A Waldorf High School Chemistry Program

with Appendices



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Cover image: 3D rendering of a molecular model of alanine peptide. The original can be viewed at: Molecular Modeling.png. Digitally altered from its original version; modifications made by Dhatfield, licensed under Creative Commons

Introduction

Since main subjects are taught in blocks, it is possible to design a program to meet the developing students' interests and needs. There are several ways to view the four high school years, ways which supplement and support each other and form the basis of the traditional approach to organizing chemistry and other subjects. We have in addition several general objectives for a chemistry program, namely, to provide a foundation for understanding fundamental chemical concepts and procedures and to do this in a Goethean or phenomenological style. Time limitations place restrictions on the total material and/or depth of the coverage.

The Question of Breadth

The original Waldorf School in Stuttgart, Germany, ran six days a week and had a six week summer vacation in contrast to our five days per week (Today German schools also have only five.) and a summer holiday of some 12 weeks. Altogether American schools have perhaps 36 weeks, not all of them are full due to various holidays. Main lessons also may run only two 45-minute periods for 1½ hours total. In general we have each year one three-week main lesson block, giving us 2 x 15 = 30 classroom hours per year in contrast to perhaps 36 in the original school. Some schools have tried using extra main lesson time, mathematics skills classes or art blocks in the afternoon to bolster the schedule. At least one school has extended the school day to produce two main lessons a day. However most of us must make due with 30 hours a year or 120 over the high school program. In contrast, public schools or prep schools generally have one period a day for a whole year, or a total time of 5 x 37 weeks = 185 classroom hours (somewhat less for prep schools). I taught in a prep school which allocated 7 hours per week to chemistry, allowing two full laboratory periods per week for a total of some 259 class hours. Today public schools also may similarly expand weekly classroom hours allocated to their science offerings.

How can we overcome this gap in technical education? Naturally we strive for depth, to present material so that it sticks, more likely in a block system than in daily lesso https://upload.wikimedia.org/wikipedia/commons/2/26/SVG_molecular_model.png ns. Rudolf Steiner expected the teachers to be efficient, so that more could be learned and digested in a shorter time, allowing us to reach state expectations with fewer classroom hours. Still, it is difficult to match a conventional course, nor do we really want to do this. We are teaching all students, not only those with an interest in science or college. The solution which I have used is to offer extra chemistry lessons to interested students. We have done this on Saturday mornings (the most effective), in electives and in after school club settings. These courses generally emphasize theory and calculations, the main things we cannot push too far with general students in a Goethean context. These courses have been offered in the 11th and 12th Grades, which seems to be more appropriate than in earlier

grades, especially considering the content of the 11th Grade. A recent graduate, now completing university and applying to medical school, related that he decided to major in chemistry because of his delight in learning details of atomic structure. He was totally enthralled by orbitals and energy levels. I believe that we have a duty to open up these highly technical areas to students whose interests and abilities also need nurturing.

Goethean Chemistry

In a Goethean approach to chemistry, we begin with observations and a clear review of these observations. Students are allowed to reflect on these things during the night. The following morning on Day 2 the observations are revisited and implications are drawn out, implications which generally lead to further experimentation, and so the process continues. On the third day ideally students will participate in their own investigations, verifying or exploring the area being studied. This threefold main lesson is an extremely efficient and powerful method of penetrating a subject. It is also quite difficult to put into practice, given limitations in time to carry out real laboratory investigations and often also limitations of student equipment and laboratory space. To the extent it can be approximated, however, considerable efficiency in learning can be accomplished.

Clearly, for students to undertake their own laboratory investigations they need space and a science laboratory designed for this purpose. The Waldorf school with the best designed laboratory that I am familiar with is Kimberton Waldorf School. Each student pair has a complete set of equipment in their desk for experimentation, with adjoining sink and gas. There are two labs, one for physics and chemistry, one for biology and geology. They share a generously-sized preparation and storage room. When the time comes for a school to remodel or build, it is certainly worthwhile to include generously proportioned and equipped science rooms.

In Chemistry we are seeking to probe into the innermost hidden dimensions of the material world. Thus the introduction to Chemistry is postponed in the Lower School until 7th Grade (in contrast to Physics, which begins in Grade 6). When students enter the high school, we should be able to presume that they have had an introduction to combustion, the limestone cycle and to acids and bases in 7th Grade and to photosynthesis, food types and digestion in the 8th. Nevertheless all must be (briefly) reviewed and confirmed before proceeding with new material. In any case there is no guarantee that all class teachers will have carried the subjects to sufficient depth. In fact the program in the Lower School should be more the experience of chemistry, the transformation of materials, without concern about why or how these things take place. Also students from other schools may not have the experiential foundation we would hope for. So it is always best to begin with a thorough review, but a review done efficiently, in a new way, a more advanced way, a more sophisticated way.

Reaching the General Student

Some students are naturally attracted to science and will be pleased to learn as much information as possible. However. there are always several students, often a majority, who do not have a positive view of technical subjects. In general we have three ways of reaching and activating such students. First of all we can introduce subjects historically, showing science as evolving over time, not a fixed body of knowledge to be memorized. Secondly the introduction of historical personalities and their struggles to reach new insights can appeal to anyone. Thirdly, we provide ample opportunity for the students themselves to enter into the process through striking demonstrations and their own experimentation.

Further, using the teachers' meditation, calling to view each student in turn during the evening meditation, often gives rise to a special thought or story or relation to current events, with which the lesson may begin or be made directly relevant to life today.

9th Grade Chemistry

A tradition has developed in Waldorf schools of teaching Organic Chemistry in 9th Grade. This makes sense from a number of points of view. Organic Chemistry continues the developments in 8th Grade Chemistry of nutrition and the oxygen cycle. But more important, 9th Grade students feel arrived in the modern world, full of energy. Physics in the 9th Grade concerns the internal combustion engine, energy and power. The origin of this power today is primarily fossil fuels: petroleum and coal. These are end products of organic processes, originating in plants. And Organic Chemistry is the area where the exciting and relevant research is taking place today. Finally 9th Grade may be viewed as in some ways corresponding to the earth element, coal and petroleum being as down to earth as it gets. Students should be ready to discuss drugs objectively. So the experimentation with substances which change consciousness is particularly appropriate.

References

CHEM. *Chemistry, an Experimental Science*
_____. *Laboratory Manual*
Julius, Fritz H. *Fundamentals for a Phenomenological Study of Chemistry*
McBride, J. Michael. *Freshman Organic Chemistry I*, Open Yale Courses
McGee, Harold. *On Food and Cooking*
Mitchell, David S. *The Wonders of Waldorf Chemistry*, AWSNA Publications

Course Outline

Observations of a candle
Experiments with a candle
Conclusions from the candle experiments
Tests for carbon dioxide and for water
Demonstration: Magnesium and carbon dioxide
Human breath products
Photosynthesis and respiration: Equations
Oxygen Cycle: Picture (would make a good frontispiece)
Demonstration: Glucose and concentrated sulfuric acid
Analysis of glucose
Sugar and starch tests and properties
Carbohydrates
Chromatography experiments
Fermentation

Distillation
Transformations of sugar
    Chemical equations
    Organic families: alcohols, ethers, aldehydes, ketones, acids, esters, soap
Petroleum: Origin
    Stages of the industry
    The alkane series
    Refining: Fractional distillation
        Octane rating, catalytic cracking, etc.
    Saturated and unsaturated hydrocarbons
Coal: Origin and types
Destructive distillation

Some Block Notes

Opening Demonstration
Fill a two-foot rubber tube with starch; blow through a Bunsen burner

Combustion
My favorite way to begin is with the opening exercise in the *Chemistry, An Experimental Science* program, namely, observations of a candle, a simple, yet challenging exercise, and ultimately lots of fun. However it must be introduced properly, else students protest that they already know about candles (which they of course do not). I point out that at a new stage, one must first review everything learned up until that point, but at a deeper level and very rapidly. My daughter was told by her college chemistry professor on the first day, that, prior to beginning new material, they would review all of high school chemistry, and in three weeks! Likewise, in graduate school, courses will often first briefly summarize what all should know from undergraduate work. And so we begin high school chemistry by looking at combustion, through the candle. One can also show Faraday's lectures on the candle, still in print after 150 years, and point out that actually what goes on in there is highly complex, and no one actually understands all the nuances even today. The first exercise is a contest: to take a simple candle (Shabbos paraffin candles are generally available in supermarkets.) and make as many observations as possible, first unlit, then lit. This exercise also involves a measurement review of using a scale, timing device, rule.

Next comes a set of small experiments with a lit candle, described in the associated exercise book. They involve testing various materials as wick; exploring the structure of the flame and bowl; relative temperatures in the flame; contents of the parts of the flame. For some students, this is the most fun they have ever had in a science class.

Tests, Chemical Changes, Main Substances

Next, tests for the products are introduced (limewater and cobalt chloride paper) and, of course, our own breath with straws and test tubes. It is always good to show the oxygen generated by plants. Elodea weed under an inverted funnel and collected in a test tube in a fish tank is convenient, but it takes several weeks for a testable quantity. For the fraction of oxygen in air, iron filings or steel wool in a wet inverted test tube over water can be used, but only if untreated filings or wool are available. (Make your own.)

A simple, yet visually striking demonstration of magnesium burning in carbon dioxide clearly shows the carbon, as well as a simple, yet vivid, chemical change. The equation (word and symbol) is obvious, building confidence in the student's ability to relate phenomena to formulas.

