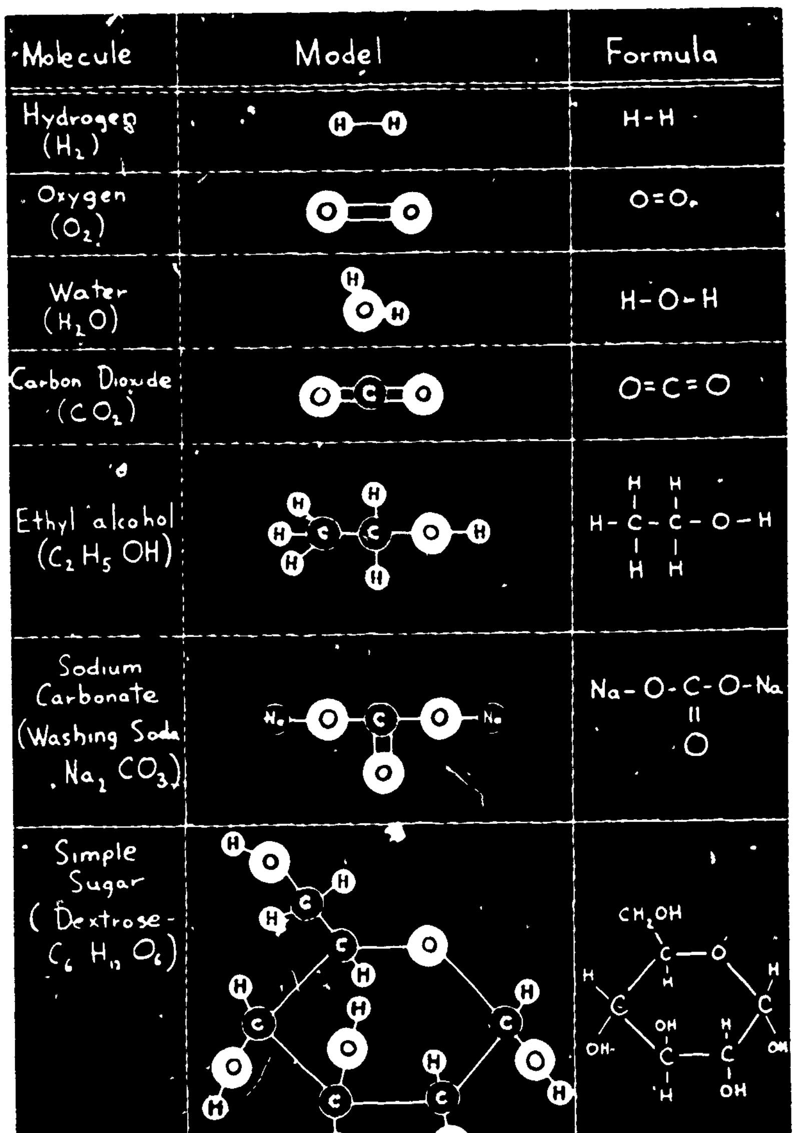
[Some of the best clues to the shape of single molecules have come from measurements of the quantities of elements involved when compounds are formed or decomposed. Such measurements show that when different kinds of atoms react, the amounts of each are always in some definite ratio to the others. This suggests that each individual atom has a numerically fixed capacity, or combining power, which the scientist calls its *valence*. The capacity to combine is due to the amount of electric charge that atoms may require. Such charged atoms or groups of atoms are called *ions*. For example, in table salt (sodium chloride) the sodium ions, which have one plus (+) charge, are attracted to the chloride ions, which have one minus (−) charge. An analysis of salt always shows the ratio of sodium ions to chloride ions to be 1:1. Sodium is then said to have a valence of plus 1, and chlorine a valence of minus 1. The combining powers (valence) of some other common elements are given in the accompanying table.]

SOME ELEMENTS AND THEIR MOST COMMON VALENCES

Element	Valence	Element	Valence
Copper (Cu)	+1 or +2	Carbon (C)	+4 or −4
Hydrogen (H)	+1	Nitrogen (N)	−3
Silver (Ag)	+1	Phosphorus (P)	−3
Sodium (Na)	+1	Oxygen (O)	−2
Calcium (Ca)	+2	Sulfur (S)	−2
Iron (Fe)	+2 or +3	Bromine (Br)	−1
Tin (Sn)	+2 or +4	Chlorine (Cl)	−1
Zinc (Zn)	+2	Fluorine (F)	−1
Aluminum (Al)	+3	Iodine (I)	−1

INTRODUCTION: An understanding of valence will be useful in building models of the molecules mentioned in this chapter. Present such material from the preceding paragraphs as is appropriate to the children's level of interest and ability. Explain to the children that in a model, the number of "hooks," or links, by which one atom is joined to others represents the valence of the atoms. Children will find that making models helps them visualize what some molecules might look like. Point out to the class quite strongly, however, that such models are little better than diagrams in three dimensions. They are only crude representations of what is known. To build a model that resembles a molecule as scientists think it really looks, they would have to take into account many other factors, such as the correct spacing between atoms, the angle at which the atoms are joined, the movement of atoms in a molecule, and the fact that atoms are not hard little spheres.

Using an opaque projector, show the children the accompanying diagrams, or sketch the diagrams on the chalkboard. Have the children

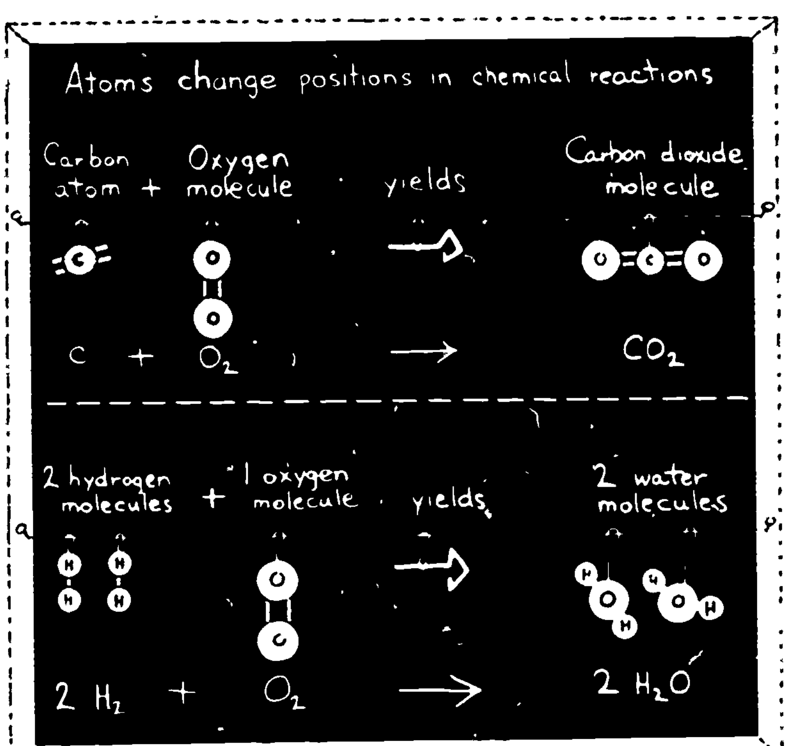


build models of each of the molecules. In assembling the models, these simple rules must be observed: only elements with unlike charges can be combined (plus and minus); no atom can have more atoms attached to it than it has "links" (valence number); and all "links" must be occupied. (These rules are accurate for all the molecules shown in these illustrations, although there are exceptions for other compounds.)

A wide variety of materials can be used in representing the atoms and their linkages in building molecular models. The atoms might also be painted to identify them as being of a certain element and marked + or − for their electric charge.

Allow the children to use any materials their ingenuity can suggest. A particularly useful material is styrofoam. This is the foamed plastic from which "snowballs" are made during the Christmas season. Styrofoam snowballs are available in various colors and sizes from ½ inch to 6 inches in diameter, and are inexpensive. Their lightness, durability, and striking appearance make them easy to work with and they form ideal "atoms" for model-making. Styrofoam balls are linked simply by punching holes into them with a knitting needle, and then inserting short lengths of pipe cleaner to hold them together.

Extending Ideas: The children can use their models of atoms and molecules to show how atoms change position when compounds are formed or decomposed. By suspending the atom models from a long wire or string running across the chalkboard, various reactions can be shown. The accompanying illustration shows the formation of two different compounds.



Suggest that the children label each part of the display, and explain what happens in the reaction by sliding the models along the string and rearranging them to form the end products. (Any high school chemistry text will provide more examples of reactions in which the correct number of atoms is shown.)

Learnings: Atoms are joined together in definite arrangements to form molecules. The arrangement of the molecules of each compound is different from the arrangement of the molecules of every other compound. The valence of an element determines how many "links" its atoms can have with other atoms.

ACTIVITY 38 (y,z)

MAKING MODELS OF ATOMS AND MOLECULES IN SOLIDS (variation a)

Purpose: To demonstrate the ways atoms and molecules are arranged in solids

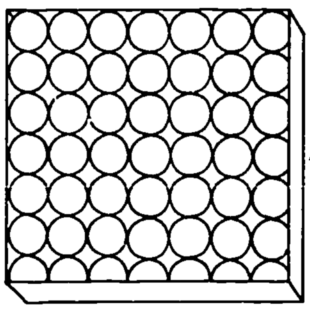
Concept to be developed: There are many different ways in which atoms and molecules can be packed into a given space.

Materials needed:

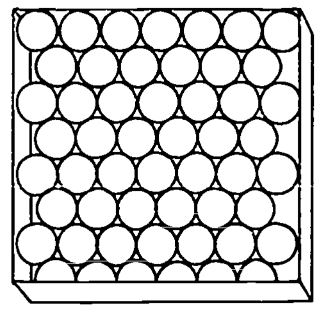
- Flat round disks or buttons, about ½ inch in diameter
- Shallow, flat-bottomed trays or jar caps, 4 to 8 inches in diameter
- Soap-bubble solution
- Capillary tube, medicine-dropper tube, soda straw, or fine-bore plastic tubing (from an aquarium supply shop)

INTRODUCTION: Review with the class the idea that solids are made up of many particles grouped together. Do the children think these particles are grouped in any particular way or just randomly arranged like marbles in a sack? Have them investigate the many different ways in which model atoms or ions can be arranged in a given space.

Provide the children with trays and a large number of disks (coins, cardboard disks, bingo or lotto markers, buttons, etc.) to serve as "atoms." Have them try different arrangements in placing the disks side by side on the bottom of the trays. Which is the most efficient arrangement for packing these atoms into the space available? *(The illustration shows two such arrangements, both of which are found in different kinds of solid matter.)*



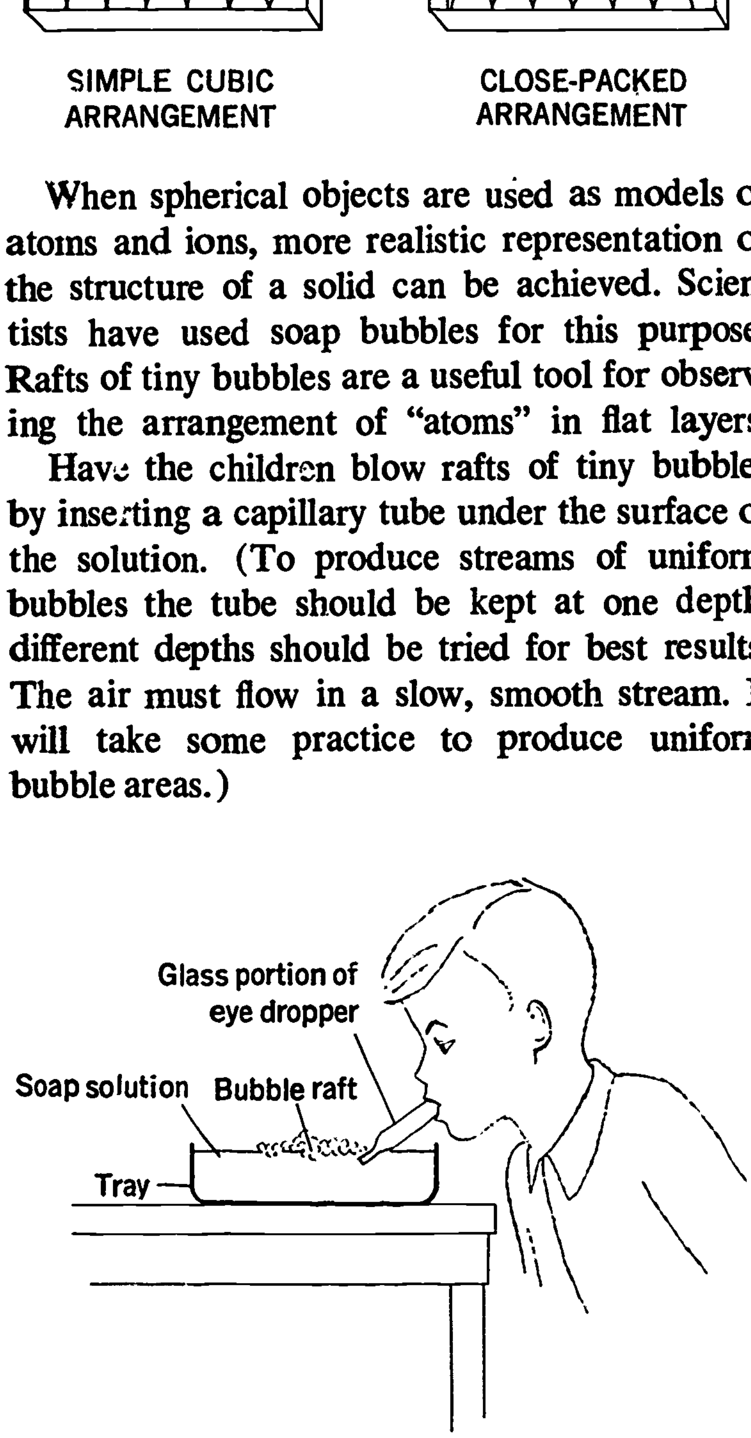
SIMPLE CUBIC ARRANGEMENT



CLOSE-PACKED ARRANGEMENT

When spherical objects are used as models of atoms and ions, more realistic representation of the structure of a solid can be achieved. Scientists have used soap bubbles for this purpose. Rafts of tiny bubbles are a useful tool for observing the arrangement of "atoms" in flat layers.

Have the children blow rafts of tiny bubbles by inserting a capillary tube under the surface of the solution. (To produce streams of uniform bubbles the tube should be kept at one depth; different depths should be tried for best results. The air must flow in a slow, smooth stream. It will take some practice to produce uniform bubble areas.)



Point out some of the following ways in which the bubbles resemble and imitate atoms and their behavior:

- The bubbles cling to each other to form rafts; this is similar to the attraction of atoms for each other to form an orderly arrangement and "solid" structure.
- The bubbles arrange themselves so as to pack the greatest number of "atoms" into the space available.
- The bubbles rise and fall and vibrate when the tray is gently tilted, resembling the motion of atoms in a solid.
- Within the raft, smaller groups of bubbles form boundaries between themselves and other groups. This resembles cleavage planes, or lines of weakness, in crystals.*

Learnings: There is an orderly arrangement of the atoms and molecules within a solid. The atoms and molecules always arrange themselves so that the largest number possible occupy the space available.

ACTIVITY 39 (y,z)

MAKING MODELS OF ATOMS AND MOLECULES IN SOLIDS (variation b)

Purpose: To demonstrate the ways atoms and molecules are arranged in solids

Concept to be developed: There are many different ways in which atoms and molecules can be packed into a given space.

Materials needed:

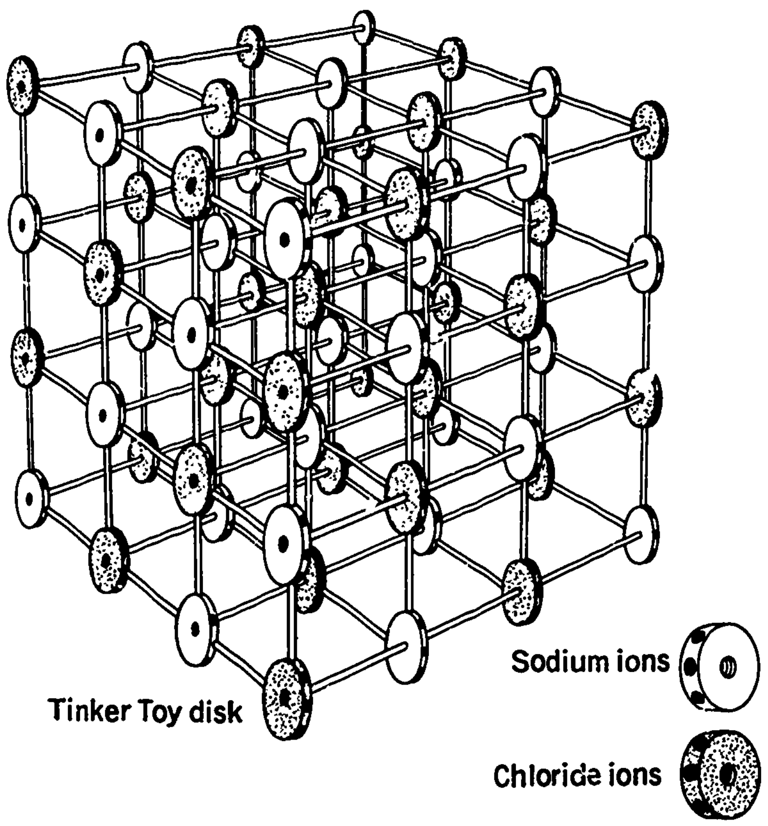
Tinker Toy or similar construction set

INTRODUCTION: Suggest that another way to study how atoms and molecules are arranged in solids would be to use construction toys, such as the Tinker Toys, for making models. In these models, the charged atoms (ions) are represented by wooden disks or cubes that join together by pegs or sticks. The illustration shows a cubic model of table salt built with such a toy. Other designs the children can make may be found in Activities 40 and 41.

Mention to the children that 64 disks can be used to simulate a crystal unit of sodium chloride. Thirty-two of these should be of one color to represent the sodium ions, and 32 should be of another color to represent the chloride ions. Have some children construct this model according to the pattern shown in the illustration. Do the children think an actual bit of salt composed of 64 ions would be visible? *(On the scale used here, the ions are magnified many millions of times; in reality such a small unit would be invisible.)*

*A good source of information on soap bubbles and their use in studying the structure of solids is *Soap Bubbles and the Forces Which Mould Them,* by Charles V. Boys (Garden City, N.Y., Anchor Books, Doubleday and Company, Inc., 1959).

These models lend themselves particularly well to showing how visible amounts of matter are built up in crystals by the repetition of a structural unit or pattern characteristic of the



solid. The children may wish to add more "ions" and build additional units onto the 64 disks of the building block.

Learning: There is an orderly arrangement of atoms and molecules within a solid.

