Discovering Chemical Discoveries

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INTRODUCTION

I am a science teacher at the elementary level. I remember when I was an elementary student: I wanted to become an inventor, and I always wondered how inventors could come out with new devices or new substances out of known "stuff"-- to me this was almost magic. Still during elementary school, I learned that such "almost magic" was the result of practicing the knowledge contained in a number of different fields known as the sciences. I learned that science had the answers to all my questions and was the source of all discoveries and inventions!

This curriculum unit, Discovering Chemical Discoveries, is intended for elementary fifth grade students, within the age group nine through eleven years. At this time in their development, children are still imbedded in a fantasy world; they still believe in some magic, some 'special powers' or supernatural properties of certain materials or energy forms (or even certain beings!). This results from combining all kinds of fiction stories and games with their natural and overflowing imagination, so they are still willing to believe in anything that is amazing and "out of this world," like having a super strength, the ability to make things disappear and reappear (even oneself), or defying the law of gravity. Yet, they already have the first skills in logical thinking, and are well aware that most things in the world around them have a logical explanation that they can understand.

At this age, formal thinking skills are intensively under construction and based on two interrelated processes, observation and discovery on one hand, and experimentation and invention on the other hand. It is in the process of observation and discovery when children break apart objects in order to "have a look inside" and know what objects are made of; when they disassemble toys and devices in order to see how they work or when they manipulate plants and animals in order to understand why they are the way they are and why they have what they have. Similarly, it is in the process of experimentation and invention when children build up diverse machines, like cranes, cars, airplanes, spaceships, submarines, or when they play with higher and higher amounts of energy, by connecting more and more batteries to a light bulb, giving excessive turns to a wind up mechanism, putting together a maximum of magnets, or when they mix (and often burn) diverse substances and materials "just to see what happens."

It is particularly this last kind of experimentation which is less understood, more obscure, but more interesting over all, mainly when the result of mixing or burning something gives out fumes, when it bubbles, when it changes color, or when it pops up!

When children experiment with substances more than with anything else, they are setting up and dealing with a 'black box' system, and are empirically—let's say blindly—trying to produce some kind of result. The main problem is that they are dealing mostly—if not entirely—with unknowns: their 'experiment' is in the style of "a bunch of this, a bit of that, it is like, that stuff, looks weird, what if, let it go all the way, let's see if…"

With respect to my teaching, it is commonplace from the beginning of the academic year, when students are ready to take their first science lesson, for a student to ask, "*Are we going to do* *experiments?"* My answer is always, "*Yes*." How could it be otherwise? This is, of course, the best opportunity to capitalize on such investigative curiosity and give them their first 'formal' course in chemistry, and to let them know that the sciences have the answers to (almost) all their questions and are the source of all discoveries and inventions!

UNIT RATIONALE

At this stage of their instruction, fifth graders are by daily experience more familiar with the physical nature and properties of matter. In contrast, they are more interested in, and excited with the chemical nature and transformations of matter (what they call "experiments"). Ironically, it is about this chemical nature of matter which they know less. Indeed, they have not been taught yet the difference between physics and chemistry as clearly defined sciences.

In Texas, the Houston Independent School District (HISD) has elaborated a science curriculum for every grade known as Project CLEAR (Clarifying Learning to Enhance Achievement Results), which is in alignment with the State curriculum requirements and objectives.

Project CLEAR, currently in use for science in fifth grade, is composed of nine study units, organized in a number of model lessons of approximately fifty minutes each; Unit five of the Project CLEAR is named What's the Matter (parts 1 and 2) and is organized in 21 lessons dealing with the structure of matter, its physical properties and measuring units, states, mixtures, and physical and chemical transformations; Unit seven is named N-R-G and is organized in 22 lessons dealing with the basic forms and types of energy and several measuring units as well as energy sources and transformations. These units offer an appropriate departure point for the unit and lessons proposed here.

As can be observed, the CLEAR curriculum has the approach of integrating both physics and chemistry in each one of the units mentioned above. Nevertheless the amount of instructional time and topics devoted to chemistry are comparatively small within the whole frame of the fifth grade science curriculum. So, in order to better prepare our children, it is important to develop a unit in which the students learn about chemistry as a science in its own right, learn the difference with other related sciences and acquire the basic principles and tools necessary to further study chemistry in more depth. It is by understanding a science that we can enjoy, and in turn, become more interested in it.