Burning wood shavings or excelsior demonstrates very well the various stages of combustion of organic material. Can the student imagine this process in reverse? Ask for results the next day, then point out, if they have not already thought of it, where this is going on all the time, namely, in the plant world, in photosynthesis. The oxygen cycle is now ready to be described in more detail. The remainder of the block is essentially drawing out the products of the original glucose molecules the plants produce.

Sugar and Starch

Sugar and starch are the focus of the next few days. Students have no doubt met these before. Now they should see how the experiments with starch demonstrate that their particles are much larger than those of the simple sugars. Chewing bread breaks the starch down into simple sugars, sweet to the tongue. Also glucose and fructose respond differently to Benedict's Solution, indicating different structures. How can that be?

Analysis and a Chemical Formula

I do not believe that it is possible to proceed with Organic Chemistry without addressing chemical structure and molecules. Nevertheless we still seek to build everything up from experience, phenomenologically. So with filtering, with the action of acids and enzymes, we demonstrate the difference between a monomer and a polymer. We demonstrate the difference in chemistry, and hence structure, between simple sugars. Can we go further and determine the composition of sugar itself? We know that the plant makes it from carbon dioxide and water. And combustion produces carbon dioxide and water. If we suck out the water with concentrated sulfuric acid, pouring some into a small beaker partially filled with sugar, we get a carbon tower, hinting at the role of carbon as the backbone of organic substances.

Done more carefully, we can determine the relative masses of carbon and water in glucose. Heating a measured quantity of glucose in a small beaker or test tube, we can carefully drive off water vapor until only carbon is left. This is a longish demonstration, generally

not completed in the classroom period, finished after class, with the residue available for the next class. If done carefully, the weight (mass) ratio of water to carbon is quite close to the accepted value of 18 to 12 or about 1.5. To go further, students must be supplied with the relative weights of these substances in compounds. With this in hand, an empirical formula of CH_2O appears. Unfortunately this is the formula for formaldehyde, a poison. We must add a result from 10th Grade Chemistry, where molecular weights can be obtained, that the relative weight of the whole formula is 180. Thus we have a formula for fructose/glucose of $C_6H_{12}O_6$. This analysis is exactly the kind of work which organic chemists carry out, so students experience a taste of real chemical research.

Transformations of Sugar

From the plant's production of glucose we can go in two directions. One way is downward into *coal and petroleum*. And the other way is "upward," as *sugar* gradually loses the perfect balance between the fire of hydrogen, life of oxygen and structure of carbon. For sugar gives us a burst of energy, heightens our ego (even if for a short time, leading to a drop in energy afterwards). However sugar transformed into alcohol loses structure with the carbon, and so we lose control and give over to a "spirit."

The students can bring in various sugars or the teacher can supply them: molasses, honey, guava, malted barley, etc. The sugar is mixed with water and some live yeast added. The fermentation takes place conveniently in a 250ml Erlenmeyer flask, fitted with a one-hole stopper and glass right angle bend attached to a short rubber tube and a longer glass tube reaching into a 250 ml beaker with limewater, forming an air lock and the characteristic test for carbon dioxide. Following the complete fermentation, students should taste the results, which will not entice anyone to drink. The mash should be distilled, best mixing some together to obtain sufficient distillate. The result can also be tasted. A second distillation will generally be needed to obtain a concentration which may be burned. (Prohibition, stills and related songs are possible here.)

Formaldehyde and acetaldehyde are easily prepared by heating a copper wire coil in a burner and inserting it into a test tube containing a few ml of the corresponding alcohol. The copper oxide on the wire oxidizes the alcohol to the corresponding aldehyde, which can be wafted toward the nose. The removal of the water (of life) has produced a substance poisonous to life. Now the fun begins with concentrated sulfuric acid. First ether is produced as a result of the dehydration of ethanol, diethyl ether. Removal of the water causes further loss of control, to a loss of consciousness. The ether can be (carefully) wafted toward the nose after the removal of the burner and a little cooling off of the tube.

A variety of *esters* can be demonstrated, depending on the availability of organic acids and alcohols. With time and a good lab, students can make some themselves, though with much caution, as they are working with concentrated sulfuric acid. A ml or two of an organic acid and an alcohol in a test tube, followed by a small amount of concentrated

sulfuric acid, one ml or less, is all that is needed. The reaction can be encouraged by gentle heating, with the mouth of the testtube pointed away from everyone.

If time permits, making *soap* is always lots of fun. Students can add some food color or fragrance if they like. Soap can be made in a petri dish (fitted with plastic liner) or in a small carton supplied by the student. The crucial step is stirring until the soap cools enough to thicken. If this does not happen, the result is three layers: lye, soap and fat.

An introduction to the important analysis method of *chromatography* is worthwhile. Liquid phase using a rectangle of filter paper in a stoppered Erlenmeyer flask is a convenient setup. Food colors or inks can be separated using water as the medium.

Petroleum and Coal

The petroleum industry should be discussed—from exploration to drilling and refining. Fractional distillation can be described, based on the students' own experience of distillation of a mash. Cracking, reforming, octane rating are worth explaining. The various products and their uses and the need for refining should be described.

How far the coal industry is addressed depends on time and interest. Destructive distillation of coal and wood and the resulting products can be easily demonstrated.

Industrial Tours

Possible tours include a plastic molding operation, local brewery, petroleum refinery, bakery.

Appendices

9-1 Clap! Snap! The Black Crack!
9-2 Student Laboratory Desk Equipment
9-3 Observations of a Candle
9-4 Candle Experiment Notes
9-5 Scientific Observation and Description
9-6 Description of a Burning Candle
9-7,8 Further Investigations of a Burning Candle
9-9 Oxygen Cycle
9-10 Percent Carbon in Glucose, Sample Results
9-11 Notes
9-12 Experiment: Fermentation
9-13 Experiment: Distillation of Ethanol
9-14 Destructive Distillation
9-15 Soap
9-16 Transformations of Sugar
9-17 Notes on Transformations of Sugar (Glucose)
9-18 Experiment: Chromatography of Food Colors
9-19 Chromatography of Natural and Synthetic (or Processed) Substances. *See Grade 12, p. 78*
9-20 Experiment: Chlorophyl

Clap! Snap! The Black Crack!

From J.R.R. Tolkien, The Hobbit

Clap! Snap! The black crack!
Grip, grab! Pinch, nab!
And down down to Goblin-town
        You go, my lad!

Clash, crash! Crush, smash!
Hammer and tongs! Knocker and gongs!
Pound, pound, far underground!
        Ho, ho! my lad!

Swish, smack! Whip crack!
Batter and beat! Yammer and bleat!
Work, work! Nor dare to shirk,
While Goblins quaff, and Goblins laugh,
Round and round far underground
        Below, my lad!

9-2

Student Laboratory Desk Equipment

Name:_____ Desk #_____

250 ml Erlenmeyer flask
100 ml beaker
250 ml beaker
400 ml beaker
6 test tubes
Test tube rack
Watch glass
Glass plate
Stirring rod
Glass tube
Crucible and lid
Medicine dropper

Utility clamp with right angle clamp
Wire gauze
Test tube holder
Crucible tongs
Screw clamp
Matches
4" Ring
Bunsen burner
Flame spreader
Clay triangle (pipestem triangle)
Apron
Goggles

Check-in Procedure

1. Make sure all items are >present and clean
   >neatly arranged.
2. Report any missing, dirty, messy or extra equipment.

Note: Large equipment should be in lower drawer/cabinet.

Check-out Procedure

1. Make sure all equipment is present, neat and clean and that no extra equipment is present.
2. Clean desk top, sink and general work area.

Observations of a Candle

Introduction
Science is based on careful observations and upon reflection upon these observations. Sometimes the smallest detail may be the most important. Further, the conditions under which the observations were made may also be important, for example, where, when, under what circumstances the observations were made. And your own involvement in the experiment may be influencing results.

In the case of the candle, the mass of the candle and its size are important data for understanding what is happening. An important condition may include location (near the door or window?, close enough that your breath could influence the flame?...)

After detailed investigations of the candle itself and its burning, questions may be raised about the structure, function of various parts, details of its combustion. Further experiments can be carried out to probe the functioning of the various parts of the candle and to understand the observations made.

Procedure
I. The first day will be a contest to see who can make the most observations of the candle, first as we meet it, then while it is burning.

II. After thorough examination of the candle, further experiments will be suggested for clarifying the operation of the burning candle and the function and properties of the different parts.

III. After observing and experimenting, the students should write down their descriptions of the burning candle and the functioning of the different parts. What characteristics are important in designing a candle?

9-4

Candle Experiment Notes

Equipment: simple wax candle (e.g., Rokeach Shabbos candles), laboratory measuring equipment (e.g., scale and ruler), matches. For additional investigations: clothespin, 8mm x 8cm glass tube, square of white cardboard, copper wire (16 gauge or heavier), various potential wick materials (thread, toothpick, matchstick, yarn, braided picture wire, copper wire), aluminum foil

Procedure: Class contest: students work individually with candle and matches and lab equipment; each seeks to make as many observations as possible. Share and compare at end of class.

Further experiments (Experiment 4a) should lead to an understanding of the function of each component of the candle and the role of each section of the flame. These can be assigned as homework or carried out in class on the second day.

Introducing the Experiment: Since most students, certainly students who have attended a Waldorf lower school, will have seen many candles, some preparation is needed to stimulate interest and allay fears of simple repetition of previous work. An introduction may include:

> The fact that at each level of study, the first item on the agenda is to review (briefly) what the students have already learned in the last school: in high school, a review what was learned in the lower school, quickly filling in gaps; in college, a review of their high school chemistry program in perhaps the course of one week; in graduate school, a quick review of undergraduate work.

