NATURE OF MATTER

I. INTRODUCTION

A. Overview of the Unit

In this unit students compare their ideas about the nature of matter with observations they make of matter inside and outside the classroom. At the beginning of the unit, students focus their observations on the phenomenon itself. They examine the differences between substances and mixtures and between physical and chemical changes. In the middle of the unit, students "make sense" of their observations by explaining them using the kinetic molecular model.

We have developed the unit to meet the following criteria:

1. The instruction is intended for approximately 20 class/lab hours.
2. Equipment requirements are kept to a minimum.
3. Topics and activities used are usually included in an elementary school curriculum.
4. Activities are related to phenomena from everyday life whenever feasible.

The time needed to complete this unit may vary considerably according to students' backgrounds and according to whether it is the first or last unit included in the course. For example, if students are unable to graph data, or if they have had little chemistry at the middle/high-school levels, 20 hours of instruction may be insufficient. The content of the unit is less than what is usually included in the traditional K-6 textbook series. Although the kinetic molecular theory is introduced as an explanation of what occurs at the phenomenal level, atomic theory and bonding have been excluded because they are not particularly appropriate for elementary school children.

Chemistry can be understood and taught on three levels: the phenomenal level, the particulate level, and the symbolic level. Unfortunately, chemistry instruction usually focuses on the symbolic level, and hence students do not make connections between the three levels. In this unit students begin by observing everyday phenomena, explain the phenomena using particles, and represent the phenomena and particles using symbols. The latter occurs toward the end of the unit. This should enable students to integrate the three levels and thereby obtain a conceptual understanding of the material world that surrounds them.

B. Acknowledgments and Origins of Ideas

Very few curriculum development efforts in the teaching of chemistry have focused on integrating the macroscopic (phenomenal), the microscopic (particulate), and the symbolic levels, even though there is a body of research indicating that students generally do not make the connections. We have knowingly included some of the activities and ideas from the following efforts that have tried this at least partially:

- The ideas from the report by Alex H. Johnstone,
- Some activities on conservation of mass in chemical reactions, electrolysis of water, the flame tests, and separation of a mixture of alcohol and water from *Introductory Physical Science*,
- The baggie chemistry and the density activities from *GEMS*,
- The separation of solids (sand mixture) activity from *Science Curriculum Improvement Study,*
- Activities on heating substances, operational definitions of an acid and a base, and ideas on the particulate nature of matter from Dorothy Gabel in *Introductory Science Skills,*
- The activity on the rates of chemical reactions using magnesium strips from Christie L. Borgford and Lee R. Summerlin in *Chemical Activities,*
- Ideas on depicting the particle nature of matter from Glen Berkheimer,
- The activity on disappearing ink by Shari Morkin in *Science and Children,*
- The blueberry pie filling and cabbage juice as indicators activity shown by Maria Walsh in *SourceView,*
- Ideas on teaching "The Particle Nature of Matter" in elementary schools by Milton O. Pella and others at the University of Wisconsin.

C. General Safety Considerations

Most of the materials used in the unit are common household items. However, even when using these, it is necessary to take safety precautions because even these can become dangerous if they get into one's eyes or are heated. Some state regulations require students to wear safety glasses whenever any activity is done in the laboratory! Safety glasses should be worn for all activities, and students should be given instructions about what to do in the case of an accident or a fire. Rooms should be equipped with a fire blanket, fire extinguisher, and eye wash fountain.

Care should be taken in the disposal of nonfood chemicals to make certain that they are appropriately disposed of. Not all chemicals may be poured down the drain. Arrangements should be made with the chemistry department to dispose of anything that they deem hazardous.

Specific safety precautions are written on student pages for activities in this Nature of Matter unit.

II. STUDENTS' NOTIONS ABOUT NATURE OF MATTER

A. Students' Prior Beliefs as Described in the Research on Student Conceptions

Chemists define matter as anything that has mass and occupies space. Matter and its behavior are studied on what is called the **macroscopic level** in which observations are made of phenomena. These observations are explained using theories and models. One theory, the kinetic molecular theory, has been particularly powerful in explaining chemical and physical changes. That matter is composed of particles that are constantly in motion, as postulated by the theory, has been supported by numerous experiments. In particular, through the optical scanning microscope, the structure of some ionic, metallic, and molecular substances has been observed. This infrastructure of matter is referred to as the **microscopic level** or the **particulate nature of matter**. Since chemists are interested in explaining phenomena on the **particulate level**, they use spheres or circles as models of atoms, ions, and molecules. They use chemical and mathematical symbols and formulas to represent the chemical species. Hence chemistry can be studied on the **macroscopic**, **microscopic**, and **symbolic levels**. Students' understanding of chemistry depends not only on how well they understand these three levels of chemistry, but also on how well they integrate and relate them to each other. Research on students' conceptions of the nature of matter indicates that there is little integration across the three levels and that nonscientific conceptions exist on all three levels.

On the macroscopic level, there is evidence that even some college students do not have well-developed ideas about mass, volume, and density. Students do not differentiate mass from weight, mass from volume, and volume from surface area. It has been found that many elementary education majors think that it is possible to obtain the volume of any geometric figure (including cylinders) by multiplying length by width by height. Many students are unable to differentiate volume and surface area and do not realize that volume is independent of the shape of the material whereas surface area is not. Given their confusion about volume, it is not surprising that many students do not understand the concept of density. Some believe that objects of greater density displace more water, and others confuse density with viscosity believing that "thicker" liquids have a higher density. These nonscientific concepts about physical phenomena can be considered naive student conceptions.

On the particulate level, students' nonscientific conceptions abound. To study students' conceptions on this level, chemistry education researchers must link students' knowledge of particles with either the macroscopic or symbolic levels. Research linking particles with the phenomena indicates that many students exhibit a very rudimentary understanding of the particulate nature of matter when considering physical and chemical changes. Not only do many students fail to show conservation of particles during phase changes, but some students also depict the particles changing size during those processes. In evaporation and dissolving, some students think that the particles simply disappear. Also in dissolving, students do not differentiate what happens to the particles of ionic versus covalent substances. For chemical change, many students do not conserve particles, nor do they understand chemical change as consisting of rearrangements of particles.