UNIT OVERVIEW AND BACKGROUND

The study unit proposed here focuses on the chemical aspects of matter and energy through a number of experimental demonstrations which are the core of the corresponding lessons; such demonstrations will give coherence to the concepts and definitions taught along the unit. Laboratory demonstrations could be used for explaining a vast number of different topics from the first day, but for the sake of clarity, and in order to go from simple to more complex concepts, only a limited number of concepts will be dealt with at each session. In contrast, previously seen definitions and concepts can come back in further sessions, which gives us the opportunity to review and enrich previous knowledge. Among the demonstrations, some hands-on activities can be performed by the students entirely, but in some cases they will require a limited participation in the experiment because of potential safety problems that could arise, in which case the teacher will perform the activity and the students will be observers.

In the following paragraphs the background information for the teacher is presented for every lesson, together with a number of questions for every topic that could be posed to the students as stimuli or prompts that could be used as evaluation items or, even better, which could come out from the pupils themselves. The corresponding lesson plans are developed in a separate section.

Mass, Volume and Density: Lesson One Teacher's Background

Two of the most conspicuous properties of matter are volume and mass. Volume is the place that all matter takes in space. Volume can be measured in cubic meters (m^3), its submultiples (cubic millimeters, cubic centimeters) and multiples, as well as in liters (L), its submultiples (milliliters, centiliters) and multiples. Sometimes, instead of volume, the word capacity is used when we are referring to containers.

For objects with a simple geometrical shape (like a cube, cylinder or a sphere) it is relatively simple to measure the volume using a ruler or measuring tape, but as we have seen, volume can be measured in liters or milliliters. This resource is essential when measuring the volume of an irregular object like a stone by the water displacement method (Moyer, 4th Grade 81). This lesson will be useful in demonstrating to the students that if we change the shape of an object, this will not change its volume or mass.

It is important not to interchange the words mass and weight. Mass is the amount of matter (as children sometimes say, the amount of "stuff") contained in an object. The mass of an object is measured in grams (g), its submultiples (milligrams) and multiples (kilograms). Weight is the pull of gravity upon an object, which is measured in pounds; therefore, the weight of an object depends on where it is located in the universe (Moyer, 5th Grade 293).

For example, the mass of a man on Earth and on the Moon will be 81.65 kilograms in both places, whereas his weight on Earth is 180 pounds and on the Moon it would be only 30 pounds, because the gravity on the moon is only one sixth that on Earth (there is a conversion between grams and pounds, being one pound equal to 453.6 grams, and one kilogram equal to 2.2046 pounds).

Density, another property of matter, results from the mass of an object being divided by its volume, which is expressed as grams per cubic centimeter, or grams per milliliter in the case of liquids. For the samples used in the corresponding lesson, the density can be obtained by such simple mathematical calculations.

The density of water is one gram per cubic centimeter or one gram per milliliter when measured at sea level and at four degrees Celsius (Barnhart 611), but for teaching purposes, we can consider this as the density of water in our school setting. Any material with higher density will sink in water, whereas any material with lower density will float on water.

The density of the different elements and for some other materials like balsa wood, polystyrene foam and candle wax can be calculated for each material by dividing the mass by the volume. The next step would be to test each sample in water in order to see if they float or sink, so the students will test their results.

The periodic table is an excellent tool for the teacher to illustrate the concept of elements as the simplest one substances which cannot be decomposed or broken down into simpler ones, and which can be combined into compounds. These elements each have their own density and some other properties exclusive of each other, and it can be observed that the density of the elements increases along with their arrangement (or position) in the periodic table according to their atomic number.

The teacher must be aware that—despite the general belief—'modern' pennies (those after 1982) are not made of copper, but are almost entirely (97.2%) of zinc; however, pennies made before 1982 are 95% copper and 5% zinc (HISD, CLEAR Science Curriculum, 5th Grade, Unit 7, page 23). This lesson also offers the opportunity to clarify that pencil cores are not lead, but graphite, which is a carbon compound.

Some of the prompts or questions related to this topic are:
What is mass?
What is volume?
Will samples of different elements or compounds with the same volume have the same mass?
What is density?
Why do some things float in water whereas others sink?
Do you know what the periodic table is used for?
Do you know what letters in it represent?
Do you know which sequence or pattern the elements in the periodic table follow?

Matter and Energy: Lesson Two Teacher's Background

What is matter and what is energy? I have found that students sometimes have difficulty in understanding what energy is and in differentiating it from matter. For instance, energy is contained somehow in matter, like energy from food. In addition, sometimes it is difficult for them to identify matter when they cannot see or feel it, like gases (air). Or they can be misled when they see fire and they think of it as matter, because they see and feel it, and even it seems to take some space. They also think that fire can destroy matter: they do not realize that it has been transformed in other sorts of matter.