> Crucial to any study is careful observation and the recording of these observations in a notebook. Refer to Michael Faraday, for example.

> Even today no one understands everything that is happening in a burning candle. A series of lectures by Faraday on the candle is still in print today! (Show a copy.)

Note: This experiment is the first one in the *Laboratory Manual for Chemistry*: *An Experimental Science*, W.H. Freeman, 1963. "A Description of a Burning Candle" is in the Teachers' Guide. "Further Investigations of a Burning Candle" is Experiment 4a in the Laboratory Manual.

Products of Combustion
Demonstration of the products of combustion and of breathing is easily accomplished with lime water and cobalt chloride paper. Students blow through a straw into lime water and onto a cold surface, such as a window pane in winter or a beaker filled with ice water. Candle fumes condense on a cold surface and can be collected in a jar, then set right side up, lime water introduced, and, covered by a glass plate, shaken.

9-5

Scientific Observation and Description

Everyone thinks of her- or himself as a good observer. Yet there is much more to observation than meets the eye. It takes concentration, alertness to detail, ingenuity, and often just plain patience. It even takes practice! Try it yourself. See how complete a description you can write about a familiar object – say, a burning candle. Be "scientific" about this and start with an experiment. This means you should observe a burning candle in a laboratory, that is, in a place where conditions can be controlled. But how do we know what conditions need be controlled? Be ready for surprises here! Sometimes the important conditions are difficult to discover. But an experiment can be meaningless unless the conditions that matter are controlled. Here are some conditions that may be important in some experiments but are not important here.

- The experiment is done on the second floor.
- The experiment is done in the daytime.
- The room lights are on.

Here are some conditions that might be important in your experiment:

- The lab bench is near the door.
- The windows are open.
- You are standing close enough to the candle to breathe on it.

Why are these conditions important? Do they have something in common? Yes. A candle does not operate well in a draft. Important conditions are often not so easily recognized as these. A good experimenter pays much attention to the discovery and control of conditions that are important.

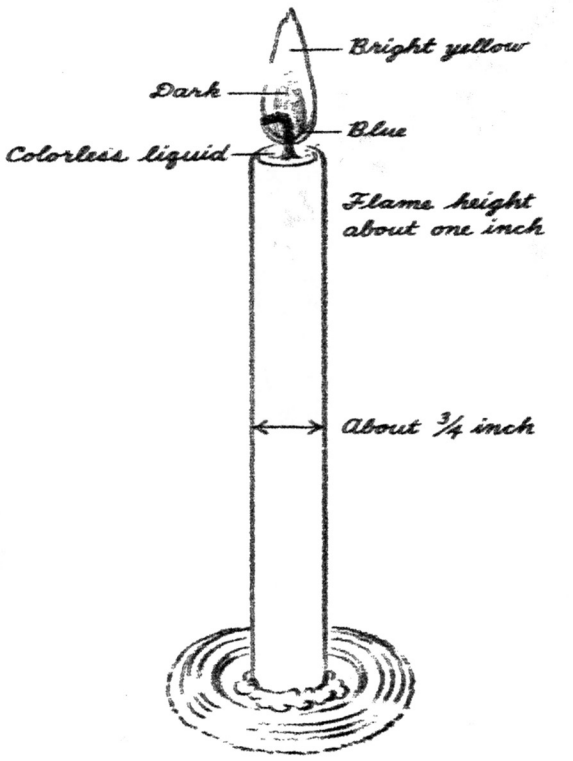
Procedure: First examine the candle carefully. Then light it and record in your notebook as many observations as you can during a short period (10–15 minutes). Turn in your observations to your teacher before you leave the laboratory.

Write a description of a burning candle, based upon your list of observations and upon any additional observations of buring candles you care to make later at home.

9-6

Description of a Burning Candle

Here is a drawing of a burning candle. The candle is cylindrical in shape and has a diameter of about ¾ inch. The length of the candle was initially about 8 inches and it changed slowly during observation, decreasing about ½ inch in one hour. The candle is made of a translucent, white solid which has a slight odor and no taste. It is soft enough to be scratched with the fingernail. There is a wick which extends from top to bottom of the candle along its central axis and protrudes about ½ inch above the top of the candle. The wick is made of three strands of string braided together.



A candle is lit by holding a source of flame close to the wick for a few seconds. Thereafter the source of flame can be removed, and the flame sustains itself at the wick. The burning candle makes no sound. While burning, the body of the candle remains cool to the touch except near the top. Within about ½ inch from the top, the candle is warm (but not hot) and sufficiently soft to mold easily. The flame flickers in response to air currents and tends to become quite smoky while flickering. In the absence of air currents, the flame is of the form shown in the illustration aboe, though it retains some movement at all times.

The flame begins about ½ inch above the top of the candle, and at its base the flame has a blue tint. Immediately around the wick in a region about ¼ inch wide and extending about ½ inch above the top of the wick, the flame is dark. This dark region is roughly conical in shape. Around this zone and extending about ½ inch above the dark zone is a region which emits yellow light, bright but not blinding. The flame has rather sharply defined sides, but a ragged top. The wick is white where it emerges from the candle, but from the base of the flame to the end of the wick, it is black, appearing burnt, except for the last 1/14 inch where it glows red. The wick curls over about ¼ inch from its end. As the candle becomes shorter, the wick shortens too, so as to extend roughly a constant length above the top of the candle. Heat is emitted by the flame, enough so that it becomes

uncomfortable in ten or twenty seconds if one holds one's finger ¼ inch to the side of the quiet flame or 3 or 4 inches above the flame.

The top of a quietly burning candle becomes wet with a colorless liquid and becomes bowl-shaped. If the flame is blown, one side of this bowl-shaped top may become liquid, and the liquid trapped in the bowl may drain down the candle's side. As it courses down, the colorless liquid cools, becomes translucent, and gradually solidifies from the outside, attaching itself to the side of the candle. In the absence of a draft, the candle can burn for hours without dripping. Under these conditions, a stable pool of clear liquid remains in the bowl-shaped top of the candle. The liquid rises slightly around the wick, wetting the base of the wick as high as the base of the flame.

Several aspects of this description deserve specific mention. Compare your own description in each of the following characteristics:

(1) The description is comprehensive in qualitative terms. Did you include mention of appearance? small? taste? feel? sound? (Note: A chemist quickly becomes reluctant to taste or smell an unknown chemical. A chemical should be considered to be poisonous unless it is known not to be!)

(2) Wherever possible, the description is stated quantitatively. This means the question "How much?" is answered (the quantity is specified). The remark that the flame emits yellow light is made more meaningful by the "how much" expression "bright but not blinding." The statement that heat is emitted might lead a cautious investigator who is lighting a candle for the first time to stand in a concrete blockhouse one hundred yards away. The few words telling him "how much" heat would save him this overprecaution.

(3) The description does not presume the importance of an observation. Thus the observation that a burning candle does not emit sound deserves to be mentioned just as much as the observation that it does emit light.

(4) The description does not confuse observations with interpretations. It is an observation that the top of the burning candle is wet with a colorless liquid. It would be an interpretation to state the presumed composition of this liquid.

9-7,8

Further Investigations of a Burning Candle

As you investigated the burning candle, no doubt many unanswered questions came to mind. Perhaps there are other questions for which you have been able to find satisfactory answers. The purpose of this experiment is to help you to find clues that will enable you to postulate answers to some of the unanswered questions. As you perform the experiments outlined below, keep thinking about possible answers to the following:

- Why is the flame blue at the base, dark in the center, and yellow elsewhere?
- What is the purpose of the wick in a candle?
- Why is it possible to extinguish a candle flame by blowing on it?
- Why is the flame shaped as it is?

Procedure:

1. Using a clothespin for a clamp, hold a piece of glass tubing about 8cm long and 8mm diameter in the flame of a burning candle so that one end of the tubing is well within the inner dark part of the flame. After holding the tubing steadily in this position for a few seconds, hold a lighted match to its outside end. (See Fig. 4a-1) Record your observations.

2. Hold the same piece of glass tubing in the upper bright part of the flame and again hold a lighted match to its outside end. Record your observations.

3. Light a candle and allow it to burn for about half a minute. With a lighted match in hand, quickly blow out the candle and hold the match about an inch from the wick in the column of "smoke" emanating from the wick. See Fig. 4a-2. Record your observations.