ACTIVITY 40 (y,z)

MAKING MODELS OF ATOMS AND MOLECULES IN SOLIDS (variation c)

Purpose: To demonstrate the ways atoms and molecules are arranged in solids

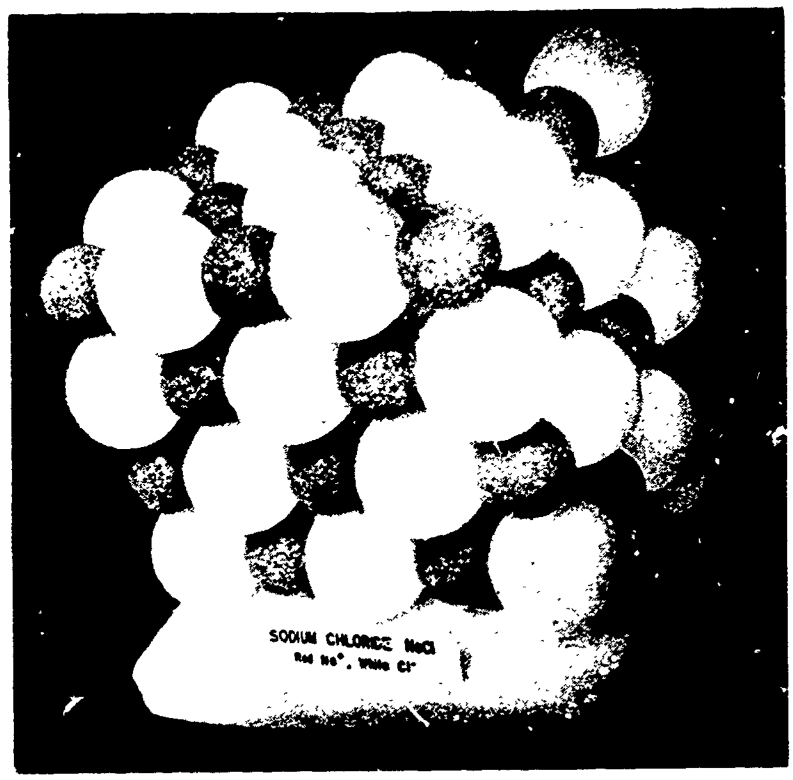
Concept to be developed: There are many different ways in which atoms and molecules can be packed into a given space.

Materials needed:

Spherical objects to represent atoms and ions (marbles, beads, Christmas-tree ornaments, Ping-Pong balls, etc.)
Quick-drying glue or cement
Rectangular trays, pans, or box lids
Opaque projector

INTRODUCTION: Suggest that the children also try using many kinds of spherical objects to make three-dimensional, or "stacking," models of the arrangements of atoms, ions, and molecules in solids. Have them bring in the materials listed above and any other materials they can suggest.

Using the opaque projector, show the class the accompanying illustrations, in which the stacking of spheres represents the arrangement of ions in a crystal. Have them try these and other



Model of a salt crystal made of styrofoam balls.

schemes of sphere-stacking.* It will be helpful for the children to use glue, cement, or bits of plastic clay to help hold the balls in place. Point out that in these models the spheres mainly show the relative location of atoms and ions to each other, and not what these particles actually look like. (In all models of this sort it should be made clear that the disks and pegs do not show the actual shape or appearance of the individual ions, but only how they are arranged in the lattice-work structure.)

Learning: There is an orderly arrangement of atoms and molecules within a solid.

ACTIVITY 41 (y,z)

MAKING A MODEL OF A LONG-CHAIN PLASTIC

Purpose: To illustrate the ways in which molecules are joined together in some plastics

*A source of additional examples is *Crystals and Crystal Growing* by Alan Holden and Phyllis Singer (Garden City, N. Y., Anchor Books, Doubleday and Company, Inc., 1960).

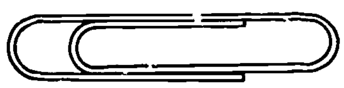
Concept to be developed: In plastics simple molecules are joined into long chains to form giant molecules.

Materials needed:

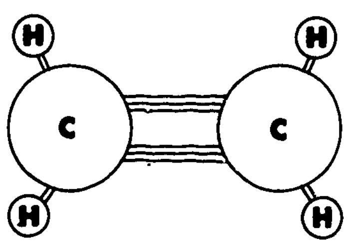
Paper clips

INTRODUCTION: Explain to the children that many common plastics are made of a basic unit (a molecule) that is linked to other identical units and repeated many times. These long chains may then join with each other by branching or cross-linking or both to form larger units of the plastic. The substance may then be twisted into fibers, spun into cloth, molded into shapes, or made into cements, paints, and other coatings. The principle of a repeating basic unit may be easily shown for a widely used plastic such as polyethylene. The following Activity will show the children more about this arrangement of atoms.

Sketch the accompanying illustration on the chalkboard to acquaint the children with the

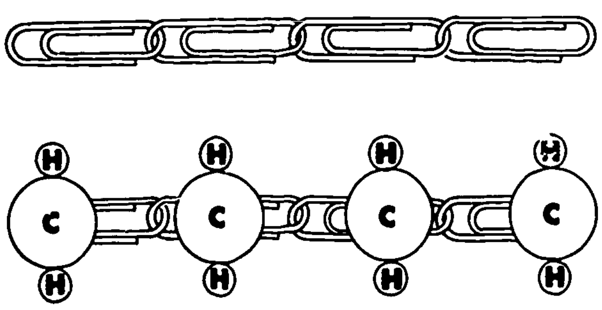


PAPER CLIP SERVES AS "BASIC UNIT" OF ETHYLENE



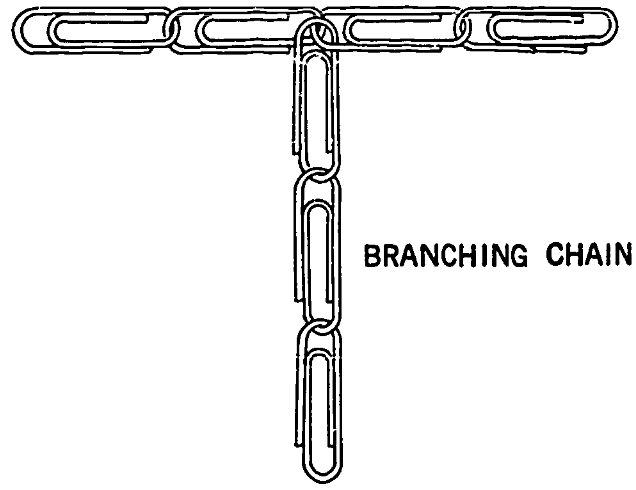
Ethylene molecule (C_2H_4)

structure of ethylene, the basic unit that is repeated in polyethylene. Have the children string together several paper clips, each of which represents one molecule of ethylene, to form a chain of "polyethylene." Can they determine how big

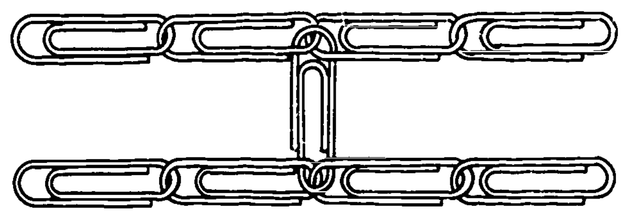


Straight-chain linking = polyethylene

one molecule of polyethylene is? *(There is really no fixed size of one molecule, since theoretically the chain can consist of any number of ethylene units linked together.)* Ask the children how many different ways they can find to link the paper clips. *(They may be joined to form straight chains, branching chains, and cross-link chains. All of*



BRANCHING CHAIN



CROSS-LINKED CHAIN

these arrangements can be produced when polyethylene is made.) This process of building up chains of molecules is called *polymerization,* and the chains themselves are called *polymers.*

Scientist points to branching portion of polyethylene model.

Learnings: Molecules of the same substance may join together to form chains. The chains may be straight, branched, or cross-linked. The process of joining the basic molecules to one another is called *polymerization,* and the resulting chain is called a *polymer.*

ACTIVITY 42 (x,y,z)

MAKING A COLLECTION OF PLASTICS

Purpose: To show the many different molecules that can be polymerized

Concept to be developed: Many of the plastics (a term that includes synthetic fibers and synthetic rubbers) developed by modern chemists are polymers.

Materials needed:

None

INTRODUCTION: Review the preceding Activity with the children. Point out to them that the process of polymerization is a relatively recent development, one that became commercially important in the twentieth century. Ask them if they can suggest some of the ways in which the process of polymerization has benefited mankind.

Explain that a large number of plastics, synthetic fibers, and synthetic rubbers are in everyday use. Ask the children to name as many plastics as they can and list these on a large chart. Have them bring in samples of each and mount them in the appropriate place on the chart.

Some of the children will be interested in finding out the basic unit of structure that is repeated and linked to form these plastics. One clue is found in the chemical names and trade names of many of these compounds, such as polyethylene, polystyrene, or polyvinyl chloride. Have the children look up words in the dictionary that are prefixed with "poly-" to find out what it means. *(It means "several," "many," etc; a reference to the linking together of many units to form the molecules of a plastic.)* Help the children to understand why we say that plastics are synthetic, or man-made. *(None of these are found in nature, but are "assembled" by man, who links up small molecular units.)*

Learning: Many of the modern plastics developed by chemists are polymers.

Extending Ideas: Review and summarize with the children how the preceding Activities have illustrated some ways in which molecules are arranged in solids. Help them to recall that the patterns of these arrangements aid us in understanding some of the properties and behavior of different kinds of matter. Explain that threads and cloth can be made from the long-chain plastics since their molecules are miniature fibers. It might be predicted, therefore, that such natural fibers as wool, cotton, and silk would show the same kind of structure, as in fact they do.

Perhaps some of the children might participate in research to find out the similarities and differences between the natural and synthetic fibers.

Summing Up Ideas: In this section the children were introduced to the structure of substances, that is, to the arrangement of the atoms and molecules within these substances. They learned how X-ray shadow pictures are made and analyzed, and how, from these shadow pictures, scientists have been able to reconstruct the pattern of the molecules. They learned of the different ways in which atoms and molecules arrange themselves in solids, and that molecules tend to assume those positions that take up the least amount of space. The children also learned of the valence of atoms, that property which determines the number of atoms any atom may be linked to. In addition, they discovered the process of polymerization, the joining together of molecules to form chains, the process by which almost all of our modern plastics are produced.

WHAT HOLDS ATOMS AND MOLECULES TOGETHER IN MATTER?

The Activities thus far have dealt with ways in which large numbers of atoms and molecules are distributed and positioned in various kinds of substances. However, the children will probably wonder about what holds these particles together; why doesn't matter fall apart if it is made of many small particles? As was mentioned in the introduction to this chapter, the answer is that atoms and molecules are held together by electrical forces.

It has long been known that electricity and matter are somehow related—that electricity could be obtained from chemicals in batteries, and that matter could be given electrical charges. However, electricity and matter were thought to be two separate entities. One of the great advances made by research since 1900 has been the explanation of the relation between electricity and matter. Matter itself was found to be electrical in nature because atoms and molecules are composed of particles that possess an electrical charge.

Many observations of properties of matter that seemed to be completely unrelated to each other became understandable if one hypothesized that matter itself was electrical in nature. The following questions often asked by children are some examples:

Why is water wet?

Why are glues and pastes sticky?

Why does my nylon sweater cling to me and crackle when I take it off?

In each case, the answer involves electrical forces of attraction and repulsion. Water wets many objects because its molecules are attracted to the molecules making up the surfaces of the objects. Glues and pastes are adhesive because their molecules have a strong electric attraction for each other and for many other molecules. The nylon in sweaters becomes electrically charged when rubbed. This electrical charge then causes an attraction between the nylon and the skin, hair, and other items of clothing.

In saying that electricity holds matter together, the following distinction must be made:

- Single atoms are held together by *strong* forces of attraction to form a molecule (see Activity 36 and Chapter 5).
- Many molecules are held together by a *weaker* force of attraction to form a large mass of matter.

The Activities that follow deal with both these cases and will lead the children to investigate the relationships between electricity and matter.

ACTIVITY 43 (x,y)

CHARGING MATTER WITH STATIC ELECTRICITY*

Purpose: To discover the electrical nature of matter

Concept to be developed: Many objects can be given an electric charge, which tends to remain in place if the object is a poor conductor of electricity.

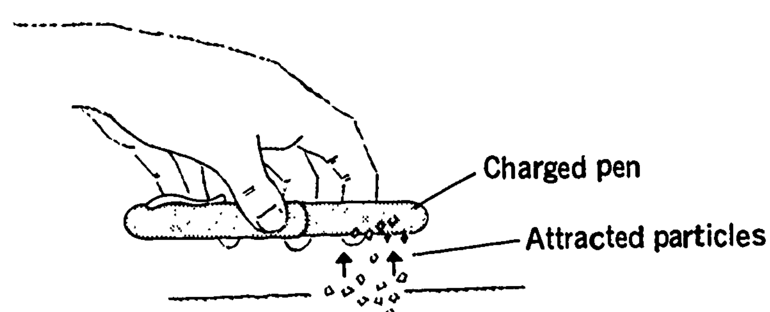
*For a more thorough discussion of static electricity and other Activities with which it can be demonstrated, see *Energy In Waves*, by Louis Cox (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

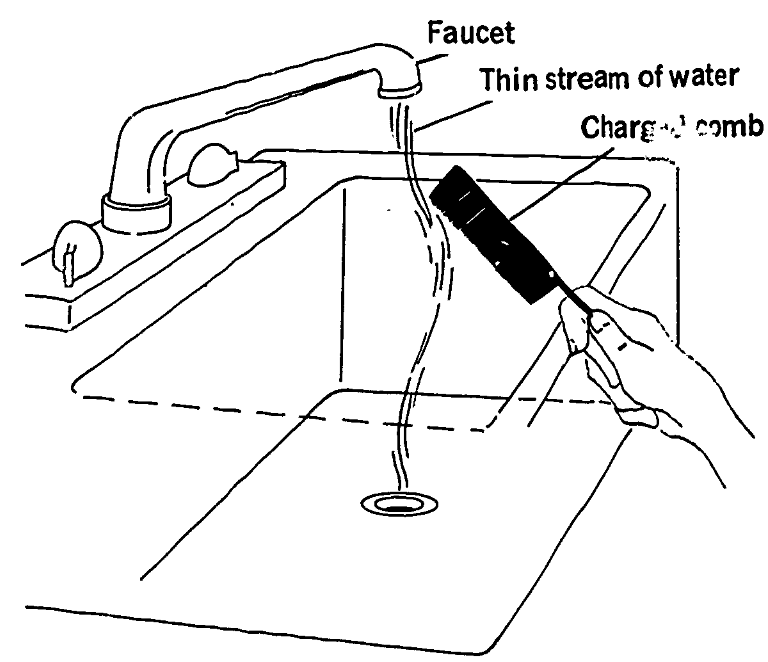
Materials needed:

Hard rubber or plastic items, such as combs, rulers, and pens
Salt
Newspaper
Granulated sugar
Pieces of paper, thread, cloth, hair, cork, puffed cereal grains, and any other material that can be torn or cut into small pieces
Wool, silk, nylon, rayon, fur, and other fabrics

INTRODUCTION: Ask the children to describe some common examples of static electricity they have noticed. For example, combing the hair on a dry day causes it to "stand on end"; one may get a shock from the door handle after sliding across a plastic-covered car seat; wool and nylon sweaters cling to the skin, and crackle when removed. Tell the children that the following Activity will help them find out about the electrical nature of matter.

Have the children rub the combs, pens, etc., briskly on their clothing, or on samples of different sorts of material such as wool, silk, nylon, rayon, and fur. (These effects work best when the humidity is low, as it is in winter, in heated rooms, or on dry days during other seasons.)

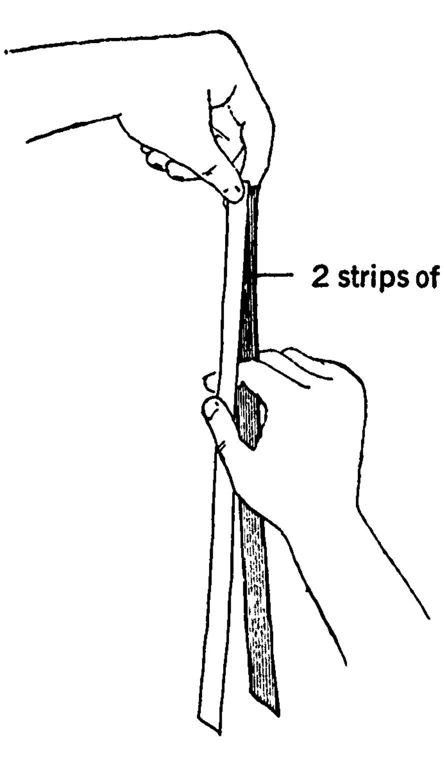


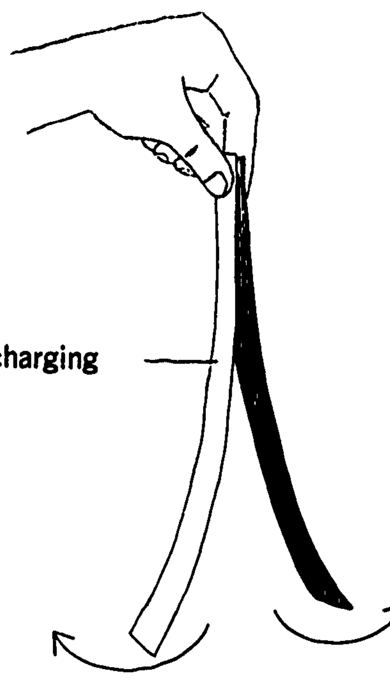


What do the children observe when the rubbed objects are brought up to the torn bits of paper, thread, and other materials? *(They are attracted to the rubbed objects, which have been* *given a static electric charge by the rubbing.)* How many different kinds of substances do they find are attracted to the charged objects? *(All of those listed above, and hundreds of others.)* Are the children able to find any substances that are not attracted? *(Probably not, since little pieces of almost all kinds of matter will be affected by a static electric charge.)* What statements can the children make to explain these observations? *(Help them to see that this almost universal reaction of matter to charged objects is a clue that there is some important connection between electricity and the nature of matter.)*

So far, bits of solid matter have shown attraction. Do the children think that liquids also show a response to an electric charge? Have some children hold a charged comb or pen close to a fine stream of water being poured out of a jar or coming from a faucet. What do they observe? *(The stream of water will be attracted to the comb very strongly.)* Suggest that they also try this with other liquids, such as mineral oil and alcohol.

Point out that charged objects can repel matter as well as attract it. To demonstrate this, ask the children to pick up some bits of paper or thread with a charged object, and to watch what happens after a minute or two. *(Some of the attracted bits seem to "jump off" the charged object as if they were being pushed away.)* This repelling effect may be seen more clearly by having children tear two long strips from a sheet of newspaper and hold them together at one end. If they then give the paper strips several light downward strokes between the thumb and forefinger of the free hand, what happens? *(If the air in the room is dry, the strips fly apart and hold that position for some minutes.)* Why?





(When rubbed, both strips acquire similar electric charges, which repel each other. Static electricity may be positive or negative in charge. Similar charges, that is, two positives or two negatives, repel each other; opposite charges, that is, a positive and a negative, attract each other.) Children should conclude that electrically charged objects may either attract or repel each other.

Help the class to extend their observations of the effects of electrical charges on these small pieces of matter to atoms and molecules. They might use smaller and smaller bits of matter to be attracted and repelled by a charged object. They could use small pieces of lump sugar, then granulated sugar, and finally powdered confectioner's sugar. Chalk dust, flour, sand, and salt might also be tried. What discoveries do the children make? *(All of these are attracted particularly well when finely subdivided.)* Ask the children to extend in their imagination this idea of smaller and smaller bits of sugar, dust, paper, water, chalk. Explain that when bits the size of molecules are reached, it seems probable that these electrical forces are what hold molecules of matter together.

Learnings: Matter is electrical in nature. For this reason, matter may be given a static electric charge. Opposite charges attract and similar charges repel each other. Molecules are held together by these electrical forces of attraction.

ACTIVITY 44 (y,z)

ELECTROPLATING METALS

Purpose: To discover what happens in the process of electroplating

Concept to be developed: Because the nature of the bond between atoms is electrical, the application of electric current can interfere with these bonds.