This lesson is appropriate for teaching what a physical transformation is and what a chemical transformation is. A physical transformation is one which does not change the intrinsic properties of matter, like mass, volume, density and chemical composition, but only changes state (solid to liquid in water, for example), shape or appearance, like folding or cutting into pieces the cardboard. On the other hand, a chemical transformation is one in which the intrinsic properties of matter are changed through one or several chemical reactions, and evidently its chemical composition. Therefore, a chemical transformation always yields one or more substances different from the original one(s).

The demonstration consists of burning cardboard for the students to understand that fire implies two basic forms of energy, heat and light, and to see the transformation suffered by the cardboard into carbon because of the combustion, and the subsequent loss of mass (and weight) of the cardboard. As well, the amount of carbon present in the cardboard will be estimated by weighing before and after combustion. The basic chemical reactions that take place in this experiment can be represented as follows:

Cellulose (cardboard) + Oxygen + Energy (spark) → Solid carbon (ash) + Carbon dioxide + Water + Energy (fire= light & heat)

A process analogous to combustion and energy transformation takes place in our bodies. Cellulose is a complex molecule of sugar (which formerly was in the wood from which the cardboard is produced). In our bodies, we have also some types of sugar molecules, like glucose, from which we obtain energy when we "burn" it, for instance, doing sport. This process also leaves behind carbon in the molecule of carbon dioxide which we exhale, water and energy in the form of heat (but not light in this case).

All living beings have the element carbon as a major component of the body, and this carbon is not present in its elemental form, but rather as the compounds and molecules that build up our cells: sugars, fats, proteins and our genetic material. We can prove it by burning almost any plant or animal tissue, like wood or meat: what is left after combustion is mainly carbon (note that exception to this is bone or shells, made mainly of another element, calcium).

Through this lesson, the concepts of the elements (carbon, oxygen, hydrogen), and compounds (cellulose, as a form of sugar) will be reviewed. An element is a substance that is composed of atoms that are chemically identical. A compound is a substance formed by chemical combination of two or more different elements in a specific proportion.

Some of the prompts or questions related to this topic are:
What is fire, matter or energy?
What is burning? What is combustion?
What is light and what is heat?
What is the cardboard made of?
What is the substance left behind after combustion of the cardboard?
Is this substance heavier or lighter than the original cardboard? How much?
Why does some water appear on the tray after burning?

Evaporation and Electrolysis: Lesson Three Teacher's Background

Some intriguing questions, which some students may not even have thought about, will be answered here, like how small we can we divide matter or if matter can just disappear. Students often think that if you cut a piece of matter smaller and smaller, at a certain moment the particles will just disappear or, in other cases, they would answer that the dividing process can continue forever! Among the definitions and concepts taught in this lesson will be that of the atom and molecule, and the states of matter. They will be presented through the comparison of water evaporation and electrolysis.

An atom is—in simple words—the smallest particle of a chemical element that keeps all the properties of such element (Moyer, 5th Grade 306). A useful explanation about this smaller part of an element is that we cannot further divide it without destroying the element, because by splitting an atom, we are changing the element into a different element with smaller mass, and the mass we lose from the original atom will be liberated as energy.

A molecule is a particle formed from two or more atoms chemically combined, which can be equal atoms, forming a molecule of the same element as the individual atoms, or they can be different atoms, forming a new substance whose properties will be different from the properties of the individual atoms that form it (Moyer 306, 316). In the corresponding lesson the example of the water molecule is used, which is a compound entirely different from the hydrogen and oxygen atoms that make it up.

The three ordinary states of matter will be demonstrated by melting ice into water and by evaporating water into steam or water vapor. The melting point is the temperature at which a solid passes into a liquid, which for water is zero degrees Celsius at sea level; this is also the freezing point; that means, the temperature at which water passes from liquid to solid state. The use of the terms melting or freezing depends respectively if the temperature is rising or dropping.

Evaporation must be differentiated from the boiling point: evaporation of water can occur at any room temperature (between zero and hundred degrees), and it takes place at the water surface exposed to the air, whereas boiling takes place at one hundred degrees Celsius at sea level, and it occurs not only at the surface, but at any point or location in the water mass. In the corresponding demonstration, evaporation is promoted by increasing the kinetic energy of the water molecules by using a hot plate but not necessarily taking the water to its boiling point.

Some of the prompts or questions related to this topic are:
What is matter made of?
Is there a limit to how much we can divide matter?
Is ice water?
Is vapor water?
What is water made of?