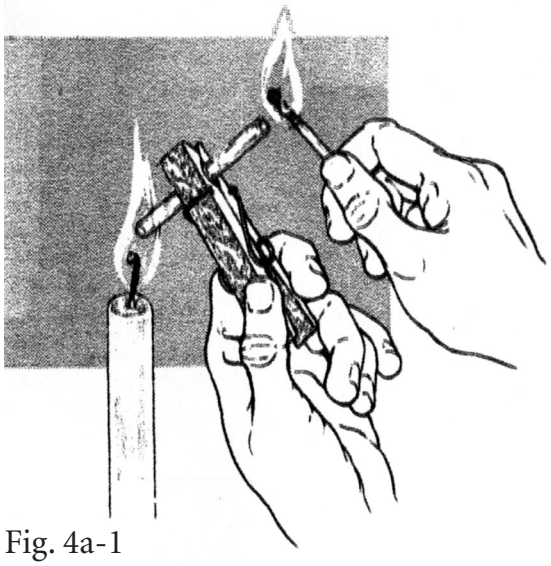


Fig. 4a-1

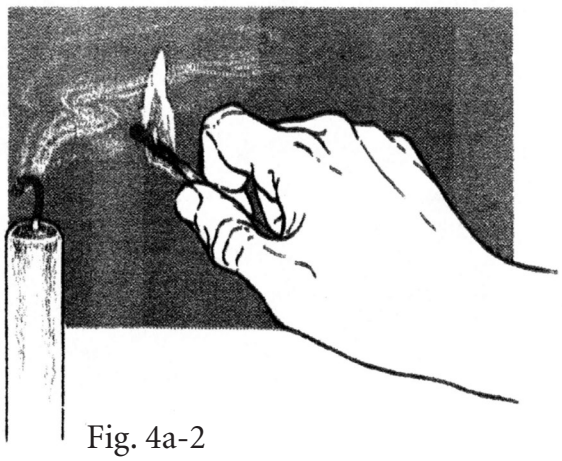


Fig. 4a-2

4. Move a horizontally-held piece of white cardboard quickly down over the flame of a burning candle to the position shown in Fig. 4a-3. Hold the cardboard in this position just long enough for the flame to scorch through to the upper side of the cardboard but not long enough to cause it to burst into flame. Note the pattern of the scorched area.

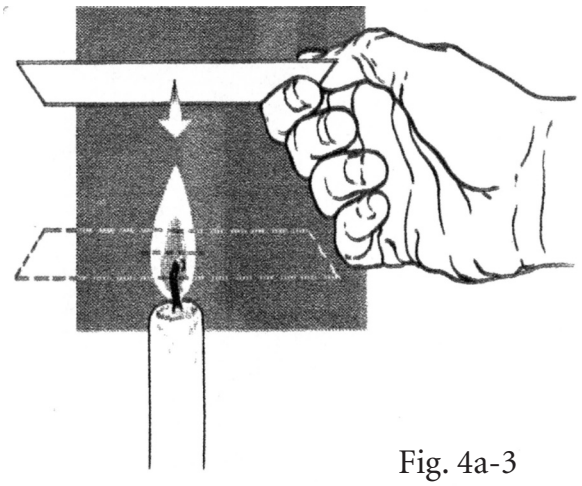


Fig. 4a-3

5. Try lighting some candle wax without the wick. Try lighting wick material such as a piece of string without the candle material. Try several different materials as wick materials by sticking them into the side of your candle (as shown in Fig. 4a-4): a toothpick, a paper matchstick, a piece of yarn, braided picture wire, a piece of copper wire, a piece of string. Try your best to make each "wick" function properly. What are some of the necessary properties for wick materials?

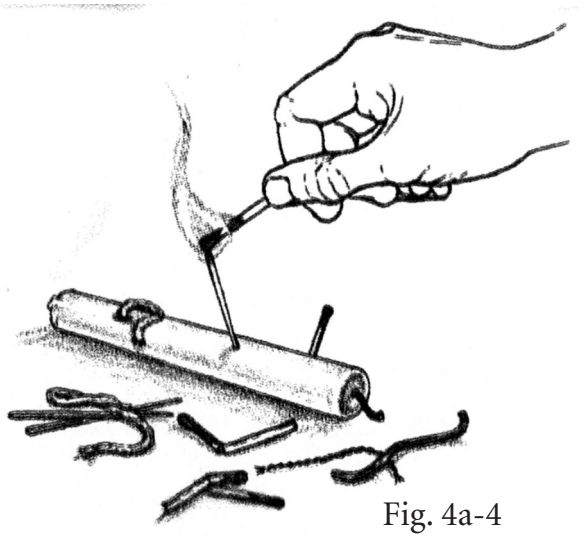


Fig. 4a-4

6. Scrape some "soot" from the piece of glass tubing used earlier into the liquid in the bowl of a burning candle. Observe the motion of these particles in the liquid. (See Fig. 4a-5)

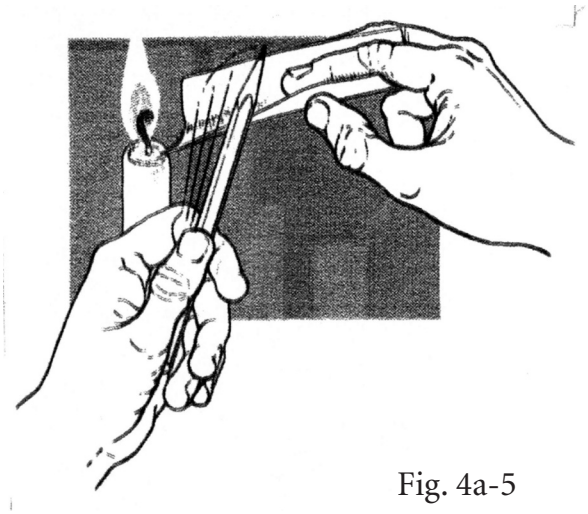


Fig. 4a-5

7. Wind a length of copper wire (16 gauge or heavier) around a pencil about ten times, leaving enough uncoiled to serve as a handle. Slip the coiled wire off the pencil and lower it into the candle flame as shown in Fig. 4a-6. Record your observations.

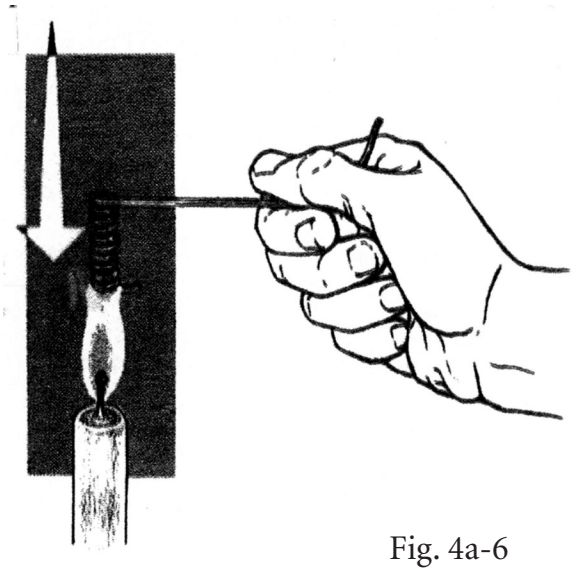


Fig. 4a-6

8. Slide a horizontally-held piece of slotted aluminum foil around the wick just below the base of the flame and above the melted wax as shown in Fig. 4a-7. Leave the aluminum in place for about 30 seconds. Account for the observed results.

9. Using a medicine dropper, place 1 or 2 drops of water on the molten wax in the bowl of the lighted candle. What happens?

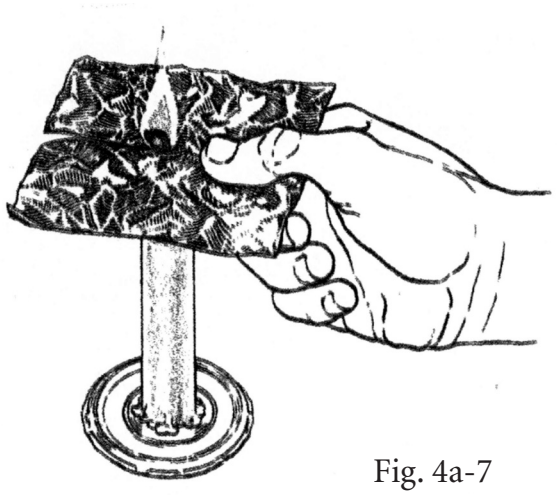


Fig. 4a-7

QUESTIONS and EXERCISES

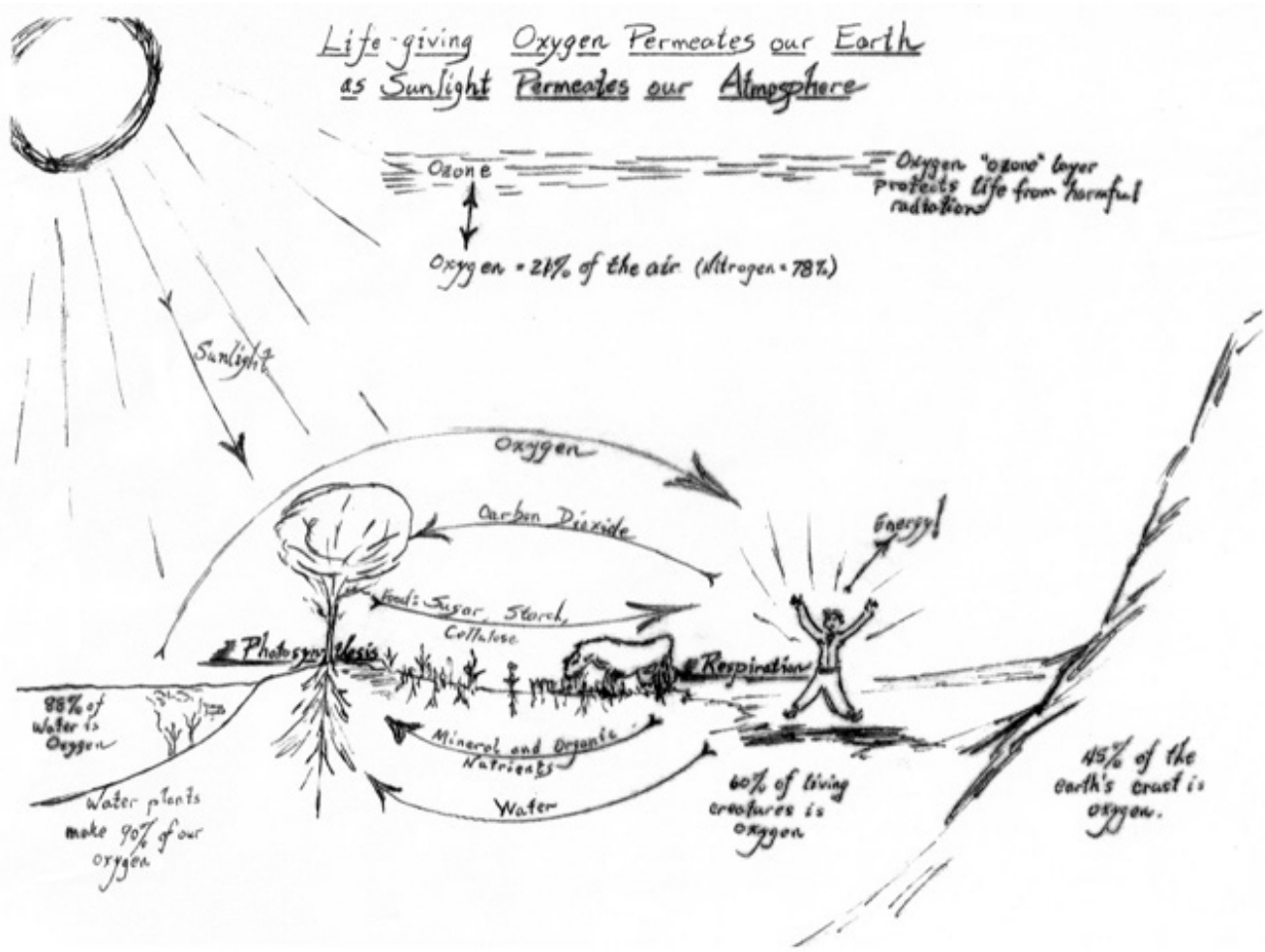
1. Will a candle of larger diameter produce a larger flame? How can you construct a candle so that it will produce a larger flame? Test your hypothesis by experiment.