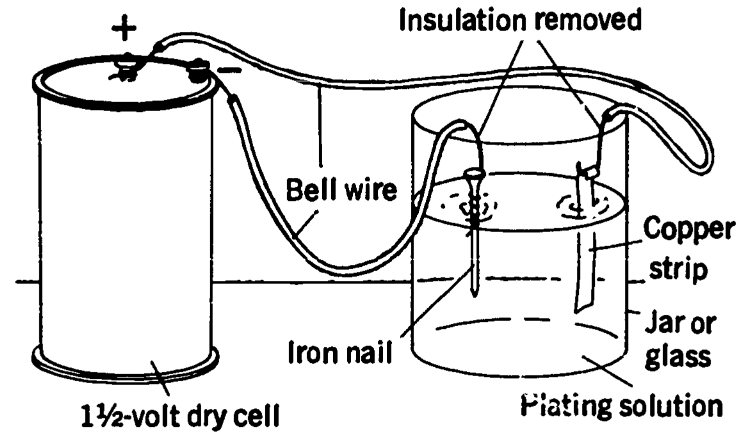
Materials needed:

- Large dry cell (No. 6, 1½ volt)
- Thin strip of copper about 6 inches long and 1½ to 2 inches wide (available from hardware stores, tinsmiths, roofing shops, hobby shops, etc.)
- Jar or drinking glass
- 2 ounces of powdered copper sulfate
- 2 ounces of dilute sulfuric acid (2 percent solution)
- A few feet of insulated bell wire
- Hammer
- Pliers
- Objects to be plated (large iron nail, table knife, screwdriver)
- Brass screw or bolt
- Steel wool pads

(Safety Note: Sulfuric acid, even at a dilution of 2 percent, can cause irritation to the skin and the eyes and damage clothing. It should be handled by the teacher and stored in a safe place. If any of it is spilled, wash it off with a large amount of cold water.)

INTRODUCTION: Restate for the children what they have learned—that electricity can cause atoms to change positions and bring about chemical changes. For example, remind the children of their experiences in Activity 16, where they saw electricity decompose water. Explain that electricity is also widely used in plating metals. Show some electroplated objects to the class. Tell the children that the following Activity will illustrate the electroplating process for them.

Dissolve about one ounce of copper sulfate in 6 ounces of water so that the solution is very deep blue in color. Add five drops of the 2 percent sulfuric acid solution to make the plating solution. Place the bared end of one piece of bell wire across the top of the copper strip, and bend a corner of the strip over it with pliers. Pound the bent corner flat over the wire in order to anchor the wire to the copper strip. The



other end of this wire is attached to the positive (+) terminal of the dry cell.

Ask a child to prepare the nail, or other object to be plated, by washing it well with a soaped steel wool pad until it is shiny and free of grease and then rinsing off the soap with water. Be sure he holds the nail by the head only, to avoid getting a film of oil on it from his fingers. Next, have him wind the bared end of another piece of wire tightly around the nail just under the head. The free end of this wire should then be bared and attached to the negative (−) terminal of the dry cell.

Lower the copper strip and the nail into the plating solution. Bend the wires going to the dry cell down against the outside of the glass to hold the nail and the strip in place. Do not let the wires or the nail and the strip touch each other. Ask the children to describe what happens. *(In a short time the nail will be plated with copper.)* Remove it, and wash well with water.

Where does the copper that appears on the nail come from? *(Charged atoms, or ions, of copper come from the solution of copper sulfate and the copper strip. Since they have a plus charge they are attracted to the opposite, or minus, charge given to the iron nail by the dry cell.)*

Suggest that the children try copperplating other metallic objects, such as old silver-plated spoons, pieces of "tin" cans, lead, zinc, and brass. These objects should first be scrubbed clean. Do the children think nonmetallic substances can be plated? *(Most cannot, since they do not conduct electricity.)* Can copper from one object be plated onto another copper strip? To find out, have the children connect a brass screw to the positive post of the battery, and immerse it in the solution. What happens? (*The screw will slowly disappear as pure, spongy copper from it is plated onto the copper strip. Zinc, which is the other metal in brass, is left in solution or may fall to the bottom of the glass. This process is used in industry to prepare very pure copper from slabs of copper that contain impurities.)*

Have the children experiment with the plating process by switching the connections from the dry cell, so that the plated iron nail that was prepared before is connected to the positive terminal, and the copper strip to the negative one. Will the copper on the nail go back to the strip? *(Yes.)*

Ask the children to give as many examples as they can of plated objects, such as silverware, automobile bumpers and other chrome work, "tin" cans (tin coated on iron), and gold-plated jewelry items. Emphasize, as in the previous Activity, that here also electricity is able to cause the atoms of many different metals to change positions. Point out that these processes are further evidence that electricity is deeply involved in the nature of matter.

Learnings: The electrical nature of matter makes it possible for electricity to break the bonds that hold atoms together in molecules. Electroplating is a process in which the electrical breaking of bonds is used to coat metallic objects with other metals.

ACTIVITY 45 (x,y,z)

TAKING APART A DRY CELL

Purpose: To examine the construction of a dry cell in preparation for the next Activity

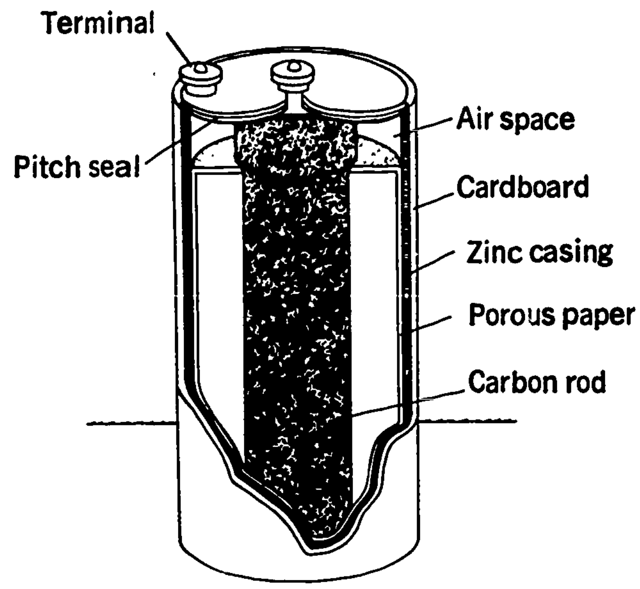
Concept to be developed: Electricity can be produced by the interaction of matter.

Materials needed:

Old dry cell (No. 6 or flashlight battery)
Fine-tooth saw (such as a hacksaw)
Newspapers

INTRODUCTION: Point out to the children that the electrical nature of matter is also strongly indicated by the fact that electricity can be produced from many substances. The children may be interested in cutting open a dry cell to see how it is made.

A dry cell can be easily cut apart with a hacksaw. (Do not use one of the so-called leakproof cells, for these have a steel jacket that will



be too hard to cut.) Spread out plenty of newspapers on the work surface as the contents of the cell tend to be messy. Saw the cell in half lengthwise to reveal the arrangement of its parts. What do the children observe in the dissected cell? *(The primary things for them to note are the three electrically conducting materials: two different solids, usually a zinc casing and a carbon rod, and the moist paste.)* What purpose does each serve? *(The two conducting materials are the source of electric charges and the paste is the substance that carries the charges between them.)* How does a dry cell generate electricity? *(Whenever two different materials that conduct electricity are placed in a solution that conducts electricity, and externally connected to each other, a chemical reaction takes place in which electric charges flow.)* What is the flow of electric charges called? *(Electric current.)* What is the moist paste made of? *(It can be made of any material that conducts electricity, since it serves the same purpose as the conducting solution in Activity 16.)*

Young children sometimes ask if they can see electricity in a dry cell. Show them a cell that has been opened. *(Electricity, as a flow of charges, is not visible; however, the effects caused by electricity, such as sparks, may be.)*

Have some children compare a fresh dry cell that has been opened with one that is used up. Do they notice any differences? *(The zinc casing of the old cell may be pitted and worn through in some places. This wearing occurs because of the chemical reaction the zinc casing has undergone in producing an electric current over an extended period.)*

Learning: Dry cells produce electricity by the interaction of their chemical components.

ACTIVITY 46 (y,z)

MAKING AND USING ELECTRIC CELLS

Purpose: To find out how the interaction of chemical components can cause electricity to flow

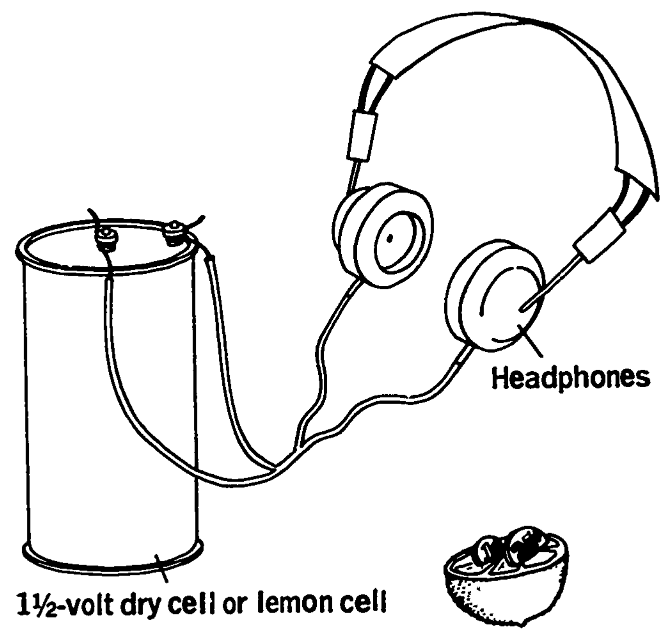
Concept to be developed: Electricity can be made to flow between two dissimilar metals.

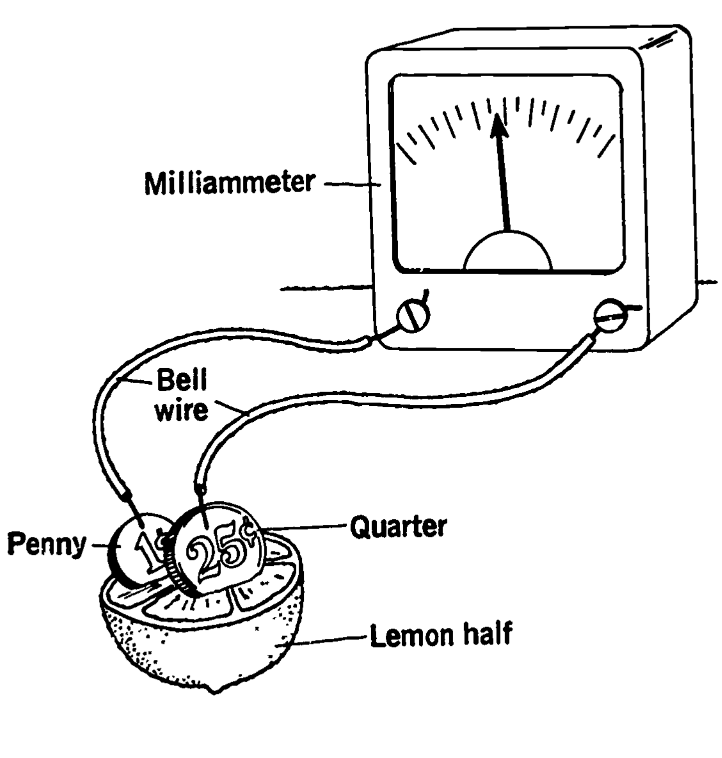
Materials needed:

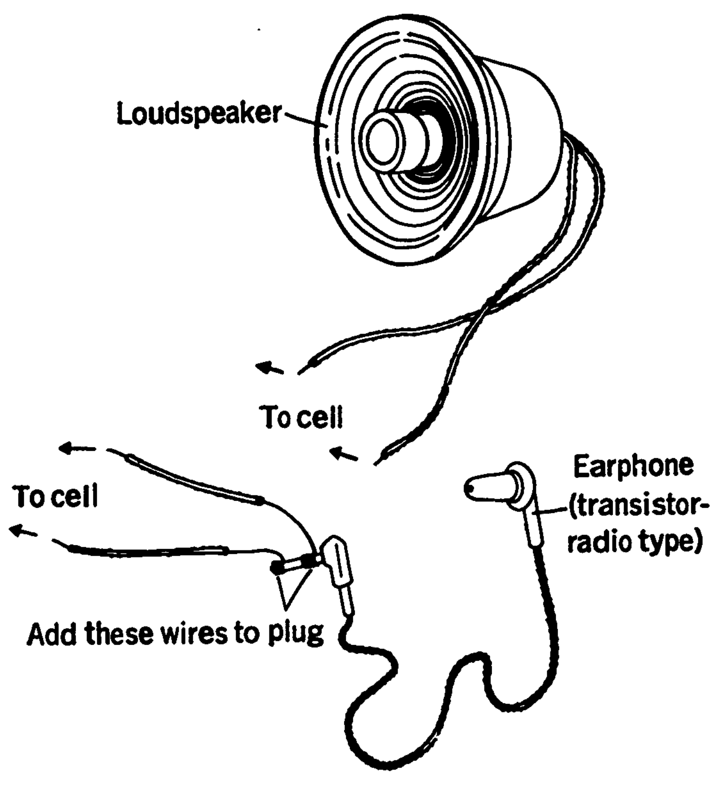
- Lemons
- Tomatoes
- Pennies
- Quarters
- Bell wire
- Knife
- Electric current detector, such as headphones, transistor-radio earphone, radio loudspeaker (permanent-magnet type), milliammeter (0-1 ma)
- Steel wool pad
- Salt

INTRODUCTION: Having dissected a dry cell, the children may now wish to construct their own electric cells. Encourage their theories as to how they might do this. Remind them that they must use dissimilar metals as conductors. What common ones could they suggest? Mention coins as a possibility and discuss what different kinds of coins are available. What kind of solution for conducting electric charges can they suggest? Encourage theories from them and lead them to focus on using a copper penny and a silver quarter, with the juice of a lemon or tomato as the conducting solution. Then proceed as follows.

Have the children scrub the coins with a wet, soaped, steel-wool pad until they are shiny and rinse them thoroughly in water. The coins should then be handled only by the edges to keep them free of the natural oil on the children's fingers. Cut each lemon or tomato in half so that two children may make electric cells from it. Push a penny and a quarter, spaced about 1½ inches apart, almost all the way into the fruit. The cell is now ready to produce electricity. The amount of electricity it can produce is too small to light a lamp or ring a bell, but it can be detected in other ways. If the two wires from a sensitive meter, such as a milliammeter, are touched to the coins, the meter will show that current is flowing. (*Caution:* Do not use this meter with any commercial dry cell. The large amount of current produced will ruin the instrument.) If a sensitive meter is not available, one



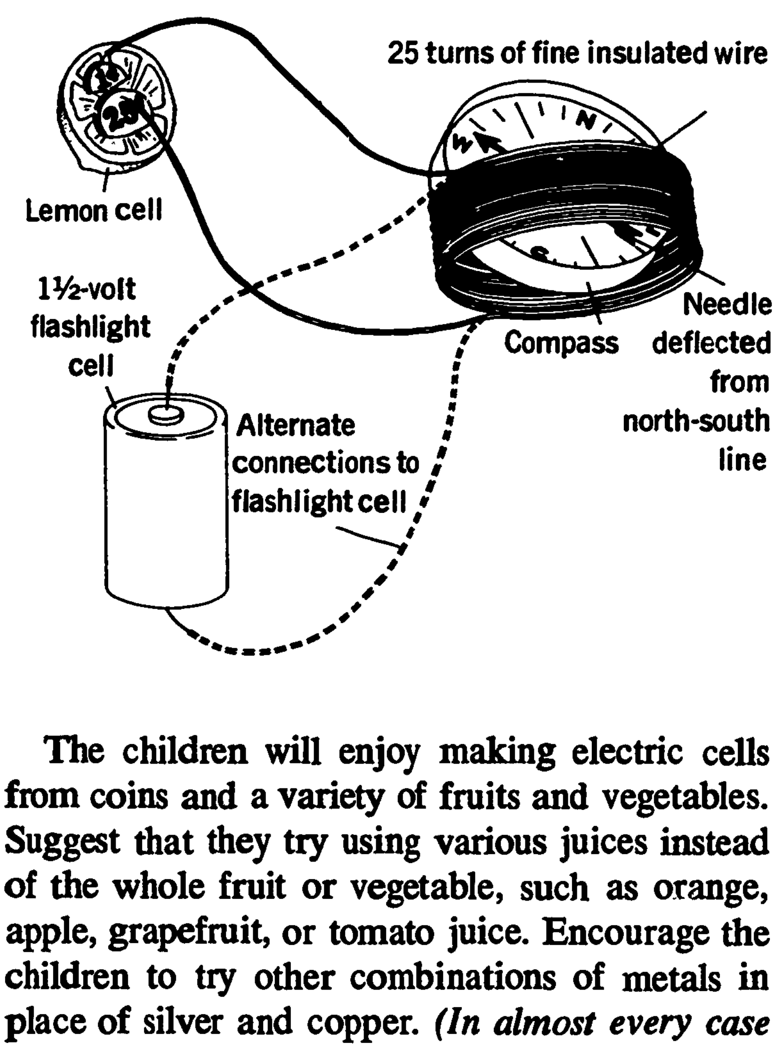




of the following current-indicating devices may be used:

Touch the leads from a pair of headphones, transistor radio earphones, or a loudspeaker to the coins. A raspy, crackling sound will be heard if current is flowing. The children should try this first on a dry cell to see how it works.

The current may also be detected by using a magnetic compass. Have the children wrap 25 to 30 turns of fine insulated wire (or bell wire) around the compass in line with the north-south markings. Then they should turn the compass so that the needle points north and south. If the free ends of the wire are now attached to a source of electricity, like a flashlight cell or the lemon cell, the compass needle will swing sharply away from its north-south position.



The children will enjoy making electric cells from coins and a variety of fruits and vegetables. Suggest that they try using various juices instead of the whole fruit or vegetable, such as orange, apple, grapefruit, or tomato juice. Encourage the children to try other combinations of metals in place of silver and copper. *(In almost every case they will find that electricity will be produced.)*

The amount of electric current produced in these cells can be increased by putting salt on the lemon, tomato, or whatever is being used to provide the conducting solution. Why? *(It makes the solution a better conductor.)*

Learning: When two dissimilar conductors are placed in a solution that conducts electricity, and connected to each other or to some external device, an electric current is produced.

ACTIVITY 47 (z)

"SQUEEZING" ELECTRICITY FROM A CRYSTAL

Purpose: To observe further the electrical nature of matter

Concept to be developed: When some crystals change their shape because of the application and release of pressure, they produce an electric current.