In electrolysis we introduce in water an anode and a catode such that we pass an electric current through the medium (this is possible when some salts exist dissolved in water; pure water does not conduct electricity). The electric energy provided makes the water molecules split into oxygen and hydrogen. The free oxygen, with an excess of electrons becomes an anion, this is, a negatively charged ion, which will go to the positively charged anode within the water (Barnhart 32), whereas the free hydrogen, with a deficit of electrons becomes a cation, this is, a positively charged ion, which will go to the negatively charged cathode within the water (Barnhart 193). An electrolysis setting is shown in figure 1 in the corresponding lesson plan.

It will be evident that the hydrogen bubbles will be more abundant than the oxygen bubbles, which is understood because hydrogen and oxygen exist in a 2:1 ratio in the water molecules from which they come, which is known as the Law of Definite Proportions (Cobb 65).

This demonstration is an excellent opportunity to explain that in chemistry, "the whole is different from its parts": hydrogen and oxygen are gases, whereas water is usually found as a liquid (but it can be a solid or a gas, too); moreover, when you put hydrogen and oxygen together as separate gases, they are explosive if you set them on fire. In contrast, water can be used to extinguish fire.

Other questions relevant to the topic during the electrolysis demonstration are:
What are these bubbles coming out of the water?
Why is the water not at the boiling point, and not even hot?
Why do we need an electric current to produce bubbles?
Why is the paper strip not wet?

Acids and Bases: Lesson Four Teacher's Background

In this lesson, the concepts taught are acid and alkali or base, dilutions, and the pH scale. This will be done by using dilutions of a weak acid like lemon juice and a weak alkali or base like baking soda solution. As well, the experiment of mixing them at different proportions will be done, observing the result of such "encounters" and measuring the pH of the resulting mixtures.

Acids and bases are both reactive, and at high concentrations they are corrosive.

Acids are substances whose solutions have a sour taste. Acids react with other substances because they give out hydrogen ions (H+) or are proton donors or act as electron acceptors (Barnhart 7). Bases are substances whose solutions have a bitter taste and have an "oily" or "soapy" feel. Bases react with other substances because they give out hydroxide ions (OH-) or are electron donors or act as proton acceptors (Barnhart 61). When we mix an acid and a base they react and form salts and water, and if the reaction is completed in such a way that all the acid reacts with all the base, the resulting solution will be neutral, this is, acids and bases tend to mutually neutralize.

The pH scale is a measure of the acidity or alkalinity of a solution in terms of the relative concentration of hydrogen ions in the solution (Barnhart 485). The range of the pH values of acids and alkalis goes from 0 for the strongest acid to 14 for the strongest alkali, 7 being the pH for pure water, the neutral pH value. In the lesson included, none of the solutions is a highly concentrated acid or base, but for teaching purposes they are called concentrates or concentrated.

An extension to this lecture involves the use of indicator paper with different liquids of natural origin, like fruit juices and milk, and compares them with other man-made solutions, like carbonated drinks, coffee or soap solution, and rank them according to their pH. The pH is really important inside the cell, and significant shifts in the acidity of an organism can be fatal. Blood in humans is kept at a pH close to neutral (7.35), and a variation as small as 0.2 can cause death (Barnhart 485).

Some of the prompts or questions related to this topic are:
What is an acid?
Is there anything opposite to an acid?
What is a base?
What happens if we put them to 'fight' each other or mix them?
What is the final substance after we mix them up?
What is a solution? What is a dilution?
Which is the strongest acid in our experiment? Why?
Which is the strongest base in our experiment? Why?
Is water in the side of acids or in the side of bases?

IMPLEMENTATION STRATEGIES

The best implementation strategy is to create enthusiasm and expectation. Therefore, the best way to start a lesson is by conducting the experiment. These lessons are intended to be developed in a laboratory, with all the reagents, materials and devices ready and at hand.

When the students arrive, the experiment must be set on the table, if possible at a central part of the room. The first thing to do is to review the safety rules and to prepare the students accordingly, for instance, with aprons, goggles or gloves when appropriate.

The second thing to do is to mention the name of the equipment and, when pertinent, the name of the substances to be used. It is possible that you don't want to give the names of certain substances when part of the learning is by having the students infer them.

Next, it is appropriate to stimulate the students by posing the suggested questions listed in the lesson background sections. These prompts must be related directly to the definitions and concepts you want to teach, and it is also important to address through your questions some of the misconceptions students could have.

Then the great moment has arrived: the experiment. The experiment must be tested previously in order to make sure it works… and safely; it is of the utmost importance to make clear to the students when the experiment of the day can or cannot be tried at home.

The demonstration is the most important part of the lecture, at least for the students, because it will give sense to the explanations, definitions and concepts taught. The demonstration for each lesson will be explained in detail in the lesson plans at the completion of the unit. After completing the demonstration, you can initiate the explanation with a series of questions about what the students just observed. Eliciting answers from the students is the best way of teaching: the students will learn better if they find the answers to our guided questions.