2. List as many of the necessary properties of a good wick material as you can.

3. Write a paragraph describing what you think is taking place within the candle flame. Justify your arguments with experimental evidence. Propose "answers" to as many of the introductory questions as you can.

A Question to Wonder About: How is the solid wax, which is composed of carbon and hydrogen, transformed into the products of combustion?

Oxygen Cycle



Percent Carbon in Glucose

Experiment: Percent Carbon in Glucose and The Formula for Glucose

Purpose: to determine the formula for glucose

Background: We know from the experiment of adding concentrated Sulfuric Acid to sugar that when water is removed from sugar, carbon remains. If we do this carefully, measuring the sugar and carbon residue, we can calculate the water removed and the ratio of water to carbon in the sugar. From other experiments it is known that the relative mass of water, H_2O, in compounds, where Hydrogen is assigned the relative mass of 1, is 18 and that of Carbon is 12. If we divide the masses of Carbon and Water in the experiment by their respective formula masses, we can find the ratio of Carbon to Water incorporated in the glucose and obtain a simple empirical formula for glucose. From other experiments (cf. 10^{th} Grade Chemistry) we know that the relative mass of the glucose formula itself is 180. So we can then find the actual formula for glucose.

Equipment: balance, Bunsen burner, small test tube (A 100 ml beaker can be used instead of the test tube, together with ring and ring stand.), test tube holder, Cobalt Chloride paper

Material: glucose

Procedure:

1. Weigh test tube.
2. Add about 1 to 2 cm glucose to test tube.
3. Weigh test tube with glucose.
4. Heat, slowly driving off water, but not so strongly as to also drive off carbon. Test the gas coming off with Cobalt Chloride paper to check for water.
5. Allow to cool and reweigh.

Calculations:

1. Mass of glucose
2. Mass of carbon residue
3. Mass of water driven off

Further calculations to find the experimental values for glucose:

4. Percent Carbon in glucose
5. Percent water, H_2O, in glucose
6. Relative units of Carbon in glucose
7. Relative units of water, H_2O, in glucose
8. Approximate ratio of (6) to (7), the ratio of units of glucose to water.
   (Note: While 6 and 7 depend on the amount of glucose used, 8 does not.)
9. Empirical formula for glucose
10. Empirical formula weight for glucose
11. Accepted formula for glucose

Discussion:

Some glucose was lost during heating. It could be smelled (caramelized sugar smell)
Some carbon burned at the end.
However the relative masses found for carbon and waer were very close to the acceted value, 1.0.

Percent Carbon in Glucose: Notes

> If done carefully a value for the ratio of carbon to water can be obtained close to 1.0. However heating too fast can drive off some carbon with the water. And insufficient heating, that is, stopping the experiment too soon, can result in leaving some water behind. Also the total heating time can easily run beyond one period. So it is probably best to do this as a class experiment or demonstration.

> The "caramel" smell is due to a wide variety of complex organic substances. Although carbon is the final result of heating, the initial darkening is not due to carbon, but to these complex substances.

> Sample Results:

Data:

Mass of beaker. 51.1 g
Mass of beaker and glucose: 64.0 g
Mass of beaker plus residue (mostly carbon) 55.8 g

Calculations:

Mass of glucose. 64.0 g
- 51.1 g
12.9 g

Mass of Carbon residue: 55.8 g
- 51.1 g
4.7 g

Mass of water driven off: 64.0 g
- 55.8 g
8.2 g

%Carbon in glucose: $\frac{4.7\text{ g}}{12.9\text{ g}} \times 100 = 36.4\%$

%H_2O in glucose: $\frac{8.2\text{ g}}{12.9\text{ g}} \times 100 = 63.6\%$

Relative units C: 36.4 : 12 = 3.64

Relative units H_2O: 63.6 : 18 = 3.53 The ratio is very close to l, namely, 1.03 = 1.0

The empirical formula for glucose is one part C to one part H_2O: CH_2O or some multiple of this.
(CH_2O is the formula for formaldehyde, a highly poisonous substance.)

The empirical formula weight (mass) is 12 + 2 + 16 = 30.

The actual formula weight/mass is 180, 6 times larger.

Thus the actual formula for glucose must be 6 times CH_2O or $C_6H_{12}O_6$.

9-12

Experiment: Fermentation

Preparation of Ethyl Alcohol (Ethanol) and Acetic Acid

Equipment: 250 ml Erlenmeyer flask, glass bend, one-hole stopper, rubber tube, glass tube, 250 ml beaker

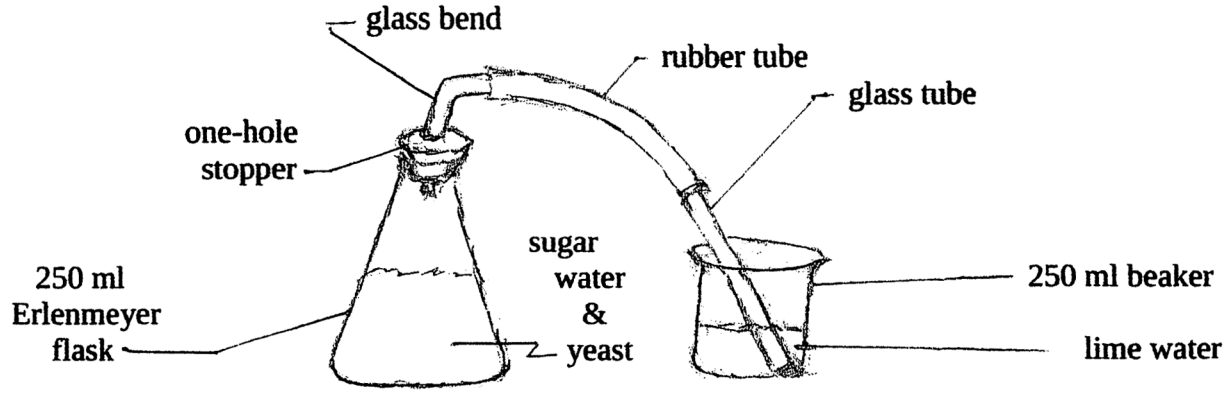
Materials: fruit juice or sugar, yeast, lime water

Approach: This experiment is done in two stages. The first stage involves mixing yeast with a sugar solution and establishing an "air lock," which keeps oxygen from getting to the mixture while the yeast is "working." Another flask is left open to the air to see the full oxidation. Students will use a selection of fruit juices and sugars and compare the results.

When the yeast has completed its work, the alcohol solution will be distilled to separate it from the water. This separation is not complete, depending as it does on the difference in boiling points of alcohol and water. (Ethanol boils at 78°C or 173°F.) The water can also be separated by freezing the solution, since alcohol has a lower freezing point (-173°F or -l14°C).

Procedure:

1. For juice simply pour about 150 ml into a 250 ml flask, that is, make it about half full. For sugar, molasses, honey, etc., dissolve about 1 to 2 tablespoonfuls in about 150 ml water and pour into a 250 ml flask.
2. Add one teaspoon yeast or about half a package and stir in.
3. Assemble the apparatus shown below.
4. Label with the sugar or juice used and set aside. Observe daily.



Experiment: Distillation of Ethanol

Oxidation of Ethanol
Ethanol (ethyl alcohol) is converted (oxidized) to acetic acid in the presence of oxygen in the air by the bacteria, "bacterium aceti," which is known as "mother of vinegar." This process may be very slow, but can be sped up by aeration, the addition of more bacteria, and by warming up to a temperature as high as 40°C or about 100°F.