Students' nonscientific conceptions are also prevalent on the symbolic level. For example, students frequently confuse the meaning of the coefficients in a chemical equation with the subscripts. Students seldom link the meaning of these numbers to the particulate nature of matter. They think of density as a chemical formula that has no relation to either the phenomena or molecular levels. Research studies have shown that more students can solve molarity, gas law, and stoichiometry problems correctly than can explain what is happening on the macroscopic or microscopic levels. It appears that chemistry for a large number of students in introductory courses consists of pulling formulas and algorithms from memory and applying them without thought about the phenomena or a particulate model.

Research on students' lack of understanding of the symbolic and particulate levels might be referred to as research on students' nonscientific conceptions. These are not naive conceptions because they are not based on what a person would derive from looking at nature. For centuries, scientists thought that matter was continuous, not particulate. A continuous view of matter would be considered a naive conception. The nonscientific conceptions of students have probably arisen from formal or informal instruction in which students have been introduced to concepts which they have not integrated with phenomena or with the particulate nature of matter.

For more detail, review studies related to students' conceptions of the nature of matter, see Andersson (1989), Krajcik (1991), or Gabel and Bunce (1993) in the *Handbook of Research on Science Teaching and Learning.*

B. Conceptions that Students Should Develop

In this unit, students are invited to examine their nonscientific conceptions about the nature of matter. It would be unrealistic for us to think that in the space of three or four weeks, they will develop scientific conceptions about the nature of matter on all three levels: phenomenal, particulate, and symbolic. Emphasis in the unit is based on making observations of phenomena to develop more scientific conceptions of *mass, volume, surface area, density, substances, mixtures, elements, compounds, physical changes, chemical changes,* and *factors affecting these changes.* An overall conception that students should develop is that *nature is not compartmentalized into black and white, solid and liquid, compound and mixture, ionic and covalent, or chemical change and physical change.* It is the scientists who classify these phenomena in order to study them. In reality, a continuum exists, which means that classification can never be exact.

On the **macroscopic level**, students should come to realize that:

1. Mass and volume are the necessary and sufficient properties of matter.
2. Volume is independent of shape, can be measured in a variety of ways, can be calculated for regular objects according to their shapes, and is distinguished from surface area. When volumes of liquids are combined, the total volume is not necessarily equal to the sum of the individual volumes.
3. Matter usually exists in three states (solid, liquid, & gas,) in a student's everyday environment.
4. Mass is conserved in physical and chemical changes, such as when a gas is produced or a solid formed.
5. Density is a characteristic property of a substance, is independent of the mass or volume measured that are used to calculate it, determines whether objects float or sink, and is different from viscosity (more viscous liquids are not necessarily denser).
6. Materials that are nonuniform in appearance are mixtures. Materials that are uniform may be mixtures or substances. Mixtures generally retain most of the characteristic properties of the individual components and can be separated by physical means such as sifting or boiling followed by condensation.
7. Substances have one set of characteristic properties. Complex substances are called compounds, which can be broken down into elements. Substances can be classified by their characteristic properties and the chemical reactions they undergo.
8. Both physical and chemical changes occur at different rates that depend on a variety of factors such as temperature and concentration.

About halfway through the Nature of Matter unit, students are introduced to the particulate nature of matter. Particles are introduced as an explanation for observed phenomena. By the end of the unit, students should acquire more scientific approaches when using the **particulate nature of matter** for the following:

1. Matter is composed of particles. Differences in solids, liquids, and gases can be explained by the proximity and bonding of particles. When solids, liquids, and gases change state, distances between particles change as the particles absorb or release energy. There is nothing between the particles but space (no air).
2. Mixtures contain two or more different kinds of particles. If the same kind of particle exists in aggregates, the mixture is nonuniform or heterogeneous. If different kinds of particles are single entities, that is, they are uniformly mixed, a homogeneous mixture or solution is produced. When two substances are mixed, the particles of one substance may fit in the interstices of the other substance even in liquids and solids. There are three general types of solutions: solids, liquids, and gases. Each results when a solid, liquid, or gaseous solute dissolves in the solid, liquid or gaseous solvent.
3. Substances can be simple or complex. Simple substances contain only one kind of atom and these are called elements. Compounds are made of more than one kind of particle, each of which loses its identity or characteristic properties when it forms the compound. The particles in most compounds are in a definite ratio whereas the particles in solutions have no definite ratio. However, there may be a limit on the proportions of the components that are possible in solution.
4. In physical changes, particles of compounds remain intact and do not split apart while particles of elements do not combine with one another. Chemical change is the result of different kinds of particles interacting with one another. Atoms of the elements may combine with other particles, or the complex particles of compounds may separate from one another or form other combinations with elements or compounds. The resulting product(s) has a new set of characteristic properties.
5. Frequency of collisions between particles can increase or decrease, and this usually accounts for the difference in the rate of physical and chemical change. When collisions increase (due to increased concentration, surface area, and contact) or become more effective (due to increased motion of the molecules), the rates generally increase.

Toward the end of the Nature of Matter unit, students are introduced to chemical symbols that represent the particles in elements and compounds. Earlier in the unit, they were introduced to mathematical symbols in formulas and learned to represent density graphically using the slope of a line. Hence by the end of the unit, they should understand the use of mathematical, graphical, and chemical symbols as follows:

1. Mathematical symbols and graphs represent relationships between physical measurements of phenomena. Hence formulas used for obtaining volume and surface area vary according to the kind of figure being measured.
2. Subscripts in compounds refer to the number of atoms of an element in a molecule of the element or in a compound. Coefficients before a substance in a chemical equation refer to the number of molecules of the substance reacting or being produced.

The powerful ideas in this unit and the investigations in which they are emphasized are summarized as follows:

1. Mass and volume are the necessary and sufficient properties of matter (Investigation 1).
2. Each substance has its own set of characteristic properties, such as density and viscosity (Investigations 1, 2, and 3).
3. When energy is added or removed from matter, it may change state (Investigation 3).
4. In a physical change, mass is always conserved, but volume is not always conserved. Substances retain their characteristic properties (Investigation 4).
5. Matter is composed of particles whose identity, motion, and spacing account for its variety (Investigation 4).
6. In a chemical change, mass is always conserved, but volume is not always conserved. Substances lose their identities due to the rearrangements of the particles (Investigation 5).
7. Complex substances can be broken down into elements which are represented by symbols (Investigation 6).
8. Compounds can be classified according to their reactions and the elements they contain (Investigation 7).