As the answers arise in the discussion, take notes on the board and encourage students to keep the information in their notebooks. The notes on the board must be written in a pre-established order intended to build up a coherent lesson. If time permits, the perfect closure would be to repeat the demonstration in order to "loop the loop": the students will understand the demonstration at a higher level, because now they have the theoretical background as well as the hands-on experience.

At the end of the unit, a test is possible by using some of the questions presented for every lesson in the background section, or applying a new approach to a test on the definitions and concepts taught, for instance, presenting a diagram or drawing of the demonstrations made and asking to the students to complete sentences, give the right word for a definition or give a brief explanation of a concept. They could even be asked to describe the whole experiment or their understanding of it. But certainly, the diagram or drawing will help the students to remember their personal experience and give the correct answers.

SAFETY

The hands-on activities from the lessons presented in this unit are inherently safe, with the sole exception of burning cardboard in lesson two. This is the only activity that must be conducted only by the teacher and at a reasonable distance from the students. The teacher must wear the basic safety equipment, this is, goggles and apron, and have a bare metal trash bin, some water or fire extinguisher aside.

For the other experimental activities, the students ideally must practice the basic safety rules and wear the basic safety equipment, which will strengthen their safety awareness.

Five basic safety rules are:

1) Do not try or do anything with the substances, equipment and instruments that is not indicated by the teacher.
2) Do not eat or drink anything in the laboratory (not even your own food), unless indicated by the teacher.
3) Wear the safety equipment given to you.
4) Locate the emergency exit(s) fire extinguishers and other safety equipment.
5) Report to the teacher or nearest adult any dangerous situation you perceive.

The basic safety wear for the students and the teacher includes:

1) Closed shoes.
2) The hair must not be loose.
3) Apron.
4) Goggles.

After the lesson it is advised to the students to wash their hands and any stain that they could have in their clothes.

CONCLUSION

This unit can be seen as a first formal chemistry course for fifth grade students, in which chemistry is presented as a science in its own right through the different lessons and hands-on activities. It is desirable that more lessons centered on chemistry would be written for fifth grade students, and the format presented here could be used as a blueprint or guideline for the development of new materials.

Finally, the core idea about this 'first chemistry' unit is that it may represent an advantage for the student who is heading for middle school, because in addition to the acquired knowledge, it will give him or her a better idea of the boundaries and connections between chemistry and other sciences. If so, it will represent an advantage as well for the middle school teacher in charge of the chemistry courses.

LESSON PLANS

Lesson One: Mass, Volume and Density

Objectives and Goals

The objective of this lesson is to investigate some of the most evident properties of matter, namely mass, volume and density, by measuring the volume for a constant mass of different elements and the mass that different elements have for a constant volume, and in a second step by obtaining the density from the previous measurements.

The goal is that the student practices measuring mass and volume, and understands that one of the basic differences of the various elements is their mass, and that there are no two elements with the same characteristics. The students must realize that the elements are arranged in the periodic table in increasing mass sequence. As well, the student will calculate the density for each one of the samples by dividing the mass by the volume. Once the density has been obtained, the student must hypothesize which materials will float and which will sink in water.

List of Materials

Periodic table of the elements, big size
Triple beam balance
Graduated beaker, 50 mL capacity
Elements (not in pure state)
Carbon: charcoal
Aluminum: aluminum foil or washers
Calcium: chalk
Copper: bare wire
Iron: small nails
Zinc: pennies after 1982 are 97.5% zinc
Silver: rings, medals, etc
Other complex materials
Balsa wood
Styrofoam
Candle wax

Procedure and Presentation

Prior to the lesson, label the samples with the name of the element they represent. Display on a table a big periodic table of the elements.

Display the different elements to the students and put them in their corresponding place on the periodic table and explain that the letters in the table are the symbols that scientist use as an "abbreviation" for the name of each element. Explain to the students that even when the samples are not pure elements, they are nevertheless made mostly of the element they represent. The balsa wood, Styrofoam and wax are not simple elements and must be grouped separately as complex materials.

Discuss with the students: What is mass? Explain to the students that mass is the amount of matter contained in an object. Proceed to measure with the balance exactly three grams of every element, but if this is not possible with some samples due to a limited amount, record the exact mass of the sample available on a separate sheet of paper. With the wood, foam and wax, you can measure the same three grams, which will show the big difference in volume of these materials with respect to the elements, after which you can only take only one gram in order to handle comparable volumes for the next step.