Make note of any differences between the closed and the open flasks. Compare the smell as well as the appearance. If available, add some "mother of vinegar," a gelatinous mass which grows as vinegar forms. Continue to make observations periodically until the end of the block.

Distillation of the Mash
Of the two kinds of distillation, fractional and "pot," we will use the latter.

Procedure:
1. Examine your mash. Smell, taste, observe any changes which have taken place. Also observe the results of other students' fermentation.

2. Assemble the apparatus shown below. If a water spigot is available as a source of flowing water, use it as your water source. If not, a funnel can be used. The water must flow slowly to avoid bursting the connections. Note that water flows in at the end of the condenser. Pour mash in through a funnel and stopper the top of the flask. When apparatus is assembled, you may begin heating and letting the water flow.

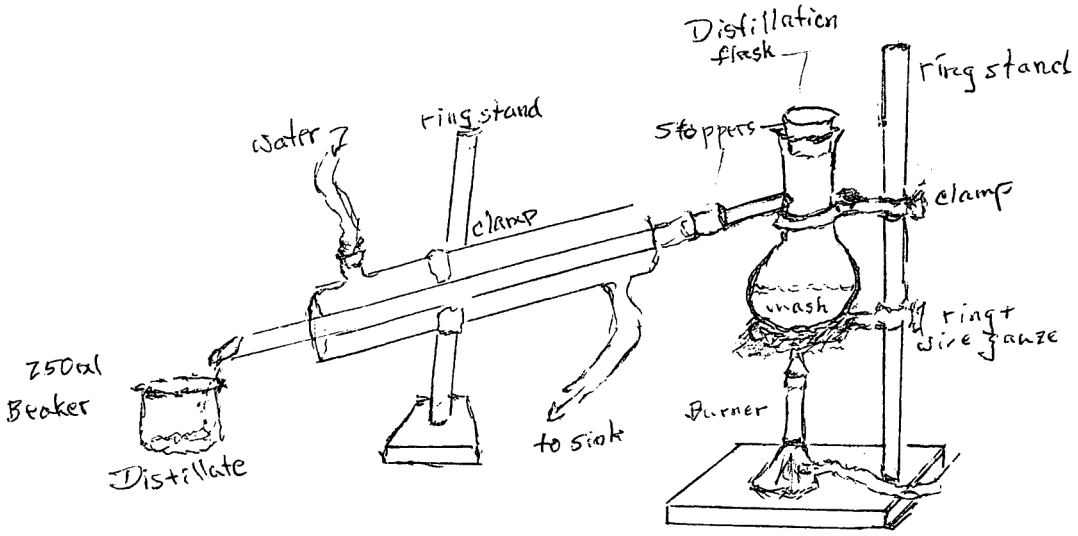
Caution! Do not bring any fire near the exit from the distillation tube! Alcohol is flammable and it will be mixing with air, causing a combustible or explosive mixure! Limit fuel to your Bunsen burner when heating the mash. Alternatively, the flask may be heated by a concave heater designed to heat flasks. This avoids the danger posed by open flames.

3. Note the smell and feel to the finger of the distillate, the liquid which emerges from the condenser, and compare with the mash. Do not boil off all the mash! You wish to separate the ethanol, which will come off preferentially. The concentration of ethanol in the mash will gradually diminish, and the distillate will contain more water. (Why?)

4. Turn off burner and water. Then try to ignite the distillate. If you have enough distillate, you can carry out a second distillation and try to burn that distillate. Mixing the first run with that of other students' will produce sufficient quantity for a second distillation, which should burn.

Questions:

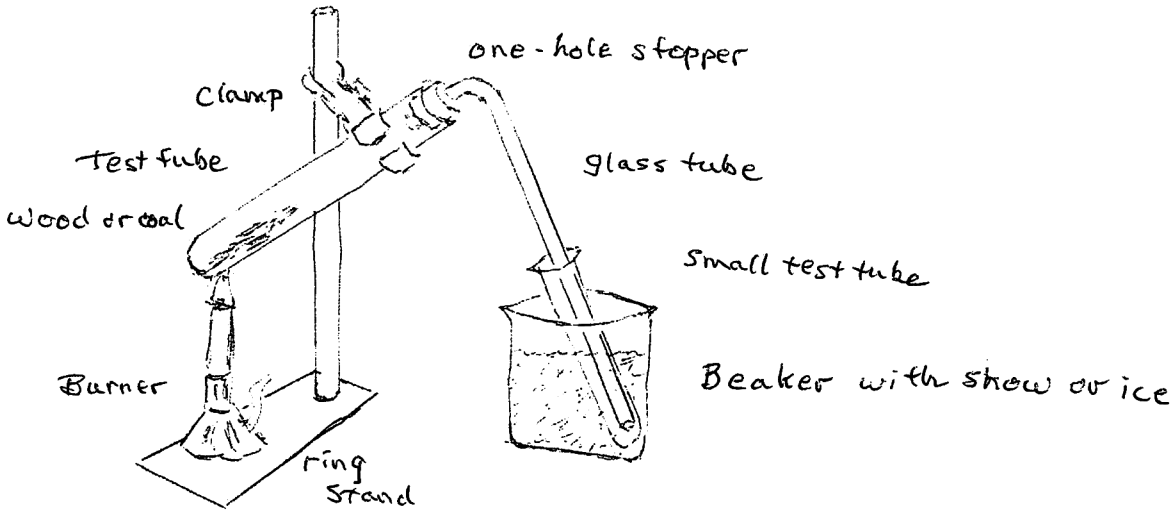
1. Explain why it is possible to separate ethanol from water by this procedure. Why is the process incomplete?
2. Write equations for the following chemical reactions:
   a) conversion of glucose to ethanol
   b) oxidation of ethanol to acetic acid
   c) combustion of ethanol



Destructive Distillation

Destructive distillation is easily carried out using the apparatus shown below. The beaker may be filled with snow or ice water. The distillate should also be tested for water using cobalt chloride paper. Students should also notice the smell of the vapors. They are flammable, demonstrated by lighting the gases escaping from the end of the glass tube. Because air is kept out, the wood cannot burn. The residue in the test tube is black and is known as charcoal, which the students have used or will use in art class. The vapors include wood alcohol (methyl alcohol or methanol), acetic acid (as in vinegar) and acetone (found in airplane glue.) The smell may remind students of some of these substances. The smell often reminds one of burnt marshmallows. Remove the charcoal and demonstrate its use.

Coal can also be distilled in the same way using another set of equipment. The result is "coke," used in refining iron ore to make steel. The change is not as dramatic as in charcoal and not readily useful for the students.



9-15

Soap

Procedure:

1. Prepare a mold. A petri dish with a plastic liner works well, or a small cardboard box, also a paper cup.

2. In a small beaker weigh out 12 grams of lye ("Drano"), sodium hydroxide = NaOH *Caution: Do not touch the lye. It will burn you.* If it gets on your skin or clothes, wash it off with water immediately.

3. Under the hood or in a ventilated area, add 30 ml of water to the beaker of lye. Stir gently until all lye is dissolved. Allow to cool. *Caution: Do not breathe the fumes. They are highly caustic!*

4. For your fat/oil, use one of the following recipes. Each is the amount for 12 grams of NaOH.

   A. 76 grams lard

   B. 30 grams lard and 50 grams olive oil

   C. 83 grams olive oil

   D. 30 grams lard plus 35 grams coconut oil

   E. 18 grams coconut oil, 25 grans olive oil, and 30 grams lard

   Note: Peanut oil can be substituted for the lard, 1:1

5. Warm the fat/oil to between 34–35°C (95–98°F) ("lukewarm"). Both lye solution and fat should be at this temperature.

6. With both ingredients at the proper temperature, mix the lye into the fat by pouring in the lye slowly and with constant stirring. Continue stirring until the soap is thick like pea soup or sea-foam candy.