III. COGNITIVE RATIONALE

General Comments

The general approach in this unit moves from the simple and concrete concepts to the complex and abstract concepts. This is done in two ways: multiple representation and chemistry content.

Multiple Representation

In the beginning of the unit, students make observations on the macroscopic level of phenomena that are related to everyday life. In the third investigation, students are introduced to the particulate nature of matter as an explanation of what they observe. Hence they integrate the macroscopic observations with the particulate representation. Finally, in the sixth investigation, students use symbols to represent the phenomena and the particles, thus integrating the phenomena, the particles, and the symbolic representations.

In addition, multiple representation of scientific concepts are used throughout the unit on another level. After students observe phenomena, they frequently represent relationships in mathematical and graphical forms.

Chemistry Content

Students begin the unit by observing characteristic properties of materials that are not undergoing change. Physical change is introduced in the third investigation with the separation of mixtures by boiling and condensation. Chemical changes are introduced in the fifth investigation and classifying chemicals by their chemical changes follows in the seventh investigation.

Specific Comments

Investigation M1: Measuring Mass and Volume and Calculating Density

Students investigate the *Meaning of Density* during this investigation by looking at soft drink/can systems and the components of these systems. They find the density of solids and liquids by using several methods, including the determination of the slope of a line and the division of mass by volume. They relate these numerical values to whether or not objects float in rubbing alcohol, water, and saltwater. Another concept developed is that the density of a system is not always the average of the densities of its parts. At the end of this investigation, students think about mass and volume as fundamental properties of all matter.

Investigation M2: Thinking about the Densities of Solids, Liquids, and Gases

Students begin this investigation by considering the *Differences Between Density and Viscosity for Liquids.* Then the densities of systems composed of gases in balloons are discussed, which builds up concepts initially developed during Investigation 1. The last section of this investigation applies concepts about the densities of solids, liquids, and gases to a problem that distinguishes between hard-boiled and raw eggs.

Investigation M3: Separating Mixtures into Component Parts

In the third investigation, students use all the methods they can think of to separate mixtures. They also make inferences from temperature/time graphs for water and for a water and rubbing alcohol mixture. Students practice identifying substances and in the process think more about *Properties Characteristic of Substances.* This unit reinforces ideas about density because that is one characteristic property used to identify water and rubbing alcohol after distillation. This investigation bridges investigation efforts and makes the point that particles compose matter.

Investigation M4: Observing and Explaining Physical Changes

Students begin this investigation by formulating *Rules Concerning Linear Dimensions, Surface Area, and Volume.* This is preparation for considering variables that affect the speed of dissolution. Students are encouraged to think about why particles of matter would dissolve faster under particular conditions such as smaller size. Students are expected to control variables such as volume when testing rates of dissolution. They check if mass and volume are always conserved during the dissolving of sugar in water and during the dissolving of rubbing alcohol in water. Evidence of interstitial space is given by looking at dry ice sublimating, ice melting, water being compressed, and air being compressed. Then students are asked to consider the relative amounts of interstitial space in solids, liquids, and gases. Students use words, drawings, and tangible models to show their learning of generalizations about the particulate nature of matter. They begin to use these generalizations to explain the diversity of substances and the interactions of these substances.

Investigation M5: Observing Chemical Changes

Students are introduced to *Chemical Change* by observing the reactions of several common substances in a Ziploc™ baggie. Because students have not yet been introduced to chemical symbols and formulas, word equations and common names are used. Students observe three signs that one or more chemical changes are occurring. These are: Heat is produced, the color changes from red to yellow, and a gas is produced. Although all of these changes are also evidence of a physical change, it would be a rare occasion for all to occur simultaneously, especially without the addition of heat. It is important for students to realize this.

The second activity builds upon the first when students determine whether all components that were originally added to the bag are necessary to produce the effects. This requires students to control variables in a rather sophisticated way because they must consider both the kind of chemical and the volume of the chemical used. If the activity is carried out carefully, they will find that two of the changes (which are actually physical changes) involve heat. The dissolving of the melting salt produces heat (hence some of its effectiveness initially in melting ice), and the dissolving of baking soda absorbs heat. They will also find that for the color change, the red solution must be present, whereas only water and the two solids are needed to produce the gas.

In the second activity, it appears that something is coming out of the chemicals that might affect the mass of the products. Although it would appear ideal just to weigh the baggies before and after the reactions to determine if mass is conserved in a chemical reaction, the results are misleading and rather hard for students to understand because of the buoyancy effect in using the balance. As a result, two other activities are substituted. In the Alka-Seltzer™ activity, students are likely to predict that the mass decreases because a gas is produced. In the other reaction, when a precipitate is formed, students are likely to think that the matter becomes heavier. Both of these are common conceptions of most elementary school children and some college students. Since students have already been introduced to particles earlier, the conservation of mass can be explained in terms of the particle nature of matter.

The final activity in the investigation gives students an opportunity to explore the factors that affect reaction rates, and to relate their findings to the particle nature of matter. After students observe the differences in reaction rates, explanations can be given in terms of the increased number of collisions of the particles due primarily to increased concentration, and to the increased effectiveness of the collisions due to faster moving molecules at higher temperatures. Students will also see that some metals are more effective than others, and this observation can be used in the discussion of the elements in the fifth investigation. Although catalysis is not illustrated in the experiment, it could be discussed here. Since students already have looked at increasing the dissolution rate when making solutions, comparisons between the factors affecting the rates of physical and chemical changes could be made.

Investigation M6: Classifying Substances as Elements and Compounds

Up until this point, students have not made the *Distinction Between Substances that are Compounds and those that are Elements.* The first activity helps students determine that when a substance is heated, several things can happen. Some of the possibilities are: color changes, flame is produced, smoke is produced, the substance disappears, or a liquid appears. Many of these observations could occur for either an element or a compound. Of the materials that students heat during the investigation, the most obvious one that might be considered a compound is sugar because it looks so different. However, it might be that it combined with something in the air, and that a new product was formed. Further tests would be needed to give greater credibility that the substance decomposed. For example, if the sugar were heated in the absence of air, or heated in air and with a cold evaporating dish held over it to show that water is formed, or the final product was tested to show that it is carbon, the evidence would corroborate decomposition.