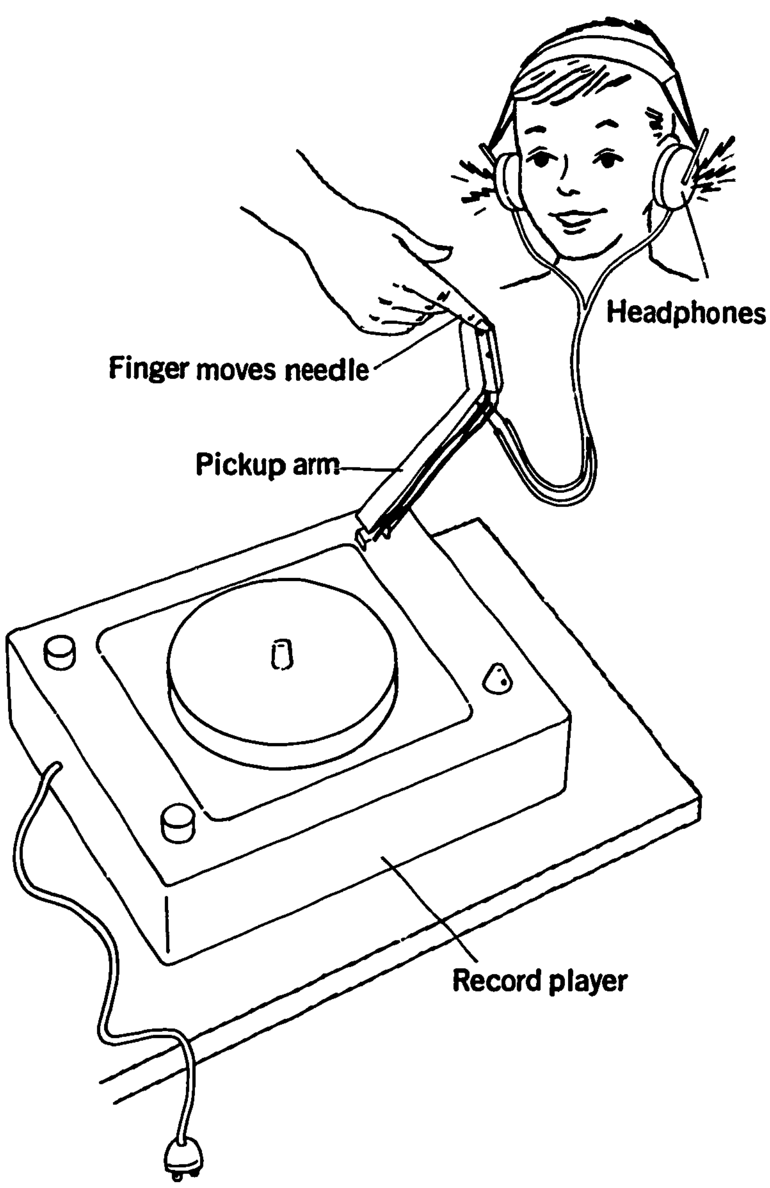
Materials needed:

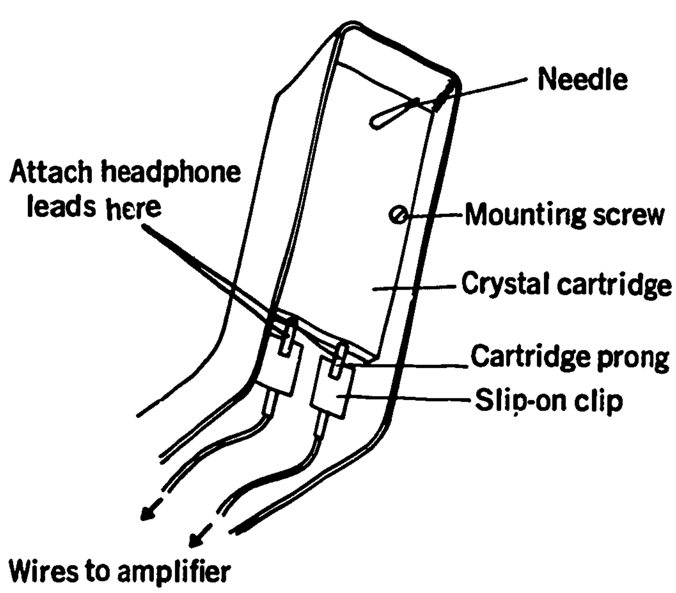
- Phonograph with crystal or ceramic cartridge (magnetic cartridge will not work)
- Headphones
- Phonograph recording
- Small screwdriver
- Flashlight battery

[In the case of some crystalline solids, it is possible to observe directly that they contain electric charges. These charges become evident when the shape of the crystal is changed as it is squeezed and again when the pressure is relaxed. The change in shape means that the electrically charged ions of which it is made have moved. But the movement or flow of electric charges is an electric current. Therefore, when the right kind of crystal changes its shape because of pressure, pulses of electric current are produced. Crystals of Rochelle salt, quartz, and some ceramic materials are substances that show this effect markedly. The phenomenon is called the "piezo-electric" effect. It is widely used as the sound pickup element in many phonographs, microphones, and other devices that convert pressure into electricity. A Rochelle salt crystal is used in the pickup cartridges of many phonographs, and the piezo-electric effect can be easily demonstrated with such a cartridge.]

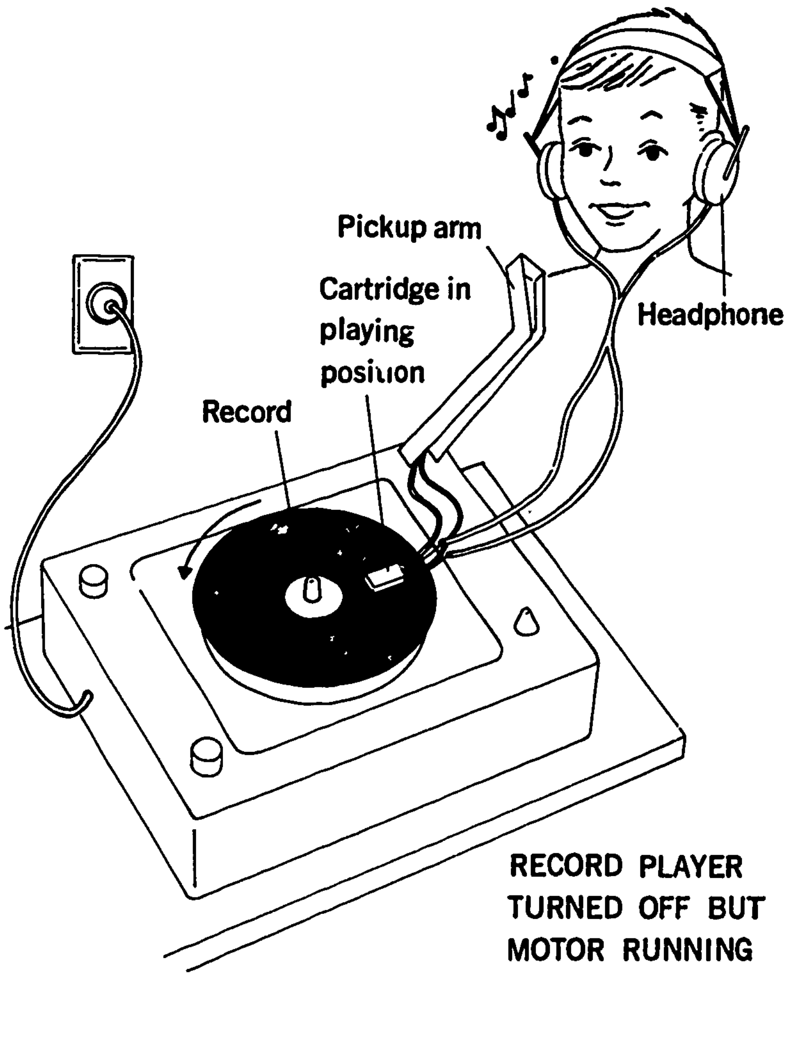
INTRODUCTION: Remind the children of their experiments with growing crystals in previous Activities. Tell them that another interesting thing about crystals can now be considered. Explain that when certain crystals are put under pressure, their shapes change, and when this happens, a pulse of electric current is produced. Explain that this is basically what causes many phonographs and microphones to pick up sound. Mention that the following Activity will show them how phonograph and microphone pickups work and will give further evidence to support the idea of the electrical nature of matter.

Tell the class that the feeble electric current produced by the crystal cartridge *alone can be* heard with a pair of headphones. Show the children that the record player is not plugged in or turned on. Raise the arm of the player and point out the two wires running back to the pivot joint and down into the circuit. (Stereo cartridges will have 3 or 4 leads. Try combinations of two until the best results are obtained.) Touch the two tips of the leads from a pair of earphones firmly against the bare ends of the prongs protruding from the rear of the cartridge. (There is absolutely no danger in this procedure.) Have several children take turns wearing the earphones and listening while you rub the needle back and forth gently with a fingertip. *(A rasping, crackling sound will be heard in the earphones.)* Why does this happen? *(As the phonograph needle rides over the grooves of the finger, it follows a wavy path that causes it to vibrate. The vibrations are transferred from the needle to the crystal which then changes its shape with the motions of the needle, and a very feeble electric current emerges.)* What is this process called? *(This is known as the piezo-electric effect.)* How does the loudness of this sound compare with that produced by touching the earphone leads to the terminals of a dry cell? *(The crackling sound made by the dry cell in the earphones is almost loud enough to be heard throughout the room, if everyone is listening intently. The much weaker noise made by the crystal shows that it produces a very small amount of electricity.)*

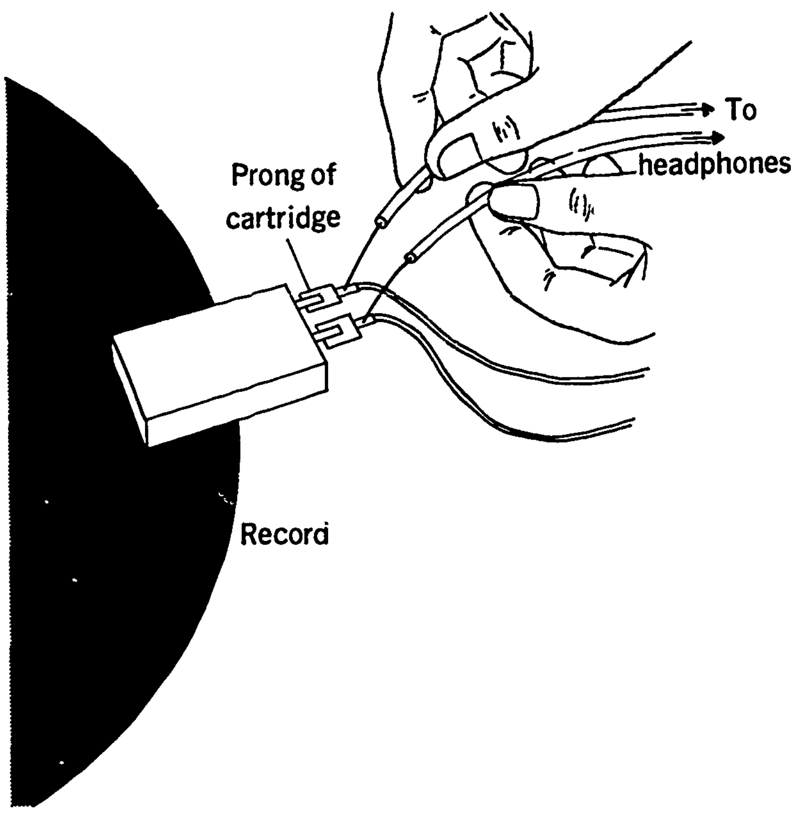




UNDERSIDE OF CARTRIDGE



RECORD PLAYER TURNED OFF BUT MOTOR RUNNING



Records can also be played and heard using the earphones only. Release the cartridge from the arm. (The cartridge can be removed from the pickup arm by unscrewing the two bolts holding it in place. It will then hang down freely from its leads.) Place a record on the turntable and turn on the motor only. If one switch turns on both the motor *and* the rest of the player, turn the volume control to minimum so that no sound will come through the loudspeaker. In most machines the wires are attached to the cartridge by means of small slip-on clips. If so, these may be slid off and the cartridge removed and examined by the children. Make a note of the colors of these wires so that they can be reattached in the same way after the demonstration. Point out the construction of the cartridge. *(The needle, which is free to move; the container, in which the crystal is mounted; and the prongs at the back of the cartridge, through which the current flows out of the crystal to the rest of the machine.)* Hold the two leads from the earphones against the terminals of the cartridge, and rest the needle gently on the turning record in playing position. The music will be heard loud and clear in the earphones.

Learnings: If some crystals have their shape changed by the application of pressure, an electric current can be detected. This type of electricity is called piezo-electricity.

Summing Up Ideas: In this section the children were introduced to the idea that the bonds between atoms and molecules are electrical in nature. They learned how opposite electric charges attract each other and how similar electric charges repel each other. They also learned about the electrical nature of matter, which supports the theory of electrical bonds. They learned how an electric current can be produced in electric cells, and how the electrical nature of matter is utilized in the process of electroplating metals. They also learned about piezo-electricity, that is, the electricity that can be squeezed out of crystals.

IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning or application are:

- Matter is porous.
- There are spaces between the molecules of a substance through which smaller molecules may pass.
- Atoms are joined together in a specific pattern to form the molecules of each substance.
- There is an orderly arrangement of the atoms and molecules within crystalline solids.
- Many of the modern plastics are polymers.
- Matter is electrical in nature.
- Many objects can be given an electric charge, which tends to remain in place if the object is a poor conductor of electricity.
- Oppositely charged objects attract each other.
- Similarly charged objects repel each other.
- Molecules are held together by these electrical forces of attraction.
- Dry cells produce electricity by the interaction of their components.

In the intermediate and upper grades, the children should be led to develop concepts that are more complex and quantitative:

- When a solid is dissolved in a liquid, the molecules of the solid fit into the spaces between the molecules of the liquid, and vice versa, thereby causing the resulting solution to occupy a smaller volume.
- X-ray shadow techniques help to determine the relative positions of molecules in a substance.
- The valence of an element determines how many links its atoms can have with other atoms.
- Molecules of the same substance may join together in straight, branched, or cross-linked chains to form giant molecules called polymers.
- When two dissimilar conductors are placed in a solution that conducts electricity, and connected to each other or to some external device, an electric current is produced.

5

INVESTIGATING THE ENERGY OF ATOMS AND MOLECULES

"Where is the fire in a piece of wood when it is not burning?"

"Is there anything hotter than fire?"

"How does a refrigerator make things cold?"

"What are atoms made of?"

"What is radioactivity?"

"Why doesn't the Sun burn up if it is so hot?"

These questions, typical of those asked by children, are basically about the relationship between matter and energy. Energy can be produced from matter, and matter is changed when it is affected by energy.

This chapter is concerned with how atoms and molecules are affected by energy. The combination of the two concepts—that matter is particulate, and that energy is associated with all changes of matter—is an extremely powerful tool to use in describing many phenomena.

The first concept presented in this chapter is that all substances possess varying amounts of heat energy. This heat energy is actually the amount of motion shown by the atoms and molecules of a substance, and the average motion is measured as the temperature of the substance—the greater the average motion, the higher the temperature. Even at room temperature, all objects have considerable heat energy due to the motion of their atoms or molecules. A glass of water at room temperature is hotter than a glass of lemonade that has been in the refrigerator for an extended period. In terms of energy, the molecules of the water have more energy of motion than those of the lemonade. The colder a substance is, the slower its particles are moving.

Theoretically, the temperature of a substance can be reduced until its molecules have no motion, or heat energy. This temperature, 459.69 degrees *below* zero on the Fahrenheit scale and 273.16 degrees *below* zero on the Celsius (centigrade) scale, is called absolute zero. Scientists have been able to devise cooling systems that approach to within a small fraction of one degree above absolute zero.

The second concept developed in this chapter is that when the amount of energy in a piece of matter is greatly changed, the movements of its molecules cause many changes in the substance. For example, matter expands and contracts with changes of temperature. Another example is that a substance will change its state from solid to liquid or gas depending on the amount of energy applied. At extremely low temperatures molecules have so little energy that they move close together and vibrate in their places. Under such conditions, almost all substances are in the solid state. Carbon dioxide, which is a gas at room temperature, can exist as solid "Dry Ice" at a temperature of about −109°F.

In liquids, the agitated molecules are not as tightly bound to each other as they are in the solid state. They can roll and slip past each other, with the result that a liquid does not hold a definite shape but takes on the shape of its container.

Continued heating of a substance will raise its temperature to the boiling point. The molecules gain enough energy to leave the surface of the liquid and enter the gaseous state. As an example, the boiling point of pure water is reached at a temperature of 212°F. (100°C.). In this state the molecules possess such large amounts of energy that the gas expands and moves out into space unless it is in a closed container. The distances between gas molecules are very great compared to the distances between molecules in liquid or solid state.

There is apparently no limit to the amount of heat energy that may be given to matter. At temperatures of many thousands of degrees, however, no compounds stay together. The movements and energy of the individual atoms are stronger than the forces of attraction that held them together as compounds at lower temperatures. The atoms of uncombined elements can be heated even further to temperatures of millions of degrees. At the surface of the Sun, for example, the temperature is about 11,000°F. (6,000°C.). In the Sun's interior, matter exists at a temperature of 20 million degrees. Atoms in this condition are called a "plasma," or the "fourth state of matter," the other three being solid, liquid, and gas. Even at these enormous temperatures, the atoms can still be identified as those of particular elements.

Obviously, the range of temperatures that children can experience in the classroom is only a small middle segment of the span from absolute zero to the interior of a star. However, such limited experiences can be presented in such a way as to build the concept that the effects of heat energy on matter are steps along a vast continuum.

The third concept developed in the chapter deals with the transfers of energy that take place between the atoms and molecules during physical and chemical changes. Changes in matter may either absorb or release energy, depending on the substances and conditions involved. For example, heat energy must be added for ice to melt, but in order to freeze water back to ice heat energy must be removed.

Activities are described in which children can discover that adding heat energy to melt or evaporate substances has a cooling effect on the substances providing the heat. This is why perspiration evaporating from the skin makes us feel cool. When substances are made to condense or freeze, the heat that is removed raises the temperature of the substances absorbing the heat. Refrigeration systems, in which the heat energy in one body of matter is transferred to some other substance to produce cold, are based on an application of these principles.

So far most of the information has been about physical changes of matter. The principles of a balance and flow of energy apply equally well to chemical changes of matter. Energy is always involved in the rearrangement of molecules into new combinations when compounds are formed or decomposed. The burning of wood is a common example of a chemical change that produces heat and light energy once it has been started. Directions are given for Activities in which children find out that heat is produced in other chemical reactions, such as rusting, but in amounts that are usually undetected.

Energy is a many-sided concept because it can be observed in many forms, such as heat, light, electricity, magnetism, sound, and chemical and nuclear energy. These different forms of energy can also be converted to one another. For example, in the flight of rockets, the chemical energy of the fuel is converted to heat, light, sound, and tremendous mechanical energy (thrust, or push) by burning. For most of the Activities in this chapter, heat (as one of the forms of energy) has been selected to illustrate some of the relationships between energy and matter in general.*

The final section of this chapter presents some experiences with the basic question: What is inside an atom? Following the discovery of radioactivity in 1896, it became apparent that atoms did not live up to their name, which comes from the Greek word *atomos,* meaning "uncuttable," or indivisible. The atoms of some elements, such as uranium, were found to be disintegrating into smaller fragments, and releasing rather large quantities of energy in the process. Some of the new fragments were particles smaller than any atom; others were the whole atoms of different elements entirely. Hence, matter was being changed from one element to another. Atoms are not, therefore, the ultimate, simplest building blocks of nature. The work of many scientists during the next years led to the following basic picture of atomic structure:

- All atoms are themselves built of "elementary" particles, such as electrons, protons, neutrons, and many others.
- In ordinary matter an atom contains one or more positively charged particles (protons) at its center or nucleus, and is surrounded by an equal number of negatively charged particles (electrons).

*For a more complete discussion of energy, see *Energy in Waves,* by Louis Cox (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

• The electrons move about the nucleus in various paths and patterns, which depend upon the number of electrons and their energy content.