Fill the graduated beaker with water up to 30 mL, and proceed to measure the volume of every sample by the water displacement method. Where necessary (in the cases when the sample could not be adjusted to the three grams mass), normalize the volume of the sample for three grams by the rule of three.

If the sample size and availability of carbon, aluminum foil and calcium allows it, shape three solid cubes of two centimeters per side (or three solid balls or rods of equal dimensions) for each one of these elements (make sure that the aluminum foil cube or ball keeps as little air as possible in between the different layers). Then proceed to verify by water displacement that the three samples have the same volume; correct for any differences until the three samples have the same volume. Cut a cube of the same dimensions of wood, foam and wax.

Then, measure the mass of each sample in the balance and demonstrate that different elements and materials have different masses for a constant volume.

Make a table in which to fill in the mass of the different elements and materials for a given volume and their volumes for a given mass.

At this stage we are ready to obtain the density of the different samples and add this to our table. Divide the mass of each one of the samples by its volume and give the results as grams per cubic centimeter.

Water is known to have a density of one gram per cubic centimeter or one gram per cubic milliliter. If something is denser than water, that is, if the result of the division of mass by volume is bigger than one, this material will sink. On the other hand, if the result of the division is smaller than one, this material is less dense than water and it will float. Have the students compare the results for the different samples, make their hypotheses, and test them by putting the samples in water.

Lesson Two: Matter and Energy

Objectives and Goals

The objectives of this lesson are to explain the difference between matter and energy, giving the corresponding definitions, and to explain the difference between elements and compounds.

The goal is that the students realize that combustion is a chemical reaction, one of the most frequently seen, and that they understand the transformation of a complex material like cardboard into two forms of energy, light and heat, and the decomposition of a complex (organic) compound, cellulose, into the elemental carbon (among other things), and water through such chemical reaction.

List of Materials

Periodic table of the elements
Goggles
Six index cards (cardboard)
One aluminum foil tray
Double pan balance
Lighter or matches (only the teacher)

Procedure and Presentation

For safety reasons, the teacher must be the only one performing the combustion of the index cards for every team; the students are allowed to do the rest of the hands-on work.

Put one index card in each plate of the double pan balance and observe that the balance is in equilibrium. While leaving one card in the balance, remove the other one, put it inside the aluminum tray and burn it; normally it will hold one piece if it is not crushed.

Discuss with the students the fact that the burning card is going through a chemical reaction and it is emitting light and heat energy while burning. Explain go the students that the black substance left behind after combustion is carbon, one of the elements in the periodic table, and find it; on the other hand, show to the students that some moisture has remained from the combustion in the aluminum tray, and explain that this moisture is water that comes out of the burning card.

Bring the burned card into the balance and compare its mass with that of the unburned card; it has lost a lot of its original mass (and weight) through the chemical reaction of combustion. Ask the students how many burned cards would equal the mass of the unburned card.

Repeat the combustion with five more cards, putting each of them one at a time after burning, on the balance until they equal the mass of the unburned card. Discuss the fact that five (or maybe six) burned cards equal the mass of the unburned card. This demonstrates that through burning, the cardboard has lost about 80 per cent of its mass, which means that, out of cellulose, only 20 per cent (approximately) is carbon and the rest is hydrogen and oxygen. Note that this does not necessarily means that the carbon left behind is chemically pure, because there are some other elements present in minute amounts, nor all the carbon is in the ashes, because some of it has gone into the air as carbon dioxide; nevertheless the proposed explanation is good enough and useful for the objectives of the lesson.

Lesson Three: Evaporation and Electrolysis

Objectives and Goals

Among the objectives of this lesson are to show the three states of matter, namely solid, liquid and gas, and how a substance can pass from one state into another and to teach the concepts of atoms and molecules.

The goals are, on the one hand, that the students witness the transformation of ice into liquid water by melting and of water into vapor by evaporation and/or boiling, and on the other hand that the students understand the concept of atoms and molecules by showing and explaining electrolysis to them.

List of Materials

Periodic table of the elements
Ice cubes and (liquid) water
Two pyrex beakers, 250 mL capacity
Electric hot plate
Dry battery, twelve volts
Two bare copper wires, 20 cm long
Two pencil graphite cores, 5 cm long
Scotch tape
Goggles
Mitts or small towels
Several paper strips, about twenty centimeters long by two centimeters wide
Two thermometers (of more than 100 degrees Celsius capacity)
Sharp knife for wood

Procedure and Presentation

Melting/evaporation and electrolysis must be performed in parallel for comparative purposes.

Melting/evaporation

Put several ice cubes in a beaker and fix with scotch tape one paper strip across the mouth of the beaker, crossing the diameter of the beaker.