This leads to the subsequent activity where students now decompose water using electrical energy, collect the gases, test for hydrogen and oxygen, and then determine the ratio of the volumes of the two gases. Some students may be familiar with the formula for water from prior courses, many immediately relate the ratio in the formula for water. This, however, assumes that equal volumes of gases contain the same number of molecules (Avogadro's hypothesis) which is not intuitively evident. In the activity, students are presented with the mass relationship of hydrogen to oxygen and are asked to make sense of the data. This may exceed their capability, and the instructor may need to discuss the fact that the experimental evidence supports the hypothesis that equal volumes of ideal gases at the same temperature and pressure contain equal numbers of molecules.

With the establishment of the formula for water, students are now ready to interpret chemical symbols, formulas, and simple equations in terms of particles (atoms and molecules). Emphasis should not be on students balancing equations, but on interpreting them and showing that atoms, not molecules, are conserved in the equations. This can be related to the conservation of mass shown earlier. Simultaneously, students should be relating particles to the symbols and be able to distinguish between particles of elements and particles of compounds. The investigation ends with the flame tests for the elements. Students have already been introduced to the elements in the previous activity, and this demonstration shows one way that elements differ.

Investigation M7: Classifying Compounds by their Reactions

The seventh investigation provides an application of what students have learned thus far in the unit and takes them one step beyond in illustrating that *Compounds can be Classified not only According to their Properties, but also According to the Elements that they Contain.* In the first activity, students test a variety of household items with natural indicators, which enables them to classify the items into categories of acids, bases, and others.

In the second activity, students test a variety of substances with several acids and bases to arrive at an operational definition of an acid or a base. By examining the formulas of acids and bases, they should conclude that groups of compounds have comparable formula, that is, acids contain hydrogen and bases contain hydroxide.

The next two activities give students the opportunity to apply knowledge learned in the unit. In the first design activity, students prepare their own indicators from fruits and vegetables, and in the second, they make invisible ink. Both activities show how science relates to everyday life, and both are appropriate for children at the elementary level.

IV. INSTRUCTOR NOTES

A. Equipment List

Equipment	Per lab group of 4	Per class for demonstration	For unit
Graduated beakers or overflow cans	6 1 L		
Balance	1 to 500 g		
Ruler	4 30 cm		
Tape measure	1		
Safety goggles	4		
Medicine droppers	3		
Graduated cylinders	3 10 mL, 3 50 mL 3 150 mL or larger		
Glasses or beakers	3 100 mL		
Aluminum blocks	several 2 cm cubes ±		
Aquarium	16 L	1	
Test tubes	1 doz		
Test tube holders	1		
Metal spheres (small)	3 mm diam ±		1 pkg
Weighing boats or shallow but broad vessels	convenient for use with balance		2
Pieces of plate glass	1 10 cm x 10 cm		
Knife	1		
Cutting board	1		
Scissors	1		
Deep dish pizza pan	1		
Cloth screen (fine)	30 cm x 30 cm		
Cloth screen (medium)	30 cm x 30 cm		
Cloth screen (large)	30 cm x 30 cm		
Margarine cutter (for equal volumes)	commercially available	1	
Magnets	20		
Convex lens	1		
Heater (alcohol)	1		
Stand for test tubes	1		
Test tube holders	2		
Centicubes	1 pkg 100		
Hot plate	1		
Mortar and pestle	1		
Stirring rods	5		
Petri dishes	3		
Syringes large	2		
Hand warmer	1		
Quart bottle w/gasket	1		
Ring stand	1		
Iron ring	1		
6-V battery	1		
Electrodes	2		

Equipment (cont'd.)	Per lab group of 4	Per class for demonstration	For unit
Wire connectors	2		
Peg board	130 cm x 30 cm		
Clamps	2		
Tesla coil		1	
Spectral gratings or spectrometers	4		
35-mm film containers			
Spectral tubes containing:			
mercury		1	
helium		1	
hydrogen		1	
neon		1	
Magnet board	1		
Magnets (small)	20		
Atomizers	1 (perfume bottle size)		
Dark construction paper	1 pkg (11 in. x 14 in.)		
Wire gauze (several different sizes)	1 15 x 15 cm^2 fine mesh 1 15 x 15 cm^2 medium mesh 1 15 x 15 cm^2 coarse mesh		
Thermometers	2		
White egg cartons	2		
or paper cups of equal size	24		

Consumables	Per lab group of 4	Per class for demonstration	For unit
Salt, table	tsp		1 box
Salt, rock	tsp		1 L
Rubbing alcohol 5 L			
Pepsi™ regular	2 cans		
Diet Pepsi™	2 cans		
Graph paper			pads
String			1 ball
Labeling tape			7 rolls
Sheet plastic (thin)	30 cm ± wide		2 rolls
Gelatin (Jell-O™)			
regular	1 pkg		
diet	1 pkg		
Empty soda cans, regular	1		
Empty soda cans, diet	1		
Straws			2 pkgs
Potatoes		5	
Cooking or mineral oil		1 L	
Balloons (rubber or vinyl)		100	
Rubber bands		1 pkg	
Tissue paper (thin)			1 pkg
Eggs			1 doz
Baking soda		1 pkg	