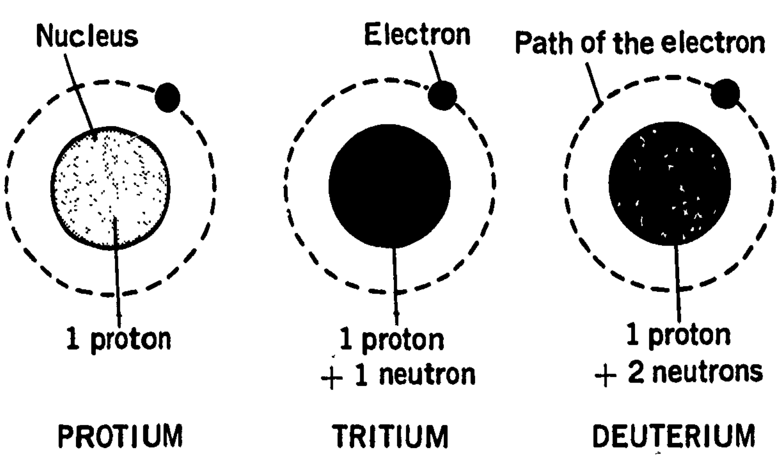
• All atoms of a particular element have the same number of protons.

According to this scheme, an atom of the simplest element, hydrogen, is composed of one proton and one electron; the atoms of all other elements are multiples of this plan. The next element, helium, has two protons and two electrons, the next, lithium, has three of each, and so on up to element number 103.

However, the simplicity of this scheme turned out to be deceptive when the relative weights of different atoms were compared. If a hydrogen atom (composed of one proton and one electron) has a weight of one unit, then element 92 (with 92 protons and 92 electrons), uranium, should weigh 92 times as much. Measurement showed, however, that it is over 200 times heavier than hydrogen.

The problem was resolved with the discovery of another fundamental particle—the neutron. Neutrons have no electrical charge, and they weigh as much as protons. It was found that a uranium atom is indeed a multiple of hydrogen in having 92 protons; the great discrepancy in weight is due to the many additional neutrons contained in the nucleus of a uranium atom. In addition, it has been found that the atoms of most elements may contain different numbers of neutrons. Atoms that have the same number of protons but different numbers of neutrons are called *isotopes*. For example, hydrogen, all of whose atoms have one proton and one electron, has three isotopes—protium, which has no neutrons; deuterium, which has one neutron; and tritium, which has two neutrons.

THE ISOTOPES OF HYDROGEN



Of exceedingly great interest has been the discovery of antiparticles. These are counterparts of the particles of ordinary matter, but differ in having an opposite electric charge or "spin." The counterpart of an ordinary proton (+) is the antiproton (−), and there are antielectrons, antineutrons, and many others.

It seems theoretically possible that, from such antiparticles, *antimatter* could be constructed. For example, "antihydrogen" would be made up of a negative proton as the nucleus, with a positive electron moving about it. However, when antiparticles and ordinary particles meet, they are both annihilated, with the release of tremendous amounts of energy. A problem for the future is to devise a "bottle" made of ordinary matter to contain antimatter. Some astronomers have conjectured that antimatter may exist in outer space in galaxies other than our own. The huge amounts of energy that have been detected coming from two galaxies in collision is about equal to what a reaction between antimatter and ordinary matter should produce.

The simplicity of this picture is still deceptive because many other particles, such as neutrinos and mesons, have been discovered in addition to the three basic ones—the proton, the electron, and the neutron.

The Activities for this section deal with these modern concepts of the structure of atoms. By building atomic models and through other Activities children can become familiar with some of the basic ideas held by scientists about the ultimate nature of matter.

HOW DO WE KNOW MOLECULES OF MATTER ARE IN CONSTANT MOTION?

Although atoms and molecules are too small to be seen individually, their agitation and movement can be observed in several ways. For example, the evaporation of substances (Activities 23 and 24) and the passage of molecules through balloons and plastic bags (Activities 32, 33, and 34) indicate that the particles of which matter is composed are in constant motion.

ACTIVITY 48 (x,y,z)

TRACING THE MOTION OF MOLECULES (variation a)

Purpose: To demonstrate that molecules are always in motion because of the heat energy they possess

Concept to be developed: The continuous movement of particles suspended in a liquid or gas is called **Brownian motion.**

Materials needed:

- Lumps of sugar
- Tea bags
- Chunks of copper sulfate
- Crystals of potassium permanganate
- Masking tape
- Drinking glasses or jars
- Eyedroppers
- Glass marbles

(*Safety Note:* Copper sulfate and potassium permanganate, obtainable at drugstores, are poisonous, and should not be tasted.)

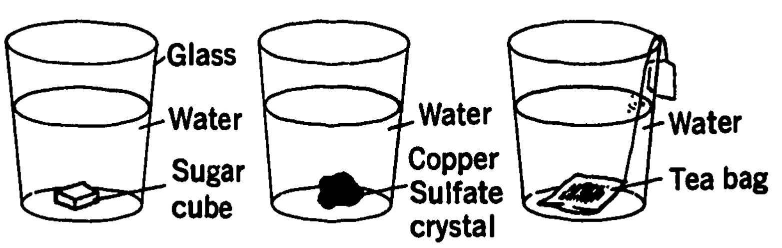
INTRODUCTION: Remind the children of their experiences concerning evaporation, sublimation, and the passage of molecules through balloons and plastic bags. Ask them to theorize about the significance of these with regard to the motion of atoms and molecules. Ask them to suggest other ways of demonstrating this motion. After considering, and perhaps performing, the Activities they suggest, proceed with the following Activities.

Have the children fill several drinking glasses with water to within an inch of the top, and allow the water to come to room temperature. (The glasses should be placed in a location where the temperature will stay more or less constant.) They may now lower a piece of each substance to be dissolved to the bottom of the drinking glasses. Caution them to try to use pieces that are approximately equivalent in size or amount. Also, the glasses must not be shaken, stirred, swirled, or otherwise disturbed. Have the children prepare another set of glasses as controls, in which the same quantities of the chemicals have been dissolved by stirring.

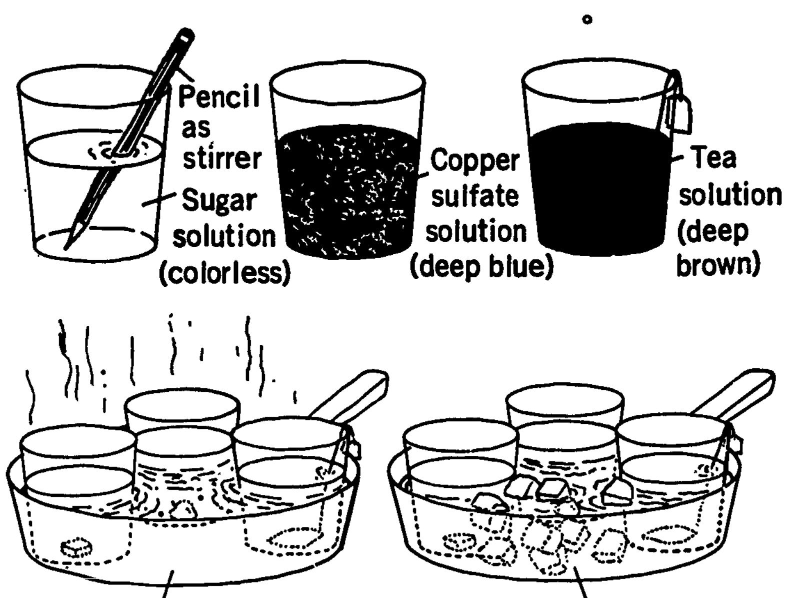
Do the children think the compounds that have not been stirred will dissolve? Will they spread evenly throughout the water? How long will it take? *(The substances will all dissolve, but will take different lengths of time to do so depending on how easily they go into solution. The time may be from about an hour to several days before they are evenly dispersed in the water.)* Tell the children that the motion of the particles dissolved in the water was first explained by the Scottish botanist Robert Brown, and it is called Brownian motion in his honor. Some of the children may be interested in reporting on his work.

Have the children observe the speed with which the substances dissolve by comparing the experimental glasses with the controls. The colored substances will be easily traced by the depth of color. Explain that the solutions to be tasted will have to be sampled at regular intervals with an eyedropper. A few observers, acting for the class, can sample the sugar solution at the start of the Activity and every 30 minutes thereafter.

EXPERIMENT: Substances dissolving without stirring



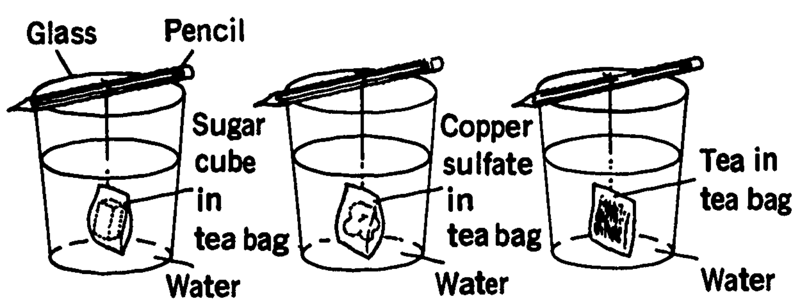
CONTROL: Substances dissolving with stirring



Have them squeeze the rubber bulb of the eyedropper to expel the air and draw up a few drops of the solution. The same children should taste the drops each time since sensitivity to taste varies with different individuals. Point out that the solutions should be sampled in two places—close to the substance dissolving, and just below the surface of the water.

It will be interesting for the children to keep records of how quickly or slowly the different substances diffuse evenly. Would the results be different if hot water were used? If cold water were used? To test this, two more sets of glasses should be prepared and one placed into a pan of hot water and the other into a pan of cold water. Ask the children to predict what might happen in each case and to test their hypotheses. *(Adding heat energy by using hot water should cause the molecules to move more quickly than they do in cold water.)*

Extending Ideas: Can the children suggest other factors that might affect the speed at which the particles spread or diffuse through the solution? Does gravity affect the speed with which uniform spreading is attained? Suggest that they investigate this factor by suspending the substances to be dissolved near the top of the water, or halfway down, instead of at the bottom of each glass. The substances can be placed inside tea bags that have been slit open and are later sealed with a thin strip of masking tape, as shown in the illustration. Place one or two marbles in the tea bags to weigh them down. Have the children record how long it takes until uniform diffusion is reached, and compare the results with what took place before. *(The substances near the top of the liquid will diffuse much more quickly than did those resting on the bottom, because gravity pulls the particles downward.)* Point out that although the dissolving solids seem to be stationary, their molecules must be moving since they can be detected throughout the solution.



Learnings: Atoms and molecules are in constant motion. The continual movement of the particles suspended in a liquid or a gas is called Brownian motion.

ACTIVITY 49 (x,y,z)

TRACING THE MOTION OF MOLECULES (variation b)

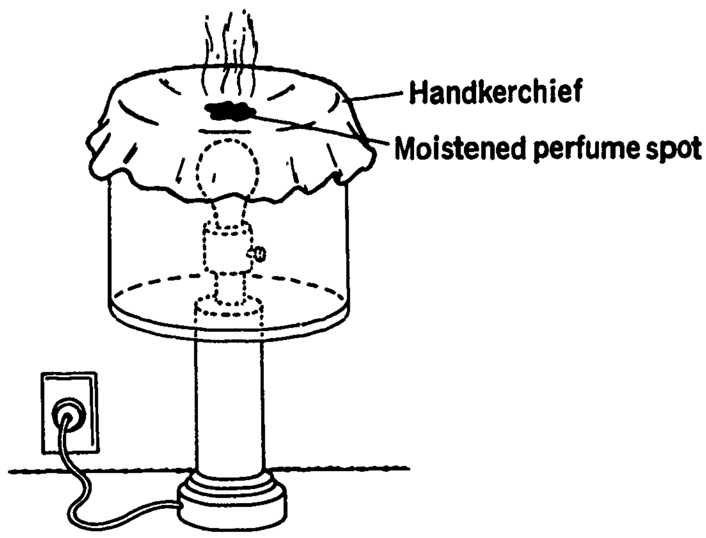
Purpose: To demonstrate that molecules are always in motion

Concept to be developed: The motion of molecules is determined by their energy.

Materials needed:

Table lamp with open-top shade
Handkerchiefs
Various perfumes

After closing the door and the windows (to make sure the air in the room is still), place several drops of perfume on a handkerchief located at the front of the room. Have the children raise their hands when they are sure they smell it. (Hands will go up in order, from the front of the room to the back.) How does the odor get there? *(Help the children to see that the molecules of perfume move out into the room.)* Can they think of a way to speed up the motion of these molecules? *(By placing another cloth, moistened with a different scent, over the top of a lighted table lamp with an open shade.)* Why does this make the perfume molecules travel more quickly? *(The heat energy given off by the light bulb is absorbed by the perfume molecules. The greater their energy, the faster they will travel.)*



Learnings: The molecules of a substance are in constant motion. Increasing their energy increases their speed.

ACTIVITY 50 (y,z)

OBSERVING THE EXPANSION AND CONTRACTION OF SOLIDS

Purpose: To show that changing the temperature affects the motion of molecules in solids

Concept to be developed: Increasing the energy of molecules in a solid causes the distances between them to increase; decreasing their energy causes the distances between them to decrease.

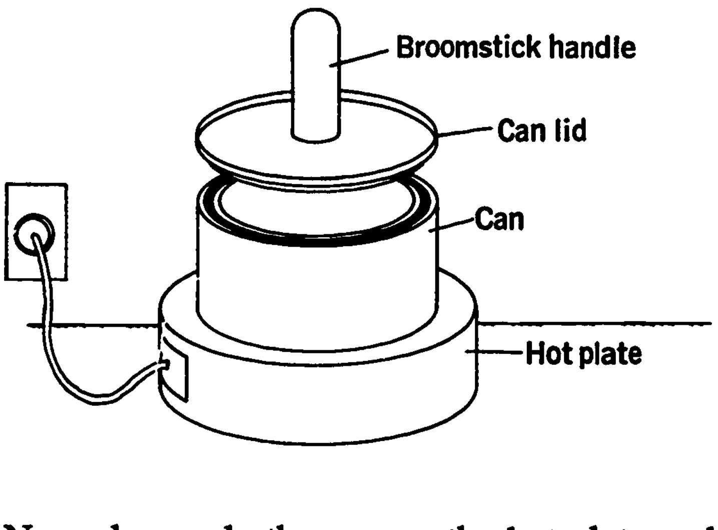
Materials needed:

Small empty can with press-on cover
Hot plate
Piece of broomstick or a wooden dowel, about 5 inches long
Nails
Pliers
Screwdriver
Hammer

(Safety Note: Cans that have contained inflammable or poisonous substances—wax, fuel, etc.—should be carefully cleaned and washed before using.)

INTRODUCTION: Besides learning that molecules are in constant motion, the children can also observe that changing temperatures affect the motion of molecules. To present this idea in a graphic way, ask them if they know why it is that a metal cap, stuck tight on a glass jar, may be loosened by heating? Encourage their ideas on this and help them to understand that the cap expands when heated so that it fits the jar top more loosely. Explain that this heating has in some way affected the motion of the molecules in the cap. The following Activity will clarify this situation.

Nail the short length of broomstick or the dowel to the can cover to make a handle. Point out that it requires a strong push to force the cover into place on the can, and it must then be pried off with a screwdriver or similar tool.



Now place only the can on the hot plate and let it become quite warm. Then try to put the cover on the can. What happens? *(It will be possible to fit the lid onto the can and to remove it with ease.)* Grasp the hot can with the pliers and set it down on a nonburnable surface. As the can is cooling, try to replace and remove the cover repeatedly as before. At some point the can will "grab" the cover, or a hard push will be needed to seat the lid. It will then have to be pried loose in the usual way. Ask several children to repeat this Activity while the class thinks about possible explanations. *(Heating the can gives its molecules more energy, causing them to move further apart, resulting in expansion of the metal. The cooler cover can then slip easily into the enlarged groove in the top of the can.)*

Extending Ideas: After this Activity, discuss with the children how this experience with the expansion of matter is involved in the following situations:

Why are spaces provided between the slabs of concrete sidewalks? *(To allow for the expansion of concrete in warm weather, thus preventing heaving and breaking.)*

Why are there spaces between the ends of railroad track sections? *(So that the tracks will have room to expand.)*

Why does pouring very hot water into a milk bottle or thick glass jar often cause it to crack? *(Hot water causes glass to expand; however, the outside does not expand as quickly as the inside since glass is a poor conductor of heat. The result is a crack or break.)*

Why can Pyrex test tubes, or similar glass containers made by other manufacturers, be heated and cooled very rapidly without breaking? *(This type of glass expands much less than milk-bottle glass when heated, so little strain is created. Also, the thin walls of these containers permit enough heat to travel through the glass so that extreme differences do not occur between the inside and outside of the container.)*

It should be pointed out that there are a few exceptions to the general rule that heating causes substances to expand and cooling causes them to contract. Some children may wish to devise experiments to investigate the following exceptions: rubber contracts when it is heated; the alloy used in making printing type expands slightly when it cools. When water freezes, it expands to take up more space than it did in the warmer, liquid form. This action may cause the pipes or bottle to crack. *(In all of these substances, the molecules arrange themselves so as to take up more space when the substances are cooled, rather than less space.)*

Learnings: Almost all solids expand when they are heated and contract when they are cooled. When the energy of molecules is increased, the molecules increase the distances between them; when their energy is decreased, they decrease the distances between them.

ACTIVITY 51 (y,z)

OBSERVING THE EXPANSION AND CONTRACTION OF LIQUIDS

Purpose: To show that changing the temperature of liquids affects the volumes of the liquids and the motion of molecules in liquids

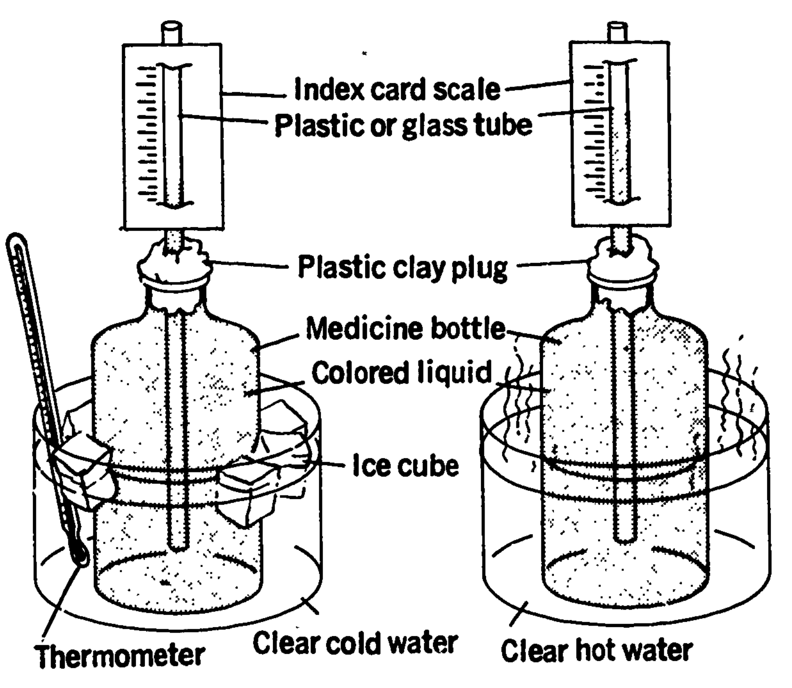
Concept to be developed: Increasing the energy of the molecules of a liquid causes the distances between them to increase; decreasing their energy causes the distances between them to decrease.