Turn on the hot plate at low heat (high heat is not necessary) and then put the beaker on the hot plate for the ice cubes to melt quickly. Introduce the thermometer into the beaker.

Observe how the ice is passing from solid into the liquid state and observe the water temperature. Once all the ice has melted, observe the water passing from liquid to vapor state and observe the temperature.

Discuss with the students that the vapor, even if invisible, is still water, and the proof is that the paper strip gets wet, because water condensates on the paper, making it wet. Mention that the temperature of the water undergoing evaporation is well above the room temperature, up to one hundred degrees Celsius if the water has achieved its boiling point. Explain to the students the concept of molecules and present to them a drawing or a model of the water molecule.

Explain to the students that the water changing state is due to an increase in the energy of motion of the water molecules, promoted by the increase in temperature.

Electrolysis

Pour one hundred milliliters of water in a beaker and fix one paper strip across the mouth of the beaker with scotch tape, crossing it by the diameter in the same way as it was done with the evaporation experiment. Introduce one thermometer into the beaker and observe the temperature.

Obtain two electrodes (it is convenient to do it before the lecture begins) by cutting in half a regular pencil and open each half by its length with a sharp knife. Carefully extract the graphite core from each opened pencil half.

Connect one wire to each end of the twelve-volt battery and wind up the other end of each wire to a graphite core, making them your electrodes. Introduce the two electrodes into the beaker filled with water, keeping them separated inside the beaker. A diagram showing the electrolysis set up is presented in figure 1.

Observe how bubbles form around each graphite core. Alternatively, disconnect one of the wires from the battery and observe how the bubbles stop forming when you disconnect either wire.

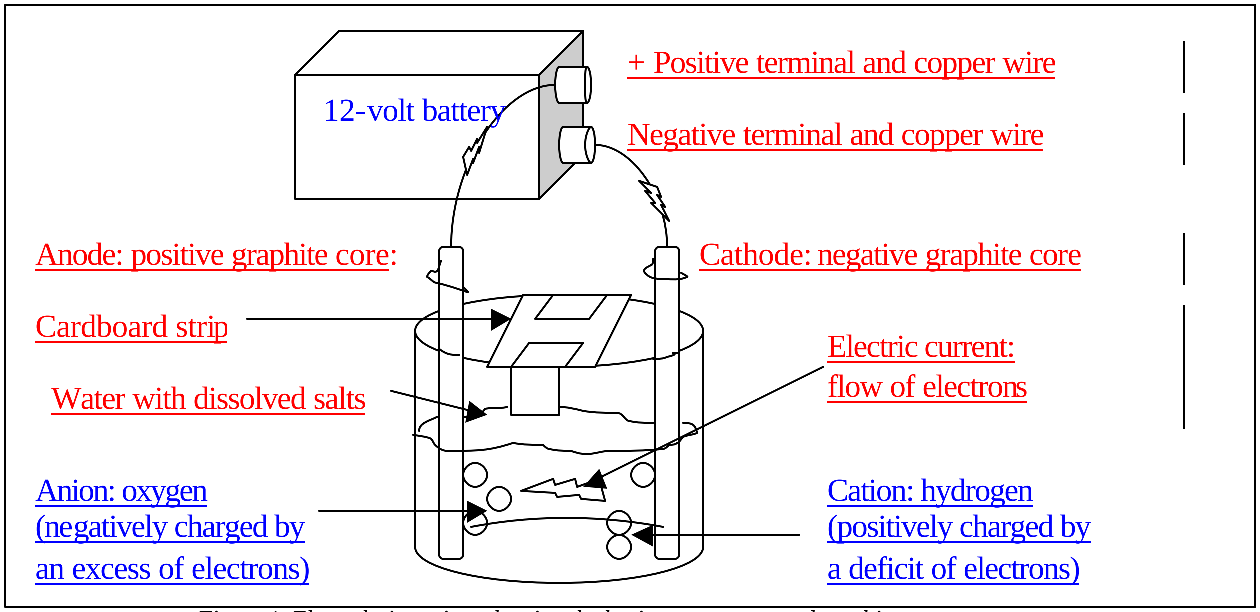

Figure 1. Electrolysis setting, showing the basic components and resulting gases.

Discuss with the students the nature of electrolysis and about the gases forming around the two electrodes. The more abundant bubbles are hydrogen, whereas the bubbles forming around the other core are oxygen. Both gases were formerly combined, in the form of water molecules, but the electric current has dissociated them into two free gases, indicated by the paper strip which is not getting wet because water is not evaporating.