Consumables (cont'd.)	Per lab group of 4	Per class for demonstration	For unit
Sand fine		3 L	
Sand medium		3 L	
Sand coarse		3 L	
Pepper		4 pkg	
Iron filings		3 L	
Margarine			
(regular)		1 lb	
(lite)		1 lb	
(extra lite)	1 lb		
Waxed paper		1 roll	
Splints			1 pkg
Rubber bands		1 pkg	
Distilled water	1/2 L		
Filter paper (coffee)		1 pkg	
Sugar (regular grind)	1 lb		
Lifesavers™ (candy)	1 pkg		
Dry ice			500 g
Plastic bag small	1		
Ziploc™ baggies	1 pkg		
Teaspoons (plastic)	3		
Small vials	3 (5 mL)		
Alka-Seltzer™		2 pkgs	
Large Ziploc™ baggies		2 pkgs	
Vinegar		1 L	
Sandpaper variety		1 pkg	
Tin can lid	2		
or aluminum foil		1 pkg	
Paraffin			1 pkg
Chalk			1 pkg
Matches		1 pkg	
Blueberry juice		1 can	
Red cabbage juice (Put red cabbage leaves in water; boil 10 min.)			
Variety of household:			
mouthwash		1 bottle	
shampoo		1 bottle	
toothpaste		1 pkg	
Drano™			1 can
Sprite™			1 L
Vitamin C		1 pkg	
Hair conditioner		1 bottle	
Lemon		1	
Flowers and Vegetables, variety		several petals of flowers,	
(whatever is readily available)		1 potato or 1 bunch of carrots)	
Tape, duct			1 roll
Tape, labeling			1 roll
Posterboard			
Lye		1 bottle	

Consumables (chemical, i)	Per lab group of 4	Per class for demonstration	For unit
Glycerin		1 L	
Gases:			
CO_2			1 cyl
H_2			1 cyl
He			1 cyl
Potassium permanganate		500 g	
Potassium nitrate		500 g	
Ammonium nitrate		500 g	
$CaCl_2$			500 g
Phenol red		500 g	
Barium chloride	500 g		
Sodium sulfate		500 g	
Metal strips:			
magnesium	9 strips		
zinc	1 strip		
tin	1 strip		
iron	1 strip		
HCL (1 M)		1 L	
Washing soda (sodium carbonate—saturated)	500 g		

Chemicals (0.1 molar)	Per lab group of 4	Per class for demonstration	For unit
Lithium chloride	500 g		
Barium nitrate	500 g		
Strontium chloride	500 g		
Sodium chloride	500 g		
Copper nitrate			500 g
Copper sulfate	500 g		
Potassium chloride	500 g		
Sodium nitrate	500 g		
Chemicals (1 bottle of each):			
ammonia			
lye 0.05 M			
oil of vitriol 0.05 M			
muriatic acid 0.05 M			
phenolphthalein			
Red and blue litmus paper		10 pks	

Supplies	Per lab group of 4	Per class for demonstration	For unit
2-hole stopper for test tube	2		
Glass tubing	160 cm long		
Plastic tubing	140 cm long		
Putty (plastic)		5 lbs	
Stoppers	variety		
Nichrome wire	22 gauge/1 spool		
Swabs		1 pkg	

INSTRUCTIONS FOR PREPARATION OF LABORATORIES AND DEMONSTRATIONS

Investigation M1

Activity M1.1

Have available three solutions: one water, one saltwater (saturated), and one rubbing alcohol.

Set out for each group of 4:

3 graduated 1-L beakers
  1 with 450 mL of water
  1 with 450 mL of saturated saltwater solution
  1 with 450 mL of rubbing alcohol
or 3 overflow cans* filled with the above

1 can regular Pepsi™
1 can Diet Pepsi™
3 metal objects, all of the same volume
  1 cylinder
  1 cube
  1 sphere
1 graduated cylinder large enough to hold
 any one of the previous 3 items

*Overflow cans can be constructed by soldering 1/4 in. copper tubing on upper side of 1/2-gal or 2 L-food can. Have copper tubing slightly off horizontal and down and for ease of water flow. Overflow cans can also be made of plastic pipes glued to upper side of large ice cream containers. Catch buckets can be any cup that fits conveniently under the spout of the overflow can.

Activity M1.2

Preparation: Have liter beakers ready with solutions same as in Activity M1.1. Mark each container, but do not identify the solution (keep record of identity of each container for lab instructor).

Set out for each group of 4:

1 container with solution
1 graduated cylinder
1 balance
1 medicine dropper
graph paper: 10 sheets for each student
1 meterstick segment

Activity M1.3

Set out for each group of 4:

1 meterstick segment
graph paper: 10 sheets
metal spheres
1 cube
1 cylinder
1 potato and other such vegetables cut up in chunks (for extra exercise)
1 graduated cylinder large enough to hold materials in exercise
or 1 overflow can with catch bucket

Activity M1.4

Set out for each group of 4

1 can of regular Pepsi™
1 can of Diet Pepsi™

Have available but not set out, for each group of 4:

1 meterstick segment
1 balance
1 graduated liter beaker or overflow cans with catch buckets
1 graduated cylinder

solutions of:
- 1 L water
- 1 L saltwater prepared as in activity M1.1
- 1 L alcohol

Activity M1.5

Preparation: Cut out pieces of thin plastic such as plastic wrap in 3 cm x 3 cm squares.

Set out for each group of 4:

1 piece of plastic 3 cm x 3 cm
1 can Diet Pepsi™
1 can regular Pepsi™
1 empty can Diet Pepsi™
1 empty can regular Pepsi™
2 medicine droppers
3 glasses (transparent drinking glasses) or 3 250-mL beakers
1 balance
graph paper
tape for labeling containers

Have available for entire class:

1 package regular gelatin (Jell-O™)
1 package diet gelatin (Jell-O™)

Activity M1.6: Demonstration/Discussion

Preparation: Ask instructor if some soft drink cans are to be cut up before class. If so, cut cans into small pieces that will fit in small graduated beaker.

Have available for entire class:

1 aquarium filled with water, about 16 l
1 large graduated cylinder
or 1 graduated beaker 500 mL
several empty cans regular Pepsi™
several empty cans Diet Pepsi™
1 pair scissors
or 1 pair metal shears
1 balance
4 aluminum blocks

Option: at the discretion of the instructor:

Set out for each group of 4:

plasticine clay
1 balance

Activity M1.7: Demonstration/Discussion

Have available for entire class:

1 roll duct tape
2 cans of regular Pepsi™
2 cans of Diet Pepsi™

Activity M1.8: Demonstration

Have available for entire class:

1 soft drink in glass bottle
1 thin plastic bag
1 roll of duct tape
1 balance

At the discretion of the teacher:

1 hunk of dry ice
1 Ziploc™ freezer bag

Investigation M2

Activity M2.1

Set out for each group of 4:

- 5 test tubes labeled (vials or culture tubes with caps can substitute for test tubes); put different shades of food coloring for ease of identification
  - 1 filled with water
  - 1 filled with saltwater
  - 1 filled with glycerin
  - 1 filled with cooking or mineral oil
  - 1 filled with rubbing alcohol
- 1 rack for test tubes or vials
- 5 stoppers for test tubes
- several BBs
- 1 transparent cup or beaker
- 1 plate glass
- 1 beaker designated for waste liquids
- 1 spoon or stirring rod

At the discretion of the teacher, have available some or all items listed below: (single containers will suffice)

- liquid dish soap
- shampoo
- pancake syrup
- vinegar
- fruit juice
- honey
- milk

Activity M2.2

Set out for each group of 4:

- 1 thick potato slab (to use for straw stands) or plasticene clay
- several straws (the bigger the diameter, the better)
- 5 medicine droppers
- 1 balance
- 5 test tubes filled with liquids used in activity M1.1 with dye for differentiating but not identifying
- graph paper

Activity M2.3: Demonstration/Discussion

Preparation: Obtain balloons of the same material, length, and shape. Inflate balloons shortly before class.

Have available for entire class:

- 8 balloons same size unless otherwise noted
  - 1 with air
  - 1 with carbon dioxide
  - 1 small hydrogen so it will not float
  - 1 hydrogen
  - 1 small helium so it will not float
  - 1 helium
  - 1 mixture of gases

Tie all balloons together with rubber band to make a bunch. Place balloons in a box.

- 1 candle
- 1 box of matches
- 1 meterstick to which the candle can be tied
- string for tying candle to stick
- 1 aquarium filled with water

Activity M2.4: Demonstration/Discussion

Have available for entire class:

- 1 doz. very fresh eggs
- 2 beakers or transparent glasses
- salt

Boil 2 eggs for 1 min and insert in cold-water bath until cold or have heater and boiler available to boil eggs. Caution: Eggs must be very fresh or experiment will not work.

At the discretion of the instructor, have available:

- 2 unfresh eggs

Investigation M3

Activity M3.1

Set out for each group of 4:

- 3 test tubes or vials:
  - 1 half-filled with sand, salt, and baking soda (grain size from one medium to another should vary)
  - 1 half-filled with salt and pepper
  - 1 half-filled with sand and iron filings (same grain size)
  - 1 cloth screen (piece 4 cm x 4 cm)
- several small rubber bands
- 1 large tray in which to pour mixture
- dark construction paper to fill bottom of tray
- 3 coffee filters
- 1 magnet
- 1 lens (convex, to be used as a magnifier)
- 3 cups for receiving sifted materials

Have available for the entire class:

- 3 test tubes or vials (at least 20 mL):
  - 1 filled with BBs
  - 1 filled with salt
  - 1 filled with sugar

Activity M3.2

Obtain 3 sticks of margarine all same brand, one regular, one light, and one extra light. Use knife or butter cutter or cheese slicer to cut margarine into equal volume pats. Place on waxed paper. Keep chilled.

Set out for each group of 4:

- 3 pats of margarine all the same volume, all same brand (keep chilled)
  - 1 regular
  - 1 light
  - 1 extra light
- 3 test tubes
- 1 250-mL beaker with cold water
- 1 thermometer
- 1 alcohol burner or equivalent
- 1 balance
- 1 segment of meterstick
- 3 splints or other utensils
- 1 ring stand
- 1 ring
- 1 wire mesh for ring

Activity M3.3

Prepare this laboratory by inserting thermometers and glass tubing in "two-hole rubber stoppers" that fit into the test tube. Use water or glycerine to facilitate slipping thermometer and tube into the stopper. Insert both items so they will be above the level of the liquid in the half-filled test tube. Insert flexible tubing that fits snugly over glass tubing.

Set out for each group of 4:

- 2 test tubes:
  - 1 test tube with 50 mL of water
  - 1 test tube empty
- 1 thermometer
- 1 glass rod approximately 20 cm long
- 1 two-hole rubber stopper with thermometer and glass rod in place
- 1 pair tongs
- 1 alcohol burner or equivalent
- 1 pkg matches
- 1 beaker 500-mL half-filled with cold water
- flexible tubing to join one test tube to the other
- graph paper
- timer or equivalent

Activity M3.4

Make 100 mL of solution consisting of equal parts of water and alcohol. Insert thermometer and tube in two-hole rubber stopper as in Activity M3.3 so that it measures the temperature of the vapor. Insert flexible tubing that fits snugly over glass tubing.

Set out for each group of 4:

- 2 test tubes:
  - 1 tube with 50 mL of solution
  - 1 tube empty
- 1 glass rod 20 cm long
- 1 thermometer
- 1 two-hole rubber stopper with thermometer and glass rod already in place
- 1 alcohol burner or equivalent
- 1 pkg of matches
- 1 beaker 500-mL half-filled with cold water
- flexible tube to join the two test tubes
- graph paper
- timer or equivalent
- 1 pinch of sugar
- 1 piece of filter paper (coffee filter paper)

Activity M3.5

Prepare this laboratory exactly the same way as M3.4.
Set out for each group of 4:

- 3 test tubes:
  - 1 tube with 50 mL of solution
  - 2 tubes empty labeled 1 and 2
- 1 glass rod 20 cm long
- 1 thermometer
- 1 two-hole rubber stopper with thermometer and glass rod already in place
- 1 alcohol burner or equivalent
- 1 pkg matches
- 1 beaker 500-mL half-filled with cold water
- 1 piece flexible tubing to join the two test tubes
- graph paper
- timer or equivalent
- 1 graduated cylinder 50 mL
- 1 balance
- 1 pinch sugar
- filter paper

Investigation M4

Activity M4.1

Set out for each group of 4:

- 100 centicubes
- 1 balance

At the discretion of the teacher:

- 1 glob of plasticine clay 4 cm diameter

Activity M4.2

Set out for each group of 4:

- 4 pieces of candy (such as Lifesavers™) that will fit in test tube
- 2 50-mL graduated cylinders partially filled with water
- 1 mortar and pestle
- 1 convex lens
- 1 stirring rod

At the discretion of the teacher:

Set out for each group of 4:

- 1 package of beverage powder (e.g., Kool-Aid™)
- 4 drinking glasses
- 1 graduated 1 L beaker
- 1 coffee filter
- 1 funnel to filter beverage

Activity M4.3

Obtain the purest rubbing alcohol you can find (at least 70% alcohol).