Materials needed:

- 4-ounce medicine bottles
- Plastic clay
- Ink or food coloring
- Pans
- Ice cubes
- Thermometer
- Water
- Mineral oil
- 6-inch lengths of glass or clear plastic tubing

INTRODUCTION: Review the preceding Activity with the children. Ask them if they think the molecules of a liquid will behave in the same way as those of a solid when their energy is altered. The following Activity will demonstrate the effect changing temperature has on liquids.

Have the children fill the bottles with water that has been deeply colored with ink or food coloring. A piece of glass or clear plastic tubing is then sealed into the mouth of each bottle with a plug of plastic clay. Ask the children to note the height of the liquid in each tube. What do they observe when the bottles are placed in a pan of hot water, and then in a pan of cold water?



(The liquid level moves up the tube when the liquid is heated, and down the tube when the water is cooled.) Slide a white card, slit in two places, over the tube to make the liquid level more visible, and to mark its height. The children can mark these crude thermometers off in degrees by obtaining check points with a commercial thermometer immersed in the water bath.

Learnings: Almost all liquids expand when heated and contract when cooled. When the energy of molecules is increased, the molecules increase the distances between them; when their energy is decreased, they decrease the distances between them.

ACTIVITY 52 (y,z)

OBSERVING THE EXPANSION AND CONTRACTION OF GASES

Purpose: To show that changing the temperature of gases affects the volumes of the gases and the motion of molecules in gases

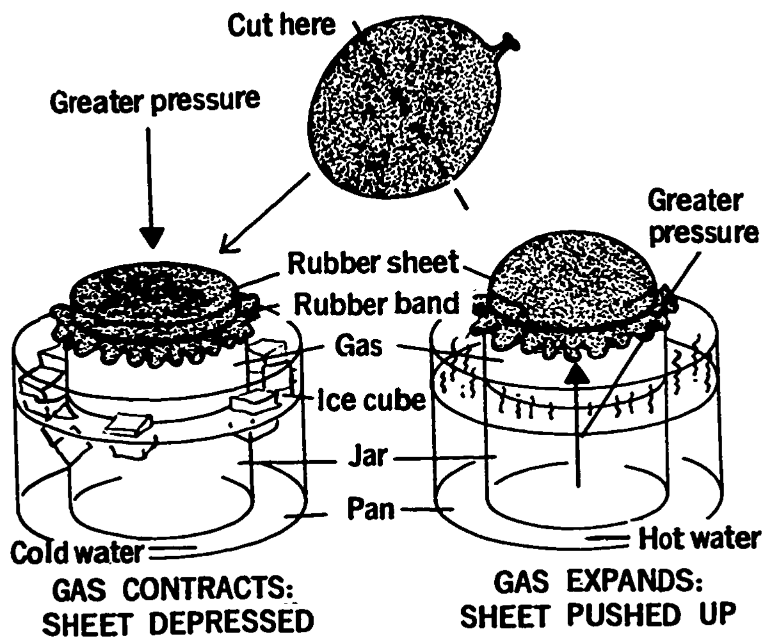
Concept to be developed: Increasing the energy of the molecules of gas causes the distances between them to increase; decreasing their energy causes the distances between them to decrease.

Materials needed:

- Balloons
- Scissors
- Wide-mouthed jars or milk bottles
- Pan or deep dish
- Rubber bands
- Ice cubes
- Hot water
- Baking soda
- Vinegar
- Dried yeast powder
- Hydrogen peroxide

INTRODUCTION: Review the two preceding Activities with the children. Ask them if they think that the molecules of gases, such as the air, behave in the same way as those of solids and liquids when their energy is increased by heating. After they have expressed their opinions, have them perform the following Activity.

Have the children cut the bottoms off several balloons to obtain sheets of rubber. Have them stretch these smoothly over the tops of the jars or bottles and hold them in place with rubber bands. These jars now contain air in which the molecules have the same temperature (energy) as the molecules in the surrounding atmosphere. This is evident because the rubber sheets are flat and level. What do the children observe when some of the bottles are placed in cold water with ice cubes and others in a pan of hot water? In each case, ask them to predict which way the rubber sheet will move and to explain why. *(When the gases in the jar are heated, the rubber will be pushed upwards because the molecules acquire more energy and move further apart from each other. This results in an increased pressure inside the jar that causes the rubber to bulge up-*



wards. When the gases are cooled, the molecules come closer together, and the pressure inside the bottle is reduced. The rubber diaphragm will then be pushed downwards or inwards because of the greater pressure of the surrounding air.)

Point out that this Activity has been limited to an observation of one case, the mixture of gases called air. Do they think the volume of other gases will be affected by temperature changes? Carbon dioxide and oxygen are two gases with which the procedure used for air can be employed.

To prepare carbon dioxide for testing, place 2 teaspoons of baking soda in each jar to be used. Carbon dioxide is produced by adding about an ounce of vinegar to each jar. (The vinegar should be added very slowly to prevent the contents from being carried up by the bubbling gas and overflowing the jar.) Wait a few minutes until very active bubbling has settled to a gentle fizzing. As the gas is produced it pushes out the air and fills the jar. Since carbon dioxide is heavier than air, most of it will remain in the jar. A rubber diaphragm can now be placed over the mouth of the jar. Have the children observe the response of the gas to changes of temperature as before.

Jars of oxygen can be prepared by adding a teaspoonful of yeast powder (or baking soda) to about one ounce of hydrogen peroxide. Place a piece of cardboard over the top of the jar and let the mixture stand for a few minutes. The tiny bubbles that escape are bubbles of oxygen gas. They will push out most of the air already in the jar. A rubber diaphragm can now be placed over the jar and the effects of placing it in hot and cold surroundings observed.

Extending Ideas: This Activity has shown that in three cases changes of temperature will cause gases to expand and contract. Suggest that some children may wish to find out if all gases act in this way. They may consult a science textbook, or an encyclopedia. *(All gases respond to increased temperature by expanding and to decreased temperature by contracting.)*

Learnings: Gases expand when they are heated and contract when they are cooled. When the energy of the gas molecules is increased, the molecules increase the distances between themselves; when their energy is decreased, they decrease the distances between themselves.

Summing Up Ideas: In this section the children were introduced to the idea that the molecules of which matter is composed are always in motion. The children learned of Brownian motion, the motion of particles suspended in a fluid. They learned how changing the energy of the molecules in a solid, liquid, or gas affects the motion of the molecules. The children also learned that increasing the energy of the molecules causes the substance to expand and that decreasing the energy of the molecules causes the substance to contract.

HOW IS ENERGY INVOLVED IN PHYSICAL AND CHEMICAL CHANGES OF MATTER?

Physical and chemical changes in matter result from changes in the position and movement of the atoms and molecules of a substance. Since energy is required to do this work, an exchange or transfer of energy occurs between the substance and its surroundings.

ACTIVITY 53 (y,z)

SEEING THAT EVAPORATION ABSORBS ENERGY

Purpose: To find out why evaporation is a cooling process

Concept to be developed: In order for liquids to be converted to gases, they must absorb energy—usually in the form of heat—from their surroundings.

Materials needed:

Paper cups
Paper towels
Water
Oil
Glycerine
Duplicating fluid or rubbing alcohol
Acetone (nail-polish remover)

(*Safety Note:* Exercise caution when using alcohol, duplicating fluid, and nail-polish remover, for they are all flammable and poisonous substances.)

INTRODUCTION: Discuss the changes of state in water as an example familiar to children. Bring out that heat energy is required to melt snow and ice to water, and stronger heating is needed to change water to steam. In reverse order, in changing from gas to liquid to solid, heat must be removed. Help the children see that when heat is removed from water to cool it, the energy must be transferred to some other agent and this agent thus becomes warmed. For these reasons condensation and freezing have a heating effect on the agent absorbing the heat, while melting and evaporation have a cooling effect on the agent providing the heat, as the following Activity will illustrate.

Have each child dip his finger in water, hold it up in the air, and tell what temperature sensation he feels. Then ask the children to dry their fingers and describe whether the fingers feel warmer or colder. Can they explain what happens? *(Body heat imparts sufficient energy to cause some of the water molecules to evaporate, so that they leave the finger and travel into the air. This heat loss is sensed as a cooling of the skin.)* Help them to see how this explanation is related to the cooling of the skin after bathing or showering.

Have them investigate other liquids to see if evaporation causes cooling. *(Some liquids evaporate more quickly than others, that is, they take up heat more rapidly from their surroundings.)* Have the children try the same finger-wetting experience with the other liquids. How do these compare as coolants? *(Acetone will show the strongest cooling effect, followed by alcohol. Water is next, and the oil and glycerine hardly cool at all.)*

Learnings: Evaporation is a cooling process. When a substance evaporates, it absorbs heat from its surroundings in order to give its molecules sufficient energy to enter the gaseous phase.

ACTIVITY 54 (y,z)

SEEING THAT A SOLID ABSORBS ENERGY WHEN MELTING

Purpose: To discover why ice can keep a liquid cold

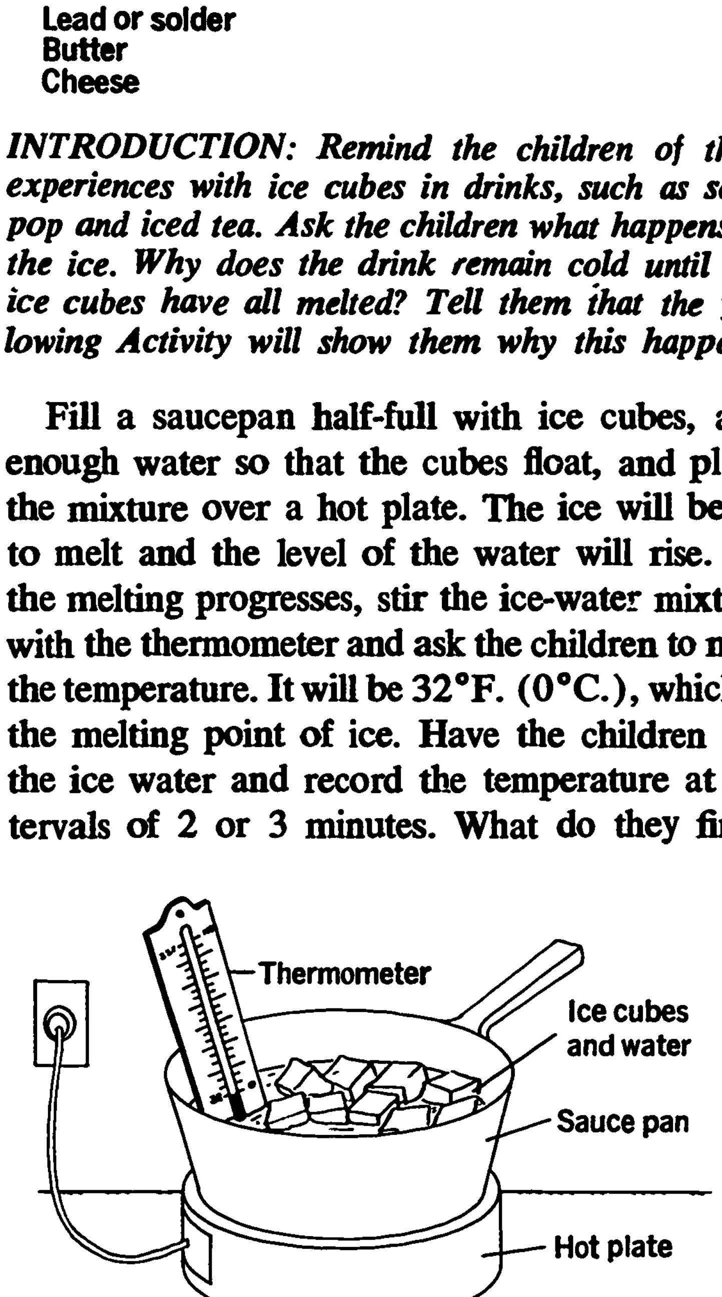
Concept to be developed: In order for solids to be converted to liquids, they must absorb energy—usually in the form of heat—from their surroundings.

Materials needed:

Saucepan
Ice cubes
Hot plate
Thermometer
Candle wax
Water
Sugar
Rosin
Lead or solder
Butter
Cheese

INTRODUCTION: Remind the children of their experiences with ice cubes in drinks, such as soda pop and iced tea. Ask the children what happens to the ice. Why does the drink remain cold until the ice cubes have all melted? Tell them that the following Activity will show them why this happens.

Fill a saucepan half-full with ice cubes, add enough water so that the cubes float, and place the mixture over a hot plate. The ice will begin to melt and the level of the water will rise. As the melting progresses, stir the ice-water mixture with the thermometer and ask the children to note the temperature. It will be 32°F. (0°C.), which is the melting point of ice. Have the children stir the ice water and record the temperature at intervals of 2 or 3 minutes. What do they find?



(As long as any ice remains and the mixture is stirred, there is no rise in the temperature. Usually when a substance is heated it gets hotter, but here the major change taking place is the melting of the ice rather than the heating of the water. As long as there is any ice to melt, the heat energy goes into agitating the ice molecules until they separate from each other to form more water.) What happens when all the ice cubes have melted? *(At this point, the temperature of the water begins to rise.)*

The children will be interested in trying to melt other common substances such as those listed above. They may be heated in a small "tin" can. (*Safety Note:* Wax vapor is easily ignited if the temperature goes too high. Melt the candle stubs by heating them in a can that is placed inside a pan of water. The can may be lifted out with tongs or pliers and the melted wax poured onto some cardboard.)

Learnings: When a substance melts, it absorbs energy, usually in the form of heat. When a substance in the solid state is mixed with some of the same substance in the liquid state and the mixture is heated, all of the solid will melt before the temperature of the substance rises.

ACTIVITY 55 (z)

OBSERVING THE ENERGY CHANGE IN THE PROCESS OF SOLUTION

Purpose: To show that energy may be gained or lost when the molecules of a substance are dissolved within the molecules of another substance

Concept to be developed: When a substance in a reaction absorbs heat, the process is called **endothermic**; when a substance in a reaction gives off heat, the process is called **exothermic.**

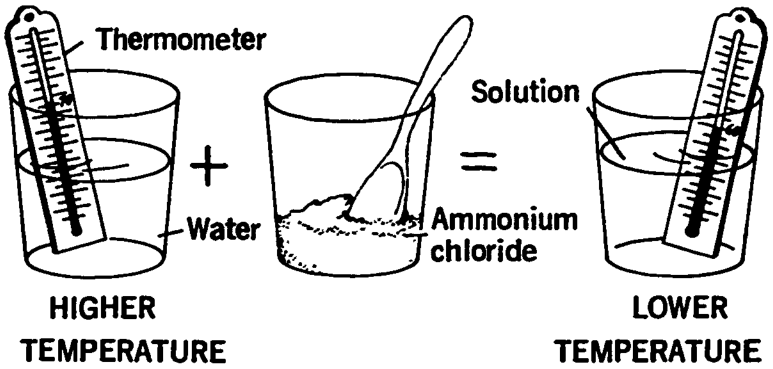
Materials needed:

- Sal ammoniac (ammonium chloride)
- Epsom salts (magnesium sulfate)
- Photographer's hypo, without hardener (sodium thiosulfate)
- Calcium chloride
- Saltpeter (potassium nitrate or sodium nitrate)
- Thermometer
- Drinking glasses
- Spoons
- Pencils

INTRODUCTION: Explain to the children that some compounds give off heat when they dissolve in water; others absorb or take up heat from the water, the container, and the surrounding air. Point out that the overall effect is a marked rise or drop in temperature of the solution. Why does this occur? Encourage the children to give their ideas. As a clue, mention that since particles of matter are in motion, energy is involved. The following Activity will help answer the question.

Have the children make solutions of the compounds listed above and record the temperature changes with a thermometer. (These substances may be obtained from a drugstore, camera supply store, hardware store, or chemical supply house. They should be obtained in powdered or finely ground form to permit quick solution.)

The following general procedure may be used by the children in making the solutions and observing the results: Fill half of a drinking glass with water. Place the thermometer in the glass. What is the temperature reading? Record this temperature. Place 5 tablespoons of one of the solids in another glass and pour the water into it. Stir rapidly to dissolve the compound. What is the reading on the thermometer now? Record the temperature change. Repeat this procedure with each of the compounds. For some of these, children will discover that the change in temperature is large enough to be felt by the hand on the outside of the drinking glass.



Ask the children to suggest additional compounds to test, such as borax, washing soda, salt, and sugar.

The class may wish to record the results as shown in the chart.

TEMPERATURE CHANGES IN WATER SOLUTIONS

Compound	Starting Temperature	Final Temperature	Change (in °F.)
ammonium chloride			(x)
magnesium sulfate			(y)
hypo			(x)
calcium chloride			(y)
saltpeter			(x)
borax			(x)
washing soda			(x)
table salt			(x)
sugar			(y)

The substances in the list marked (x) will absorb heat from the water and cool it; for those marked (y) heat is produced as the solution forms, and the water is warmed. Point out that in all of these cases, a transfer of energy occurs when atoms, ions, or molecules change position.

More dramatic results can occur if substances listed in the table as causing a drop in temperature are mixed with snow, cracked ice, or refrigerated water. Depending on the compounds, their proportions, and conditions, temperature changes of up to 40°F. can be produced. (In order to obtain reliable comparisons, be sure that the same amounts of each substance and of snow, cracked ice, or refrigerated water are used, and that the starting temperature is the same for each test.)

The children may also wish to experiment with combining the various compounds in pairs to see how effective a cooling effect they can make. *(Equal parts of ammonium chloride and saltpeter work well.)*

Introduce the children to the terms *endothermic* and *exothermic*. Write the words on the chalkboard and encourage the children to look up the meanings in reference books, such as dictionaries and encyclopedias. *(Endothermic processes are those that take up heat energy from the surroundings; exothermic processes are those that surrender heat energy to the surroundings. Thus those reactions marked (x) in the chart are endothermic, and those marked (y) are exothermic.)*

Learnings: Energy may be either lost or gained, depending upon the substances involved, when the molecules of one substance are dissolved in the molecules of another substance. If heat is absorbed, the process is endothermic, and the surroundings will be cooled. If heat is given off, the process is exothermic, and the surroundings will be warmed.

ACTIVITY 56 (x,y,z)

CHANGING THE ENERGY OF A GAS BY CHANGING ITS PRESSURE

Purpose: To show that as the pressure of a gas changes, so does the energy of its molecules

Concept to be developed: When a gas is compressed, it becomes warmer; when a gas is allowed to expand, it becomes cooler.

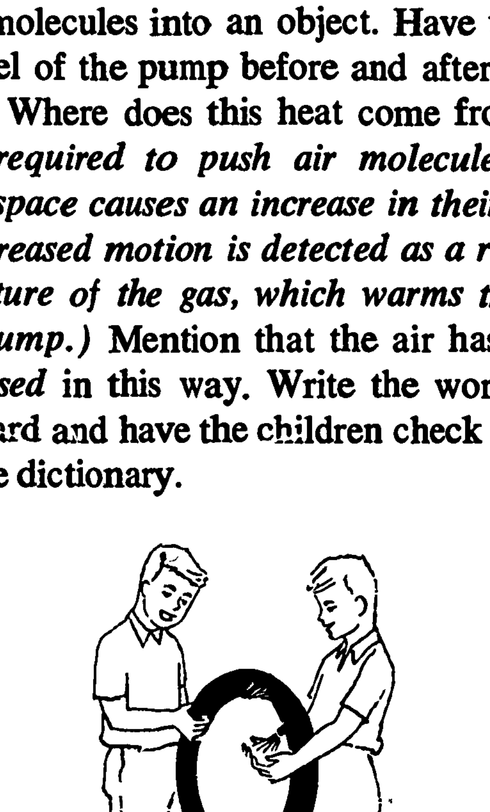
Materials needed:

Bicycle tire pump
Bicycle tire or other inflatable object
Hammer
Nail
Carbon dioxide "cartridges"

INTRODUCTION: Bring up for the children's consideration the following question: Does pressure affect the motion of molecules? The children will probably mention that air is put into tires of an automobile or bicycle under pressure. Ask the children if applying more pressure would have any effect on the air itself. Encourage them to express their theories, and then proceed with the following Activity.