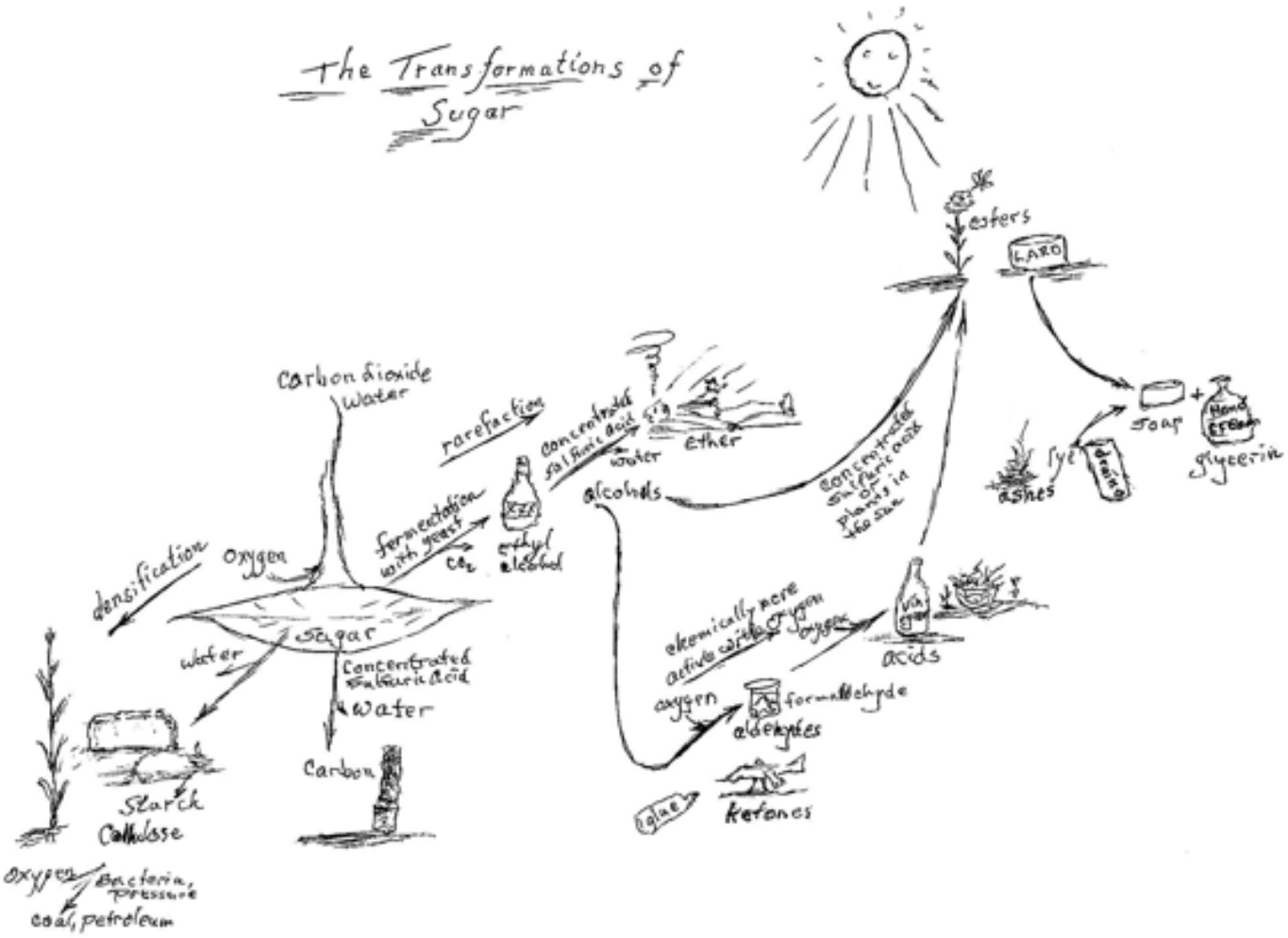
   Note: If you do not pour slowly and stir constantly until the mixture thickens (that is, reacts), you will have a mixture of three layers: fat, soap and lye!

7. Add color or scent if desired.

8. Pour the soap into the mold. Cover and allow the soap to cure for at least one day, better for a few days. Do not touch the soap for several days because the reaction is still continuing. If you must touch it, wash your hands afterward.

9. Wipe out containers with paper towels and clean up with detergent.

Transformations of Sugar



9-17

Notes on Transformations of Sugar (Glucose)

The initial product of photosynthesis, glucose, is transformed by nature and by humans in two directions: densification, leading to starch for nutrient storage and to cellulose for the hardening structure of the plant world, and, with time and bacteria and pressure, to petroleum family and to lignite and coal.

In the other direction the initial glucose is gradually simplified, losing the balance which it had in sugar.

The first loss is of carbon dioxide. Since the carbon gives sugar its structure, this loss leads to a loss of control when it is consumed, allowing another spirit to take over. This is recognized in our vocabulary, for ethanol is also called "spirits."

A further loss of some water means a decrease in liveliness as well, thus a loss of consciousness with ether (di-ethyl ether).

When a little oxygen is added to an alcohol, an aldehyde is produced, useful in glue, but also poisonous.

Oxidized further, organic acids are produced, such as vinegar and formic acid (in ants).

When these acids are reunited with the alcohol from which they came, they produce the lovely aromas in flowers, the esters. These are oils, which, together with lye, a product of burning wood, make soap and glycerin, and we end the process with natural cleansers.

Experiment: Chromatography of Food Colors

Equipment: 250 ml Erlenmeyer flask, no-hole stopper, Whatman filter paper #1, capillary tubes

Materials: Food colors, water-soluble inks

Procedure:
1. Obtain a 9x12 cm rectangle of Whatman #1 filter paper. Handle the paper by the edge and avoid touching the center of the paper with our fingers.

2. About 1.5 cm from the bottom of the paper, along the side, mark with a pencil five (5) evenly spaced dots, with the outer two about 1 cm from the edges and the others about 1.5 cm apart.

3. As a developing chamber, use a 250ml Erlenmeyer flask. The neck of the flask will serve to hold the filter paper in a vertical cylinder during development. Pour a little water into the flask, to about ½ cm depth. Dry the neck of the flask, and stopper with a rubber stopper or cork.

4. Use capillary tubes to place very small drops of the different food colors on the spots, using one capillary tube for each color. (If capillary tubes are unavailable, the dropper on the food color bottle may substitute.) On the fifth spot place a drop of an unknown mixture of food colors supplied by your instructor. Record the sequence of spots in your notebook so you will not forget which is which. Before applying the spots it is a good idea to practice on a scrap of filter paper. The spots should spread to no more than 1 mm in diameter.

5. Curl the paper into a cylinder with the long sides butted together and the line of spots around the bottom end (on the inner surface). Line up the edges evenly at the bottom end and hold the cylinder together with a small square of masking tape inside the upper end and projecting a little above the paper with the sticky side out.

6. Insert the cylinder into the neck of the flask and push it down until the spotted end is just immersed (all the way around) in the water. Press the tape against the neck, cork the flask, and allow the development to proceed until the solvent (water) front has reached to within a few cm of the top of the paper.

7. Remove the paper from the flask and mark the solvent (water) front with a pencil. Allow to dry and mount in your seminar book.

8. Further experiment: Carry out a similar experiment with samples of ink, such as black, blue, red… Which are pure substances? Which mixtures?

QUESTIONS:

1. Which of the food colors tested are pure substances? How can you tell?

2. What was the composition of the "unknown"? Explain how to test a sample food color to tell what substances are present.

3. Compare the rate (speed) at which the different food colors (substances) moved up the filter paper. Did they move at the speed of the solvent (water)? Explain how a color-blind person could identify the unknown.

9-19

Chromatography of Natural vs Refined or Artificial Substances

see Grade 12 Appendix, p. 78

Experiment: Chlorophyll

Equipment: mortar and pestle, 250 ml Erlenmeyer flask and stopper, Whatman #1 filter paper

Materials: sample of chlorophyll or plant leaves (such as spinach)

Procedure:
1. If you are working with plant leaves, they must be first crushed with a mortar and pestle. Use vigor! The leaves must be thoroughly mashed. The mash needs to be boiled in ethanol to break the cell walls and extract the chlorophyll. Continue to boil until the extract has been concentrated.

2. Add acetone **under the hood** to a depth of about 1 cm, covering the crushed plant material. (Acetone is the main ingredient in nail-polish remover.)

> ***Use no fire or matches when working with acetone;***
> ***it is flammable and can explode when mixed with air.***

3. Further crush and work the mash until thoroughly mixed with the acetone. The acetone is a good organic solvent, which works better than water with some organic substances.

4. Take a dry 250 ml Erlenmeyer flask and pour the mash into the bottom. Clean the neck and stopper.

5. Prepare a piece of Whatman #1 filter paper similar to the one used in the Food Color Experiment. You need not mark it. Curl and insert into the flask. Restopper and allow to develop until you obtain a clear separation or until the front has risen to within a few cm of the top.

6. When the chromatogram is ready, remove the paper.

7. Rinse all equipment containing acetone down the sink under the hood. Discard plant pulp in the trash. Use plenty of water so the acetone doesn't get into the room. Clean out the sink if plant materials get into it.

Question: From this experiment, what can you conclude about chlorophyll?

10th Grade Chemistry

After the explosive 9th Grade and its extremes, it is time to seek balance and equilibrium. Water forms the natural medium for this exploration, and is the element associated with the 10th Grade. Water is a very special substance, with properties which are essential for our life on earth. Water plays a balancing or mediating role in major chemical processes: dissolving and crystallizing or precipitating, acids and bases, positive and negative ions. Water is the mediator in these dynamic equilibria. In the context of exploring these processes, it is convenient to introduce several important chemical concepts: Le Chatelier's Principle, the Second Law of Thermodynamics, positive and negative charges, moles and molarity.

References

Bentley, W.A. and W.J. Humphreys, *Snow Crystals*
Davis, Kenneth S. and John Arthur Day, *Water: the Mirror of Science*
Garrett, Alfred B. *Chemistry*
Holden, Alan and Phylis Morrison. *Crystals and Crystal Growing*
Schwenk, Theodor. *Sensitive Chaos*
"Water. Our Thirsty World," *National Geographic,* Special Issue, April 2010
Wilkins, Andreas, Michael Jacobs and Wolfram Schwenk, *Understanding Water*

Course Outline

Water. Properties and importance
Experiment: Solubility and temperature with potassium nitrate
    LeChatelier's Principle
NaAc experiment: unsaturated, saturated, supersaturated solutions.
    Static and dynamic equilibrium
    Exothermic and endothermic reactions
    Spontaneous changes. enthalpy, energy, entropy, the Second Law of Thermodynamics
The electrolysis of water
    Laws of electrostatics
Relative weights/masses in chemistry. Atomic weights/masses
    Gram formula weight/mass, mole, molarity, molality
Conductivity of solutions: water, sugar water, salt water
Electrolytes and non-electrolytes

Boiling point and freezing point changes of solutions
Arrhenius and the ionization theory
Acids and bases. Indicators
Ionization of water, Kw, pH
Cells and Batteries, Electroplating
Poetry: Shelley, "Ozymandias" or "The Cloud"
"Poem of the Swampy Creek Indians"
Song: "Cool Water"

Opening Demonstration

Prepare equally concentrated muriatic acid (HCl) and lye (NaOH) solutions, mix measured equal amounts and sip. Offer to class members. Show danger signs on bottles.