Set out for each group of 4:

- 1 glass tube (at least 60 cm long and approximately 10 mm diameter)
- 2 stoppers for tube
- 2 graduated cylinders:
  - 1 filled with 50 mL of water
  - 1 filled with 50 mL of alcohol
- 1 balance

Activity M4.4

Set out for each group of 4:

4 250-mL beakers
1 L beaker with water
4 pieces of candy of equal volume
1 mortar and pestle set

2 test tubes:
- 1 with 1 tbs sugar
- 1 with 1 tbs salt

2 100 mL graduated cylinders
1 balance
2 spoons or stirring rods
1 hot plate
1 thermometer

Activity M4.5: Demonstration/Discussion

Have available for entire class:

1 beaker of ice to cool water
1 hot plate to heat water

2 petri dishes:
- 1 containing 50-mL ice-cold water
- 1 containing 50-mL steaming-hot water

1 transparency with circles the size of petri dishes. One circle saying "hot" the other "cold"
1 spoon or spatula for stirring
potassium permanganate (small quantity)
1 pair pot holders or oven mitts

At the discretion of the teacher, have available:

2 transparent glasses or beakers:
- 1 with very hot water
- 1 with ice-cold water

1 alcohol thermometer
1 ball and ring apparatus
1 bottle with balloon attached to neck of bottle
1 hot air balloon
1 convection chamber
1 bottle with metal lid firmly closed
1 bimetallic strip
1 handwarmer (chemically a supersaturated solution)
1 vial with 5 g of ammonium nitrate dissolved in 10-mL water

Activity M4.6: Demonstration/Discussion

For entire class, have available:

- a few grams dry ice
- 1 sealable plastic bag
- 1 pair pot holders or oven mitts
- ice cubes
- 1 balance
- 1 full glass of water
- 2 identical balloons:
  - 1 filled with water
  - 1 filled with air
- 2 large syringes:
  - 1 filled with water
  - 1 filled with air
- 2 rubber stoppers to put on end of syringe

Activity M4.7: Seat Activity

Have available for each group of 2:

- 1 pizza pan or large flat iron plate
- several magnets (perhaps segments of magnetic strips)
- poster board
- various color markers
- scissors
- paste

Investigation M5

Activity M5.1

Have available:

- 1 pkg Ziploc™ baggies, sandwich size
- 1 pkg baking soda
- 1 pkg phenol red tablets (obtained from swimming pool suppliers)
- 200 g anhydrous calcium chloride (obtained commercially in winter at hardware stores)

Set out for each group of 4:

- 2 Ziploc™ baggies
- 3 test tubes:
  - 1 labeled with baking soda
  - 1 labeled with anhydrous calcium chloride* (finely powdered)
  - 1 labeled with phenol red tablet dissolved in water**
- 1 rubber stopper for test tube with calcium chloride
- 3 small vials
- 3 teaspoons
- 1 10-mL graduated cylinder
- 1 tray large enough to hold baggie
- 1 large beaker to receive waste***
- 2 splints

* Calcium chloride should be kept covered until time of use.

** If dissolved phenol red turns yellow, adjust the color with a small quantity of acid.

*** Waste can be poured down the drain. Rubber gloves should be used when washing vials.

Activity M5.2

Set out for each group of 4:

4 Ziploc™ baggies

3 test tubes with identifying labels:

1 with baking soda
1 with anhydrous calcium chloride
1 with phenol red tablet dissolved in water

1 rubber stopper for test tube with calcium chloride
several small vials
4 teaspoons
1 10-mL graduated cylinder
1 tray large enough to hold baggie
1 large beaker to receive waste

At the discretion of the teacher, have available:

1 candle tied to meterstick
1 pkg of matches

Activity M5.3

Preparation:

0.1 M barium chloride = dissolve 24 $BaCl_2 \cdot 2H_2O$ g/L of solution
0.2 M sodium sulfate = dissolved 28 Na_2SO_4 g/L of solution

Set out for each group of 4:

2 test tubes:

1 half-filled with 0.1 M barium chloride
1 half-filled with 0.2 M sodium sulfate

2 small vials
1 Alka-Seltzer™ (lJ8 tablet)
1 balance
1 quart or liter, thick-walled glass bottle with lid and gasket (canning jar will do)

Activity M5.4: Seat Activity

Set out for every group of 2:

1 pizza pan or flat iron plate
several magnets
poster board
several markers of different colors
1 tube paste
1 pair scissors

Activity M5.5

Obtain hydrochloric acid.

To prepare one M HCl, dissolve 85-mL reagent HCl in water. Pour acid into enough water to make 1 L of solution.

Safety Precaution ➠

Pour acid carefully into water, not vice versa.

Use fine sandpaper on strips of metal to clean them and make the reaction more effective.

Set out for each group of 4:

metal strips: label identity of each one by placing them on marked paper
9 small magnesium strips
2 zinc strips
2 copper strips
2 iron strips
2 tin strips
1 eyedropper
1 hot plate
1 bottle of vinegar
1 piece of sandpaper
2 250-mL beakers
1 beaker of hot water
1 beaker of cold water
5 test tubes in rack each half filled with dilute HCl
1 waste container

Activity M5.6: Demonstration/Discussion

Preparation: Fill two gas-collecting bottles with oxygen from a demonstration tank using displacement of water. Stopper the bottles. The oxygen can also be prepared by adding manganese dioxide to 30% hydrogen peroxide or even hydrogen peroxide used for bleaching hair. (The 3% solution is not concentrated enough.) See a chemistry demonstration book for directions.

Have available for entire class:

1 alcohol burner or equivalent
2 cigarettes
1 iron nail
1 pad of steel wool
1 pkg matches
2 gas-collecting bottles
1 pair tongs
oxygen

Investigation 6

Activity M6.1

Set out for each group of 4:

- 2 test tubes:
  - 1 with a tsp sugar, labeled
  - 1 with a tsp salt, labeled
- 1 small piece of paraffin
- 1 small piece of chalk
- 1 tin can lid or similar iron plate (actually tin can lid works better because of the wavy surface that tends to limit movement of materials)
- 1 ring stand with ring small enough to hold tin can lid
- 1 alcohol burner or equivalent
- 1 pkg of matches

Activity M6.2

If stainless steel electrodes are to be used:

Preparation: Sodium carbonate solution can be prepared by dissolving 30 g of sodium carbonate in 100 mL of tap water at 100°C and stirring. Allow to cool to room temperature. The excess will remain on the bottom. Decant into test tubes.