Ask one of the children to bring in a pump used for bicycle tires, footballs, etc. Have them deflate a bicycle tire (tube) and then pump it up again. What do they observe about the amount of "push" required to force air into the tube?

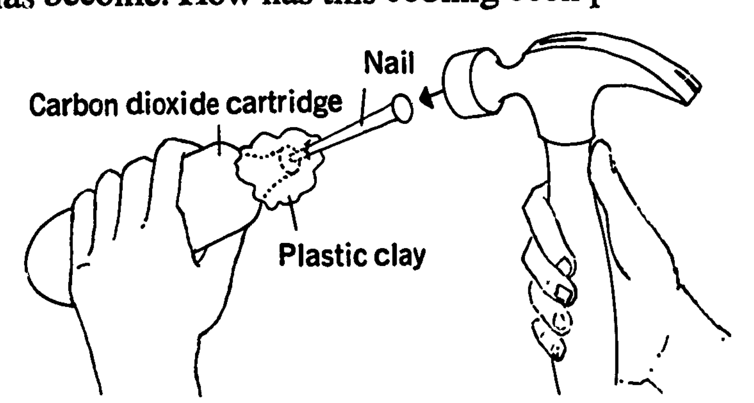
(It becomes harder to pump air in as the object inflates.) Point this out as an example of the need for muscular energy to do the work of moving air molecules into an object. Have them feel the barrel of the pump before and after the tube is filled. Where does this heat come from? *(The energy required to push air molecules into a smaller space causes an increase in their motion. This increased motion is detected as a rise in the temperature of the gas, which warms the barrel of the pump.)* Mention that the air has become *compressed* in this way. Write the word on the chalkboard and have the children check its meaning in the dictionary.



Point out that the children can demonstrate the opposite effect by permitting the air to escape from the bicycle tube. Be sure they notice that this air is cooler because it *expands* as it leaves the tube. Clarify the contrast between the terms *compressed* and *expanded* in this situation.

Each child can experience the cooling effect of expansion by blowing air out of his lungs onto the palm of the hand. First have them blow with the mouth wide open, and then with the lips pursed forming a small hole. What do they feel? *(The palm will feel quite warm when the position of the mouth is wide open, and much cooler when compressed air in the mouth is allowed to escape and expand through the small opening.)* Suggest that the children find out from their reading in an encyclopedia or science book how this principle is applied in refrigerators and air conditioners.

A more dramatic illustration of the cooling effect of a compressed gas uses carbon dioxide (CO_2) cartridges. The carbon dioxide cartridges are small steel bulbs which contain CO_2 under pressure and are used for charging soda-water siphons. (They are available at some drugstores and department stores, and at hobby shops where they are sold for jet-propelling model cars.) A sharp tap on the nail breaks the seal on the cartridge, allowing the gas to escape. As this happens, the bulb becomes extremely cold, with frost forming on it because of the condensation of water vapor present in the air. After a minute or two, when the bulb has warmed up a bit, pass it around the room so children can feel how cold it has become. How has this cooling been produced?



(The molecules of compressed gas in the tank "work" in pushing out the escaping gas, and thereby lose some energy. By definition such a loss of energy means a drop of temperature, so the gas in the tank becomes cooled. The escaping blast is cold because the compressed gas from which it comes is now cold.)

Learnings: When a gas expands, its pressure is lowered and the gas becomes cooler. When a gas is compressed, its pressure is increased and the gas becomes warmer.

ACTIVITY 57 (y,z)

DETECTING HEAT FROM CHEMICAL REACTIONS

Purpose: To discover that heat is given off in some chemical reactions

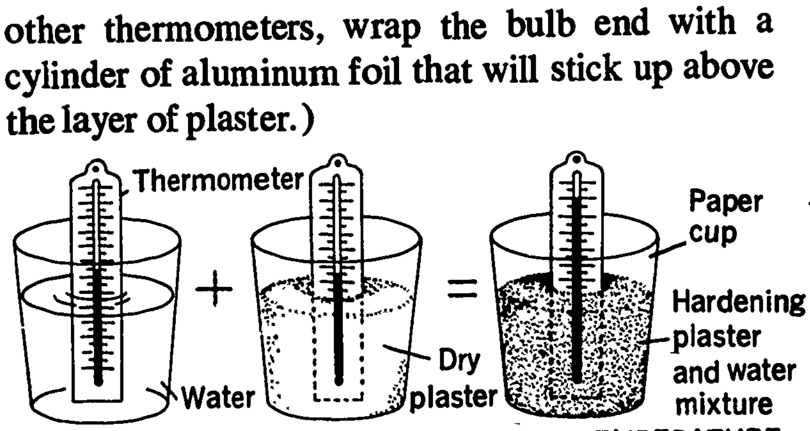
Concept to be developed: Energy is involved in chemical changes.

Materials needed:

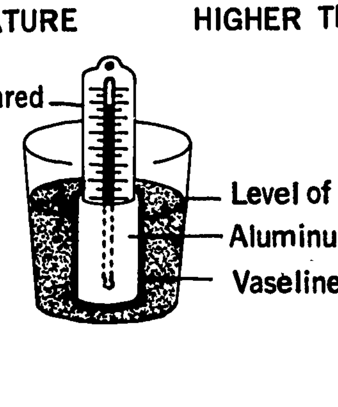
Three paper cups (4-ounce size or larger)
Stirrers (pencils or sticks)
Three thermometers
Plaster of paris (from hardware store)
Vaseline
Aluminum foil (heavy duty)

INTRODUCTION: Remind the children that in previous Activities they learned that the particles of substances are arranged into new patterns when chemical change takes place. They now know that such motion means that work is done and therefore energy must be involved. Mention that burning is one obvious example of the release of such energy. Many other reactions release smaller amounts of heat, which can be detected as shown in the following Activity.

Partially fill two cups with dry plaster and another cup with water. Add water to the dry plaster in one cup and stir until the mixture is a thin paste. Smear the lower third of the thermometers with Vaseline, and insert one thermometer in each cup. (Be certain that the thermometer is not wider at the bulb than it is at the stem or it will become stuck in the plaster. For other thermometers, wrap the bulb end with a cylinder of aluminum foil that will stick up above the layer of plaster.)



Thermometer prepared to prevent sticking in plaster (cut-away view):



If thermometers are not available, the warmth of the reaction can be felt with the hand. Have the children compare the temperature of each cup. What happens? *(As the plaster hardens, its molecules combine with water molecules and heat is released.)*

Learnings: Heat is produced in some chemical reactions. The hardening of plaster of paris is an exothermic reaction.

Summing Up Ideas: In this section the children were introduced to the idea that energy is involved in all physical and chemical changes of matter. They learned that energy is absorbed by the molecules of an evaporating liquid, and that for this reason evaporation is a cooling process. They learned that a melting solid takes up energy from its surroundings. They also learned that a substance being dissolved in a liquid may either gain or lose energy, usually in the form of heat, and that a gas takes up energy when it is compressed and gives up energy when it is allowed to expand. They saw that heat was produced in some chemical reactions, such as the hardening of plaster and the rusting of iron. In addition, they learned that processes in which heat is absorbed are called endothermic, and processes in which heat is released are called exothermic.

WHAT ARE ATOMS MADE OF?

It is useful to visualize the energy contained in matter as being somehow stored up in the bonds between the particles of a substance. Under the proper conditions, this stored energy can be released to do useful work. When dynamite is used to blast out rocks for a new road, the explosive force comes from splitting apart the bonds between atoms of nitrogen, oxygen, carbon, and hydrogen that make up molecules of TNT or dynamite.

However, the huge quantities of energy released in such explosions or in other "ordinary" chemical or physical changes are mere pop-gun blasts compared with the energy present *within* atoms themselves. The energy involved may be five to ten million times greater than that involved in ordinary chemical changes between whole atoms. Such are the nuclear reactions. In these the forces that hold the parts of atoms together are being released, and matter itself is converted into energy.

A study of atoms and their parts, therefore, will help children gain some important understandings about nuclear energy.

ACTIVITY 58 (x,y,z)

DISCOVERING THINGS ABOUT OBJECTS WE CANNOT SEE

Purpose: To discover that we can find out about atoms even though we cannot see them

Concept to be developed: Man has been able to determine the structure of the atom even though he has never seen it.

Materials needed:

- Marbles
- Coins
- Feathers
- Paper
- Wooden blocks
- Thumbtacks
- Gift-wrap paper
- Tape or string
- Small burlap sacks or other coarse-weave bags
- Knitting needles

INTRODUCTION: Discuss with the children the problem of what they can do to find out what is inside a sealed container. Point out the similarities between this situation and the problem faced by scientists studying the insides of atoms, which, because of their small size, cannot be observed directly either.

Seal a few of each kind of object in separate boxes (one box containing marbles, another a few coins, etc.). Mark the boxes with an identifying symbol and make a record of what is in each box, but withhold this information from the class. Now let the children experiment and try to deduce what kind of object is contained in each box.

Help them to see that by observing such clues as sound, weight, and whether the object rolls or slides, they are collecting evidence upon which to base guesses that are probably accurate as to the identity of the unseen objects, their number, and their composition.

When they have tried every approach they can think of, have them state their guesses and open the boxes.

A similar experience with drawing conclusions from observations can be provided by sealing a variety of objects in coarsely woven cloth bags, such as burlap sacks. (Mark each bag with an identifying symbol or tag.) The children may probe these bags with long knitting needles and feel through the cloth to find out what the objects are, how many there are, and what they are made of. Have them verify their inferences by opening the bags.

Learning: We can determine things about objects we cannot see by studying their properties.

ACTIVITY 59 (y,z)

GUESSING THE SHAPE OF A HIDDEN OBJECT

Purpose: To show that we can determine the shape of objects that we cannot see

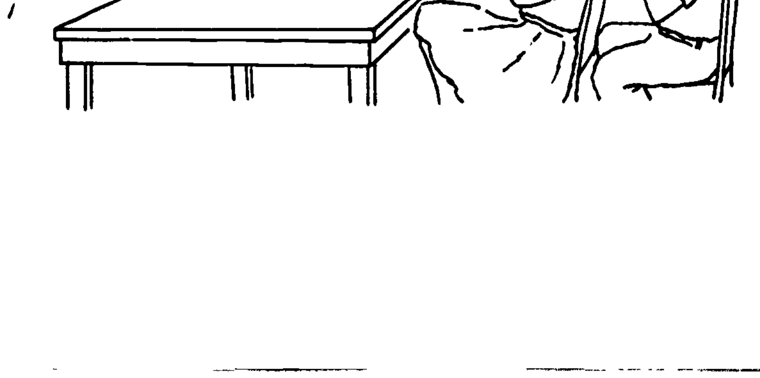
Concept to be developed: Man has been able to determine the structure of the atom even though he has never seen it.

Materials needed:

Cardboard carton
Rubber ball
Large book or board
Bowl
Scissors

INTRODUCTION: Mention to the children that they have learned to make inferences about the number and identity of objects inside containers, but do they think they could also determine the shape of an object by similar means? What objects should they use? What senses would be especially involved? Elicit their suggestions and then proceed with the following Activity.

Cut up a carton to provide a strip of cardboard about 3 feet long by 10 inches high. Use this as a screen and place behind it an inverted bowl or a book propped up at a slight angle so that it is hidden from the class. Bounce the ball off the hidden object several times so that it rebounds in an unexpected fashion. What conclusions can the children draw about the shape of the object from the observed path of the ball? Let them give directions as to how they want the ball to be bounced



—strongly? weakly? at various angles? from different heights? Have them verify their guesses by removing the screen concealing the object.

Extending Ideas: Bring out that each of the preceding Activities in this section is analogous to actual procedures used in atomic research. Scientists bounce rays from the surfaces of various materials and gain information about their structure by observing the "rebounds." The use of knitting needles is similar to the scientist's technique of shooting rays and particles through samples of matter. As a result of observing how many of the projectiles come through, how many are absorbed or deflected and at what angles, some idea of the fine structure of a substance can be deduced.

Point out that scientists can describe an atom, a distant star, or the Earth's interior, even though these have not been seen "close up." Drawing inferences and testing them by further predictions, experiments, and observations are some of the major operations in scientific work. The children can be helped to understand this indirect approach of the scientist, and can learn to distinguish between what can be observed and what can be deduced.

Learning: Man has been able to learn many things about the structure of the atom by indirect methods.

ACTIVITY 60 (z)

MAKING MODELS OF ATOMS

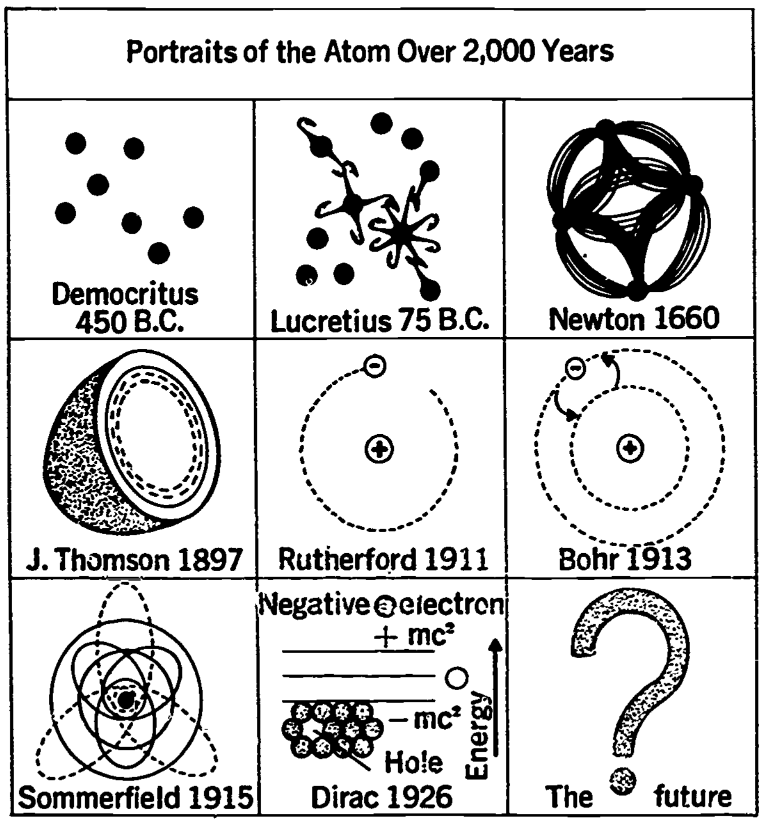
Purpose: To help the children understand atomic structure

Concept to be developed: An atom consists of a nucleus, containing protons, neutrons, and many other particles, surrounded by electrons.

Materials needed:

Modeling clay
Beads
Small balls
Wires
Pipe cleaners
Tinker Toy or similar construction sets

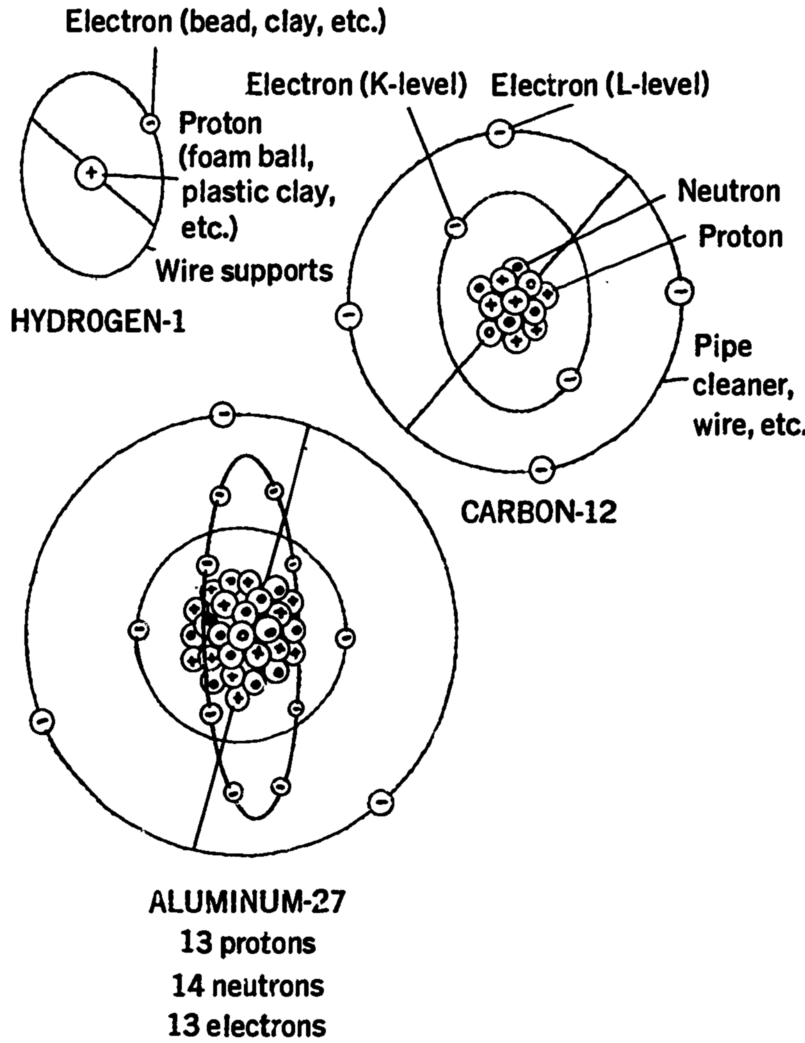
INTRODUCTION: Discuss with the children their ideas about what an atom really looks like. Plan a bulletin board display of pictures they have collected, drawn, or painted. The display may be arranged as a series of historical "portraits" of the *atom like those shown in the accompanying chart. Suggest that they find similar but more modern pictures. (The chart carries some clues in the names of the scientists and thinkers who conceived these pictures of atoms. You might have to tell the children the names of some of the scientists and mathematicians and lead them to pictures and information in encyclopedias and science books.)*



When most of the spaces in the children's chart are filled with atom portraits, bring out such points as the long span of time during which they evolved; the many changes in the portrait of the atom; that none of the pictures is completely satisfactory to scientists; and the fact that more, new, and different portraits of the atom will no doubt be drawn in the future.

A great variety of materials can be used to make atomic models. Plastic clay is probably one of the most suitable materials. It should be clearly pointed out to the children, however, that any models they can construct will be extremely crude. The models do not show what an atom *really* looks like, for that is unknown and therefore impossible to depict. Models of atoms are, at best, somewhat like road maps or blueprints, which give only the barest outlines of the details of a complex structure. For example, size and distance relationships cannot be shown to the same scale.

Sketch the accompanying illustrations on the chalkboard as guides for the children to follow in making their models.