Draw the attention of the students to the fact that the temperature of the water in this beaker is not significantly different from the initial temperature. Show the students the periodic table of the elements and find the position of hydrogen and oxygen in it, explaining that these combined in the right proportion of two atoms of hydrogen plus one atom of oxygen form one molecule of water.

Lesson Four: Acids and Bases

Objectives and Goals

The objectives of this lesson are to teach the properties and nature of acids and bases or alkalis, and the concepts of dilution and pH.

The goals are that the students experience the dilutions of the acids and bases, measure their acidity and alkalinity using indicator paper, understand the pH scale, and experience neutralization by mixing the acid and base.

List of Materials

Lemon juice, 60 mL (citric acid)
Baking soda powder
Water
pH indicator paper
11 graduated cylinders, 50 mL capacity
Plastic cups
13 plastic droppers

Procedure and Presentation

Acid dilutions

Take five measuring cylinders and label them with the word “acid” and the concentrations 100%, 50%, 25%, 12.5% and 6.7%.

Pour 40 mL of concentrated lemon juice in the 100% cylinder; this is the concentrated citric acid. Set aside 20 mL of this acid as spare solution.

Withdraw 20 mL of concentrated acid and put it into the 50% (or diluted to 1/2) cylinder, then bring it up to 40 mL with water.

Withdraw 20 mL of the acid diluted at 50% and put it into the 25% (diluted to 1/4) cylinder and bring it up to 40 mL with water.

Withdraw 20 mL of the acid diluted at 25% and put it into the 12.5% (diluted 1/8) cylinder and bring it up to 40 mL with water.

Withdraw 20 mL of the acid diluted at 12.5% and put it into the 6.7% (diluted 1/16) cylinder and bring it up to 40 mL with water. You may take out 20 mL of this dilution in order to keep all volumes equal.

Base dilutions

In a separate container or beaker, make a concentrated base solution by dissolving five grams of baking soda into 60 mL of water. Set aside 20 mL of this base or alkali as spare solution.

Take five measuring cylinders and label them with the word “alkali” and the concentrations 100%, 50%, 25%, 12.5% and 6.7%.

Pour the 40 mL of concentrated baking soda solution in the 100% cylinder; this is the concentrated alkali.

Withdraw 20 mL of concentrated alkaly and put it into the 50% cylinder and bring it up to 40 mL with water.

Withdraw 20 mL of the alkali diluted at 50% and put it into the 25% cylinder and bring it up to 40 mL with water.

Withdraw 20 mL of the alkali diluted at 25% and put it into the 12.5% cylinder and bring it up to 40 mL with water.

Withdraw 20 mL of the alkali diluted at 12.5% and put it into the 6.7% cylinder and bring it up to 40 mL with water. You may take out 20 mL of this dilution in order to keep all volumes equal.

Making a pH Gradient

Align the cylinders in a gradient of concentrations, starting at the left end with the 100% acid in decreasing concentrations up to the 6.7% diluted acid; next, put a cylinder filled with 20 mL of plain water. Thereafter, align the alkaline cylinders at increasing concentrations starting with the 6.7% diluted alkali until the 100% alkali cylinder, which will stay at the right end of the concentration gradient line.

Introduce one pH indicator strip in each one of the cylinders and align them on a white sheet of paper in correspondence with the row of cylinders. Compare the color of each strip with the color key and determine the acidity and alkalinity of each dilution by relating the color to its given pH value. Make a table of acid and alkaline values for the solutions.

Explain to the students that the pH scale is a ranking system that scientist use in order to know how acidic or alkaline a solution is, and that this scale ranges from zero for the strongest acids like concentrated sulfuric acid, up to 14 for the strongest alkalis, like concentrated caustic soda. Water, being neutral, is at the middle of the pH scale with a pH of 7.

Once the pH of the different dilutions has been determined, mix small, undetermined amounts of both the spare citric acid and spare baking soda solutions (the concentrated solutions). To do this, use only one dropper per solution. Observe the reaction that takes place and measure the pH of the final mixture. Draw the attention of the students on the fact that the acid-alkali reactions produce heat that can be felt, and carbon dioxide gas that can be seen in bubbles produced by the chemical reaction. Water, which remains in the solution, is also produced, but we cannot tell it apart from the original solutions.

By observing the pH values of the different dilutions (100 % through 6.7%) prepared in the measured cylinders, discuss: Which acidic and alkaline dilutions, when added in equal quantities, will result in a neutral mixture? Perform the experiment by mixing equal amounts of one acid and one alkali, either of the same or different percentage of dilution and determine the pH value of the final solution by using indicator paper. Find the combination or combinations that yield a final solution with a pH of 7, that is, a neutral mixture.

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