If other electrodes are to be used, ask the instructor of the course what solution is to be used.

The instructor may want the students to complete the setup described below as part of the laboratory. If not:

Setup for activity requires that test tubes be mounted upside down and held by clamps on a vertically held Peg-Board™. The test tubes are filled with water and inverted in the water that is in a large beaker so that no air escapes into the test tubes. The inverted tubes are then inserted in the clamps holding them to the Peg-Board™ while the bottom of each tube stays in the water. The electrodes are then placed in the inverted test tubes, which allows part of the uncovered electrode to be below the lip of the test tube. The other end of the electrode is then connected to the wires leading to the battery. A sketch of the apparatus is included in the teacher notes to help visualize the setup.

Set out for each group of 4:

1 6-V battery or power supply
1 set of stainless steel* or platinum electrodes
1 set of wire connectors
1 Peg-Board™ 30 cm x 30 cm vertically mounted on a ring stand
2 small test tubes
2 clamps to hold test tubes to Peg-Board™
2 small rubber bands
1 25-mL graduated cylinder
100 mL of sodium carbonate solution
2 wood splints
1 pkg matches
2 rubber stoppers for test tubes
1 L beaker partially filled with water

* Stainless steel electrodes can be obtained from Damon/Educational Division, or from similar vendors.

Activity M6.3: Demonstration/Discussion

To prepare solution for M6.3, dissolve the mass listed in a liter of solution:

NaCl	29 g
$Ba(NO_3)_2$	131 g
$Ca(NO_3)_2$	82 g
KNO_3	51 g
$Sr(NO_3)_2$	106 g
$LiNO_3$	35 g
$NaNO_3$	43 g
$Cu(NO_3)_2$	94 g

Prepare wire for flame tests by inserting nichrome wire into a cork long enough to reach into the solution. Make a small loop at the end of the wire which allows for more solution to stay on the wire.

Make spectroscopes (one for each student) by attaching small pieces of diffraction gratings to the lids of spent black 35-mm film containers. Cut a slit on the bottom of the container. Put lid back on container. *(Note: It is worth getting the hologram type of diffraction grating for this purpose. They can also be bought inexpensively from suppliers.)*

Have available for entire class:

8 test tubes in rack:
- 1 with .5 M NaCl
- 1 with .5 M $Ba(NO_3)_2$
- 1 with .5 M $Ca(NO_3)_2$
- 1 with .5 M KNO_3
- 1 with .5 M $Sr(NO_3)_2$
- 1 with .5 M $LiNO_3$
- 1 with .5 M $NaNO_3$
- 1 with .5 M $Cu(NO_3)_2$

8 nichrome wires inserted in cork
1 alcohol burner or equivalent
1 pkg of matches
1 tesla coil or high-voltage apparatus for discharge tubes

4 gas spectral discharge tubes:
- 1 with mercury
- 1 with helium
- 1 with hydrogen
- 1 with neon

1 spectroscope for each student

Activity M6.4: Seat Activity

Have available for each 2 students:

1 pizza pan or flat plate of iron magnets

Investigation M7

Activity M7.1

Preparation: Shred a small head of cabbage and boil in about 2 cups of water, or shred cabbage and place it in a blender.

Set out for each group of 4:

- 2 test tubes:
  - 1 with red cabbage juice, label
  - 1 with blueberry juice, label (from can of blueberry pie filling)
- A variety of household items such as:
  - mouthwash
  - shampoo
  - bar soap
  - toothpaste
  - drain cleaner
  - soft drink
  - baking soda
  - vitamin C
  - hair conditioner
  - a lemon
- 24 splints for stirrers
- 2 empty white egg (plastic) cartons or 24 small plastic cups

Activity M7.2

Preparation:

lye 1 M = 40 g NaOH in water = 1 L of solution

oil of vitriol = 57 mL of concentrated H_2SO_4 pour carefully in water = 1 L of solution

muriatic acid = 86-mL reagent HCl pour carefully in water = 1 L of solution

washing soda = 106 g Na_2CO_3 put in water carefully = 1 L of solution

baking soda 84 g put in water = 1 L of solution

(Magnesium strips must be shiny. Sandpaper if necessary.)

Set out for each group of 4:

7 test tubes in rack each half full and labeled:
- 1 with ammonia (household)
- 1 with vinegar (household)
- 1 with lye l M
- 1 with oil of vitriol l M
- 1 with muriatic acid l M
- 1 with washing soda l M
- 1 with baking soda l M

1 dropping bottle of phenolphthalein
1 container of blue litmus paper
1 container of red litmus paper
10 magnesium strips
1 waste container

Activity M7.3

Preparation: A saturated sodium carbonate solution can be prepared by dissolving 30 gm in 100 mL of water at 100° C. Some will settle out upon cooling—pour off clear solution.

Set out for each group of 4:

variety of colored flowers and vegetables
4 250-mL beakers
1 alcohol burner or equivalent
1 ring stand
1 iron ring to hold beaker
1 wire gauze
2 dropping bottles (bottle with eye dropper or one designed to deliver drops of liquid)
1 with vinegar (household)
1 with saturated sodium carbonate solution

Activity M7.4

Set out for each group of 4:

2 test tubes:
- 1 with red cabbage juice label
- 1 with blueberry juice, label (from can of blueberry pie filling)

1 dropping bottle of phenolphthalein
1 container of blue litmus paper
1 container of red litmus paper
10 magnesium strips
1 waste container
2 atomizers
5 cotton swabs
filter paper or high-quality paper towels

7 test tubes in rack each half full and labeled:
- 1 with ammonia (household)
- 1 with vinegar (household)
- 1 with lye l M
- 1 with oil of vitriol l M
- 1 with muriatic acid l M
- 1 with washing soda l M
- 1 with baking soda l M

1 for the class: fan or hair dryer