Discuss how the differences among the particles might be shown in the models by color, labels, and varying size. Protons and neutrons should be represented as being the same size and packed close together into a spherical mass at the center of the model atom. The similarly charged protons do not repel each other since, at very close distances, a different and stronger "nuclear force" holds them together. The electrons of a model should be noticeably smaller than the spheres used for the particles in the nucleus. The electrons are distributed in various arrangements and at various distances from the nucleus, depending on the energy they possess. They do not circle the nucleus like planets around the Sun, but move about within certain regions, or "orbitals." (The first region is called the *K* orbital, the second the *L* orbital, the third *M* orbital, and so on. In the children's models, the *K* orbital should be closest to the nucleus, the *L* orbital the second from the nucleus, etc.) This arrangement is called the "charge cloud" model.

In the accompanying table some elements are listed in the order of the number of protons in their nucleus. The children can make their models from the information in this table.

NUMBER OF PARTICLES IN THE ATOMS OF SOME ELEMENTS

Element	Protons	Neutrons	Electrons by energy level K	L	M	N	O	P	Q
hydrogen	1	0	1						
helium	2	2	2						
lithium	3	3	2	1					
carbon	6	6	2	4					
nitrogen	7	7	2	5					
oxygen	8	8	2	6					
neon	10	10	2	8					
sodium	11	12	2	8	1				
aluminum	13	14	2	8	3				
sulfur	16	16	2	8	6				
chlorine	17	18	2	8	7				
calcium	20	20	2	8	8	2			
iron	26	30	2	8	14	2			
nickel	28	31	2	8	16	2			
copper	29	35	2	8	18	1			
silver	47	61	2	8	18	18	1		
tungsten	74	110	2	8	18	32	12	1	
gold	79	118	2	8	18	32	18	1	
mercury	80	121	2	8	18	32	18	2	
lead	82	125	2	8	18	32	18	4	
radium	88	138	2	8	18	32	18	8	2
uranium-235	92	143	2	8	18	32	18	9	2
uranium-238	92	146	2	8	18	32	21	9	2

To use the table for model building, have the children look up the elements to be constructed. Point out that carbon, for example, has six protons, six neutrons, and six electrons. The chart shows the electrons of the carbon atom to be at two different energy levels—two of them at *K* and the other four at *L*. The electrons should be spaced evenly around their supports. What is noticeable about the number of electrons and the number of protons? *(They are equal in every atom.)* The number of neutrons may vary, however, so that there are different "species" of atoms of the same element. These are called *isotopes.* As an example, note the two isotopes of uranium, uranium-235 and uranium-238, shown on the chart. One has 143 neutrons and the other has 146.

The children might also draw atom models on the chalkboard or make cutouts of the basic particles and arrange them as a poster.

Learnings: Atoms are made of protons, neutrons, and electrons. The number of protons in an atom is equal to the number of electrons. The protons and neutrons are located at the center of the atom in an area called the nucleus. The electrons are located around the nucleus in various energy levels, or orbitals.

ACTIVITY 61 (z)

LEARNING ABOUT THE SPACES INSIDE ATOMS

Purpose: To introduce some ideas about the structure of an atom

Concept to be developed: Even though atoms are very small, most of their volume is made up of empty space.

Materials needed:

Paper
Small electric fan

INTRODUCTION: Explain to the children that atoms might be thought of as made of particles and space. Bring out that only a small fraction of the size of an atom is actually occupied by protons, neutrons, and electrons. For example, if the nucleus of an atom were enlarged to the size of a marble, the innermost electrons would be small points about 50 yards away.

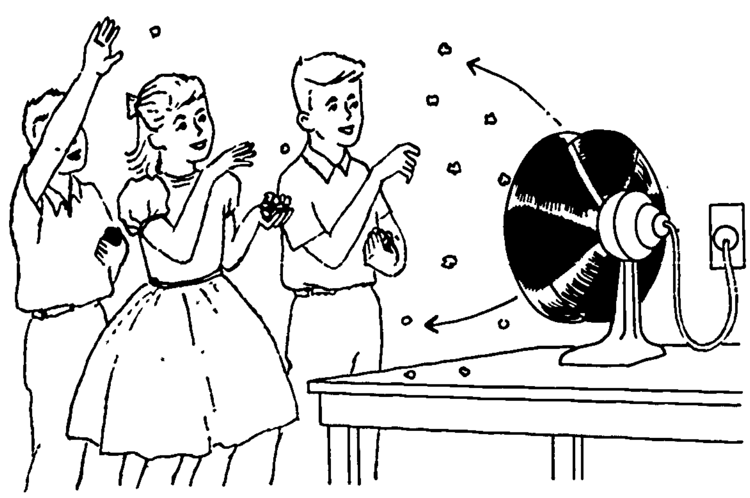
Present the following dramatic descriptions to help children understand "how small is small" when dealing with atoms, their particles, and their spaces.

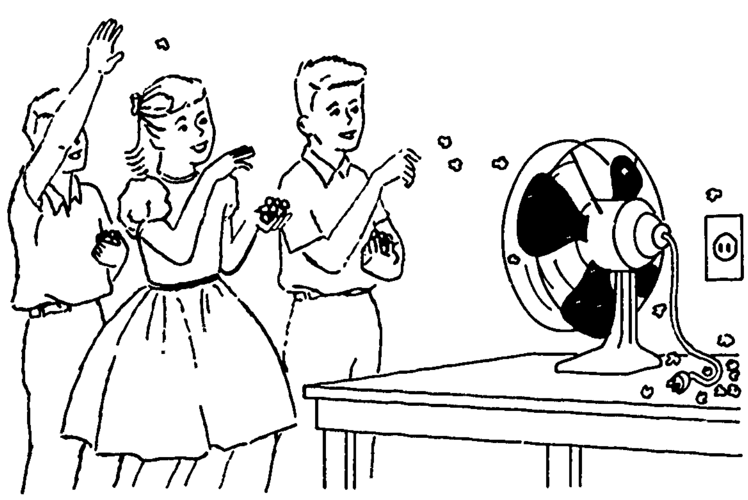
- *If an average-sized atom were enlarged to the size of a football stadium, its nucleus would be as large as a BB shot on the 50 yard line.*
- *The weight of an atom is concentrated in its nucleus. (Electrons are negligible in weight compared to protons and neutrons.) If nuclei were packed side by side in a matchbox, they would weigh more than all the automobiles in the world. In fact, the box would be so heavy that it would crash through the Earth and come to rest at the center.*
- *If all the nuclei making up the atoms of rock, soil, and plants on Mt. Everest were separated from their electrons and packed together, they could fit inside a quart milk container.*

Many books say, therefore, that atoms are made up mostly of empty space.

Ask the children if they think there is anything within this empty space. Remind them of the forces of attraction and repulsion that are acting between atomic particles. Explain to them that an atom's spaces are far from "empty." They are filled with energy fields. In addition, the spaces in an atom are effectively "filled" by the rapid motion of the electrons, somewhat as the blades of a rapidly rotating electric fan take up the space in which they are rotating. Tell them that the following Activity will demonstrate this.

Ask one or two children to toss small paper wads between the blades while the fan is on. Do any wads get through? *(Not very likely; the blades of a fan move so fast that it is difficult for the paper to pass through. The movements of the electrons of an atom make it similarly difficult for other atoms and larger objects to reach the nucleus.)* Do the children think if the wads





were thrown with sufficient speed, or with the right timing, they might slip past the moving blades? Turn off the fan, and as it is slowing down, have the children try to throw paper wads through the path of the blades. Do more paper wads get through than did before? *(Yes.)* Tell the class how this demonstration is similar to a technique used by scientists in which atoms are bombarded with high-speed particles. In such experiments the scientists are trying to hit the nucleus, not miss the electrons. Protons, neutrons, or fragments of other atoms are the projectiles used. Some of these reach the nucleus if they are shot with sufficient speed.

Learnings: Atoms are mostly made of empty space. Electrons have very little weight when compared to that of protons and electrons. It is difficult to reach the nucleus of an atom with a particle because electrons deflect the particle.

ACTIVITY 62 (y,z)

DETECTING RADIOACTIVITY

Purpose: To develop an understanding of radioactivity

Concept to be developed: Radioactivity is the emission of particles and/or energy by the nucleus of an atom.

Materials needed:

Geiger counter
Radium-dial watch or clock
Child's rock collection
Jars
Pans
Books

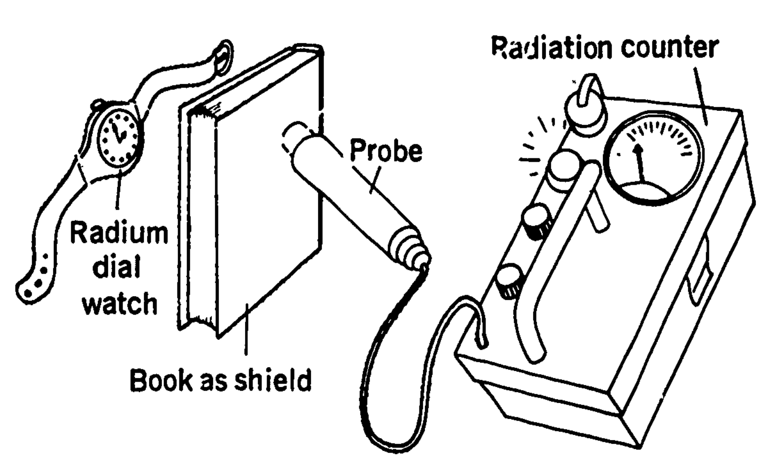
INTRODUCTION: In a discussion, ask the children to volunteer their definitions of the word radioactivity. *They may check these with a dictionary. Develop with them the understanding that radioactivity is essentially composed of invisible high-energy rays, or waves, and atomic particles moving at great speeds. Changes in the nucleus of an atom make it radioactive. For example, neutrons can be shot toward another atom and penetrate to its nucleus. The nucleus "captures" the new neutron to form a heavier nucleus which is frequently unstable. If it is, the nucleus decomposes, usually emitting a particle and energy.*

Explain to the children that natural, or spontaneous, radioactivity occurs in many elements, such as radium and uranium. Another source of radioactivity is the bombardment of the Earth with cosmic rays from outer space. Long before the first atomic bomb exploded, almost everybody and everything in the world was radioactive to some slight degree.

Scientists have also discovered how to produce radioactivity artificially in elements in which it does not occur naturally. These experiments have added much to an understanding of the nature of matter.

Radioactivity cannot be detected directly by any of our unaided senses. However, there are several ways in which children can observe some of its effects.

Geiger counters are often available on loan to the schools from a local Civil Defense unit. Point out to the class the three signals most of these instruments employ to indicate radioactivity—flashing light, clicking sound in the earphones, and readings on a meter. Turn the instrument on



and hold it so the class can see the light and meter signals. (Make sure that you are not wearing a radium-dial wristwatch). Show them that the counter indicates the presence of small amounts of radioactivity even though no obvious source is present. Allow the children to suggest explanations. *(This is the natural "background" count of radioactivity in the air, rocks, people, desk, and all materials surrounding the Geiger counter.)*

Allow the children to test various objects in the room with the instrument, such as radioactive ore samples some children may have in rock collections, luminous watches, and others.

Have the children investigate the effect of placing a shield between the Geiger counter and the radioactive source. *(Materials for shields may be metal plates or pans, books, blocks of wood, and other materials the children might suggest.)* Which materials do they find will make the best shields for radiation? *(The heaviest, densest substances, such as the metals, are better than lightweight materials, such as paper, cardboard, or wood, if the thickness of the shields is the same.)*

Learnings: Radioactivity is caused by the emission of particles or energy from the nucleus of an atom. A Geiger counter may be used to detect radiation.

ACTIVITY 63 (z)

OBSERVING THE SCINTILLATION OF CRYSTALS

Purpose: To demonstrate another method by which radioactivity can be detected

Concept to be developed: When certain substances are struck by radiation, they emit a small flash.

Materials needed:

Strong magnifier
Radium-dial wristwatch

INTRODUCTION: Write the word scintillation *on the chalkboard and ask the children to look in dictionaries and encyclopedias to find out what it means. Discuss the phenomenon with them and have them do research on how scintillation counters are used to detect radioactivity. Perhaps it will be possible to borrow a scintillation counter from your local Civil Defense group. If so, demonstrate its use to the children. Tell them that the following Activity will help them to see how a scintillation counter works.*

Ask the children how the light is produced on the face of a television picture tube. *(Some materials, such as the phosphor coatings on the inside of television picture tubes and on fluorescent lamps, produce light, or scintillate, when struck by radiation in the form of rays or particles. Inside a picture tube, for example, a beam of electrons sweeps across a phosphor coating, causing it to glow.)* Explain to the children that the luminous glow of a radium-dial wristwatch or clock is due to radioactive particles from the radium striking a substance that scintillates. The children can observe this by viewing a radium watch dial in the dark with a strong magnifying glass. They should allow sufficient time for their eyes to become adapted to the dark (about 10 to 15 minutes). A low-power microscope makes the viewing even better. Have them report what they see. *(Each flash, which seems like a miniature fireworks display, is the explosion of a single atom of radium. The energy that is released causes another substance, usually zinc sulfide, to scintillate.)*

Ask some children to find out how radiation causes light to be produced in fluorescent tubes and the television screen.

Learnings: Scintillation is a flash of light produced by some form of energy striking a phosphorescent substance. Scintillation counters, which take advantage of this phenomenon, are used to detect radioactivity.

ACTIVITY 64 (z)

MAKING PICTURES OF RADIOACTIVITY

Purpose: To demonstrate a third way of detecting radioactivity

Concept to be developed: Radioactivity will cause streaks to appear on a photographic film.

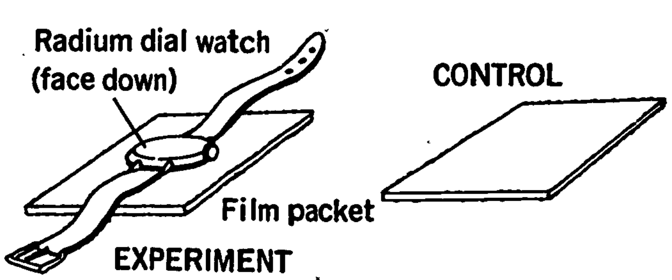
Materials needed:

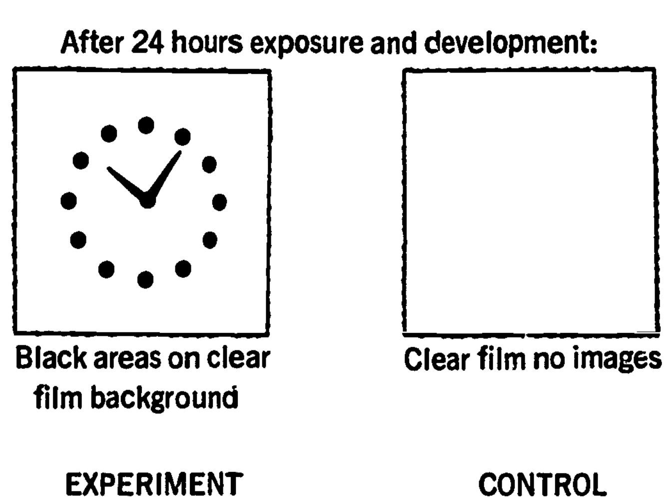
Watch or clock with radium dial
X-ray film packets (dental type)
Film developing kit (or the dentist will most likely agree to develop a few films)

(*Safety Note:* The radioactive material on watch or clock faces is harmful if tasted or inhaled. Do not use timepieces from which the glass cover has been removed.)

INTRODUCTION: Tell the children the story of the discovery of radioactivity by Henri Becquerel in 1896, a feat for which he shared the 1903 Nobel Prize in physics with Pierre and Marie Curie. Explain that Becquerel was experimenting with the relationship between the phosphorescence of certain minerals after they were exposed to light and their ability to darken a photographic plate even though it was covered with paper. One day he accidently placed a piece of uranium ore that had not been treated with light near some unexposed film wrapped in paper. When he developed the film it had been affected by the uranium. This led his researches onto the path of radioactivity and the work for which he later shared the Nobel Prize.

Place the watch or clock dial on top of one film packet and do not disturb for 24 hours. (Ask your film supplier to show you which side of the packet should face the radioactive source.) Another film packet should be placed nearby, without a watch under it, as a control. Both films should be developed the next day. (Directions for developing films are on the containers of the chemicals, or ask a dentist for help.)





The children should look for little black or gray streaks and spots against the clear background of the negative. What caused them? *(These are spots where chemicals sensitive to light and radiation were struck by rays or particles from the radium.)*

Discuss the length of time necessary to make images on the film for dental X rays, and that needed to make pictures of a radium dial in this Activity. Why is only about one second needed to take dental pictures and a whole day for the exposure in this Activity. *(The amount of radioactivity varies greatly. The luminous dials on watches vary tremendously in the intensity of their radiations. With some dials only 4 hours of exposure will produce good results; others may take from a day to a week.)* Some children will be interested in experimenting to find the minimum time required to detect radioactivity in this way from different sources. (Other items that can be tested are uranium ore specimens in children's rocks and mineral collections, and a gas mantle from a camper's gasoline lantern, which contains radioactive thorium.)

Extending Ideas: There are other ways of detecting and measuring radioactivity. A simple electroscope, when charged, indicates the presence of radioactivity by losing its charge.* The electroscope is first given a charge so that the charged grains or leaves will repel each other and fly apart. Have the children time how long it takes for the charge to leak off, and for the grains or leaves to fall together. To test for radioactivity with the electroscope, recharge it, and bring the suspected sample up to the grains as closely as possible without touching them. If they now fall together more quickly than they did before, the sample is probably radioactive. Point out that radioactive materials make air a better conductor than it ordinarily is so that the charge on the electroscope leaks off into the surrounding air. Have the children repeat this several times to be sure there is a significant difference.

Some children will be interested in other radiation-detecting instruments. Suggest that they look

*For detailed information on building and using an electroscope, see *Energy in Waves*, by Louis Cox (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

up information about cloud chambers, bubble chambers, film badges, and dosimeters.

Learnings: A photographic film becomes streaked by radioactivity. This is another means by which radioactivity may be detected.

Summing Up Ideas: In this section the children were introduced to the structure of the atom and to the idea that radioactivity emanates from inside the atom. They learned of the three basic particles that make up the atom—protons and neutrons, which are located in the atom's nucleus, and electrons, which are found around the nucleus. They learned of the way a nucleus can be broken down to emit radiation in the form of particles and energy. They also learned that radiation can be detected in a number of ways, including Geiger counters, scintillation counters, and photographic film.

IMPORTANT IDEAS IN THIS CHAPTER

For kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning and application are:

- Molecules are always in motion.
- The continual movement of the particles suspended in a liquid or a gas is called Brownian motion.
- Almost all liquids expand when they are heated and contract when they are cooled.
- Almost all solids expand when they are heated and contract when they are cooled.
- Gases expand when they are heated and contract when they are cooled.
- Evaporation is a cooling process.
- Atoms are made of protons, electrons, and neutrons.
- In an atom the protons and neutrons are joined together in the nucleus.

In the intermediate and upper grades, the children should be led to develop ideas that are more complex and quantitative:

- When the energy of molecules is increased, they increase the distances between themselves; when their energy is decreased, they decrease the distances between themselves.
- When a substance evaporates, it absorbs heat energy from its surroundings.
- When a solid melts, it absorbs heat energy.
- An endothermic process is one in which heat is absorbed; an exothermic process is one in which heat is released.
- The electrons revolve around the nucleus of an atom in various energy levels, or orbitals.
- Atoms are mostly made up of empty space.
- Electrons have very little weight compared to the weight of protons and neutrons.
- Radioactivity is caused by the emission of particles or energy from the nucleus of an atom.
- Three methods of detecting radioactivity are by Geiger counters, by scintillation counters, and by the streaking of photographic film.

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