Teaching the Block

Water

Gesture of water, necessity for life, contributions to life on earth, special or unique properties.
Oxygen, essential for life; hydrogen, element closest to fire
Ice, contribution to geology, aquatic life. Crystals, snowflakes
Homeostasis, global warming, pollution
Demonstrations and experiments: many suggestions in Wilkins, et al.

Dissolving and Crystalizing

Crystals in nature, crystal growing. Students may have grown crystals in the lower school. If not, they could grow them. A demonstration may be sufficient. Introduce dynamic equilibrium.
Solubility curve of KNO_3 as group experiment. Could be omitted if time is short, but produces a very nice curve, is a satisfying group experiment, and serves as background to the next experiment.

Solutions and mixtures: unsaturated, saturated and supersaturated solutions

NaAc experiment: individual student experiment
The results are dramatic. The cooling on dissolving and warming on crystallizing are clear.
Can you sense the pain of the sharp crystals growing?
The stress of the supersaturated solution is relieved by crystallizing a portion of the solute.
The mixture of salt and water is more orderly, yields to disorder of a solution at higher temperature. Cooling shifts the equilibrium back to the orderly condition.
Exothermic and endothermic reactions, enthalpy, entropy, LeChatlier's principle

Measurements in Chemistry
Relative masses ("atomic weights"), molecular, formula weights
Measuring Concentration of solutions: percent, mole, molarity, molality
These concepts are necessary prior to proceeding further with solutions, acids and bases...

Electrolytes and Non-electrolytes: Electricity and Solutions
Review of laws of electrostatics
Electrolysis of water. Properties of oxygen and hydrogen
Conductivity of solutions. distilled water, tap water, salt, sugar
Boiling and freezing point changes. Class experiment using various salts and concentrations
Arrhenius' life and his theory of ionization
Measurement of molecular mass could be done as extra experiment by interested students

Acids and Bases, Indicators
Properties of common acids and bases. Character, examples
Student experiment: compare various common acids and bases for feel, smell, taste (very dilute, touch tongue, rinse mouth thoroughly)
Demonstration: Universal indicator from pH 14 to 0 using NaOH and HCl, diluting 1M solutions stepwise (l, 2, ...14, 13...)
Student experiment: Titration (if time and equipment permit)
Strong and weak acids and bases, ionization of water, pH, indicators.
If time permits, buffers

Cells and Batteries
Examples. lemon, dry cell, car battery, electroplating demonstration

Industrial Tours

Electroplating plant, water purification plant, paper manufacturing

Appendices

10-1 Ozymandias
10-2 Experiment: Crystal Growing
10-3 Experiment: Solutions and Spontaneous Changes
10-4 Experiment: Freezing and Boiling Point Changes
10-5 Masses for Freezing and Boiling Point Changes
10-6 Experiment: Acids and Bases
10-7 Experiment: Titration

Ozymandias

Percy Bysshe Shelley

I met a traveler from an antique land
Who said: "Two vast and trunkless legs of stone
Stand in the desert. Near them, on the sand,
Half sunk, a shattered visage lies, whose frown,
And wrinkled lip, and sneer of cold command,
Tell that its sculptor well those passions read
Which yet survive, stamped on these lifeless things,
The hand that mocked them, and the heart that fed:
And on the pedestal these words appear:
'My name is Ozymandias, king of kings:
Look on my works, ye Mighty, and despair!'
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away."

10-2

Experiment: Crystal Growing

Materials:

Here are three recipes for making saturated solutions:

(1) Potassium Aluminum Sulfate (alum, potash alum, kalinite) $KAl(SO_4) \cdot 12H_2O$
Dissolve 70 grams salt in 350 ml (grams) water.
(Solubility: 11.4g/100g water at 20°C, oo in hot water

(2) Potassium Chromium Sulfate (chrome alum) $KCr(SO_4) \cdot 12H_2O$
Dissolve 150 grams in 300 ml (grams) water.
(Solubility: 24.4g/100g water at 25°C, 50g/100 g water in "hot" water

(3) Copper Sulfate (blue vitriol, chalcanthite) $CuSO_4 \cdot 5H_2O$
Dissolve 200 grams in 250 ml water.
(Solubility: 31.6 g/100 grams water at 0°C, 203.3 g/100g water at 100°C)

Procedure:

I. Preparation of the growing solution and the seed crystal

1. Mix the prescribed salt and water in a large beaker, and heat until all salt has dissolved.
2. Cover tightly with plastic wrap and rubber band and allow to cool to room temperature.
3. Remove cover and seed with salt dust or small crystals. A pinch will do.
4. Seal and let stand for 2 days, shaking or stirring once or twice a day.
5. Pour about 30 ml of the resulting saturated solution into a 1000 ml beaker and leave open to the air to evaporate. Seed crystals will grow. If they do not, seed the solution.

(The process may be speeded by using some of the supersaturated solution from step 2, but the crystals may not be as good.)

II. Growing the crystals

1. Pour off the saturated solution into a clean beaker, leaving all crystals behind. Leave the beaker with excess crystals to dry so they may be returned to the stock jar later.
2. Choose a seed crystal and tie a thread around it with a slip knot.
3. Make a wire cobra to hold the crystal and suspend the crystal from the cobra. Neither cobra nor thread may protrude above the solution surface, so make the top of the cobra well below the surface.

4. Heat the saturated solution to a degree or two above the growing temperature, stir with thermometer to equalize temperature.
5. Place seed and cobra in solution and cover tightly with cheesecloth cover to keep dust out, holding cloth with a rubber band.
6. Do not disturb. Keep temperature as constant as possible. (Why?) Suggestion: Place in a pan of water or in the cellar.

III. Care of crystals

When removing crystal, dry immediately, handle little, and store in a sealed jar.

10-3

Experiment: Solutions and Spontaneous Changes

INTRODUCTORY NOTES

Many salts would serve as well as Sodium Acetate Trihydrate. This one has the advantages of being readily available, highly soluble and non-toxic. Also the solubility increases rapidly with temperature, thus producing striking changes upon adding a crystal to the supersaturated solution. And the enthalpy change, or heat of solution in this case, is comparatively large. (Much heat is absorbed with dissolving and released with crystallization.) The Heat of Solution is 4700 calories per gram, a comparatively high amount.

Students should note the temperature change on dissolving, which should be quite striking. Because the system, that is, water plus salt, is moving to a greater disorder or entropy, the tendency to seek a lower energy state, that is, to release heat, is overcome. It is actually no different than water evaporating on our skin on a hot summer's day, cooling us off. The result is a lower Free Energy of the system (Gibbs Free Energy, G). This is the Second Law of Thermodynamics, namely, that systems seek a state of greater disorder, that is, Entropy. The balance between this tendency and the tendency to release energy and go to a lower energy state determines the direction of a reaction:

$$\Delta G = \Delta H - T \Delta S$$

where G is the free energy (determining direction of the reaction), H is the enthalpy or heat released and S the entropy. The higher the Temperature, the more the tendency to disorder, since this term is multiplied by the temperature.

Students should feel the pain of the crystals growing, as they shoot through the solution, as ideas shooting through the brain.

EXPERIMENT

Purpose: To prepare and compare the different types of solution.
To explore the conditions for spontaneous changes to occur and the direction of these changes

Materials: Sodium Acetate Trihydrate, $NaC_2H_3O_2 \cdot 3H_2O$ or simply NaAc

Procedure:
1, To about 4 ml water in a test tube add a few crystals of Sodium Acetate Trihydrate, $NaC_2H_3O_2 \cdot 3H_2O$, or simply,NaAc. Shake until the salt dissolves. Do you believe that the solution is saturated? Add a few more crystals and shake again. Observe. Was the solution saturated or unsaturated? Is it now? How could you test? Observe the temperature change!

2. Add one or two crystals to the decanted liquid and shake one minute and observe. Did this crystal dissolve? What can you conclude about the state of saturation of the decanted solution?

4. Pour the solution back on the crystals and add 3 to 4 more grams of NaAc. Heat the tube gently until the salt completely dissolves. While heating, gently shake the tube to mix the contents thoroughly. Observe.

5. Stand the test tube in a beaker of cool water for about 5 minutes. Do not disturb it during this time. If crystals appear in the solution, reheat until they dissolve and again stand the test tube in cool water.

6. After the solution has cooled to about room temperature, hold the test tube in your hand (so you can note the solution's temperature and changes) and add one crystal of NaAc. Observe closely!

QUESTIONS
1. Define "saturated solution."

2. Why can a solution be called "saturated" even though more solute could be dissolved?

3. Explain how to prepare each of the following:
    a) an unsaturated solution of NaAc
    b) a saturated solution of NaAc
    c) a supersaturated solution of NaAc

4. Can you offer any reason for the temperature changes you observed? What is the relationship between the changes observed in steps 2 and 6? Can you offer any explanation for this relationship?

5. What change took place even though energy was absorbed? Explain in terms of order and disorder, that is, entropy.

10-4

Experiment: Freezing and Boiling Point Changes

Purpose: To explore the effect of a solute on the boiling point and freezing point of a liquid, in this case, water. To gain further understanding of what is happening when a substance dissolves, and why certain substances conduct electricity in aqueous solution and others do not. To better understand equilibrium, boiling points and freezing points.

Background: Certain substances conduct electricity when dissolved in water. They are known as electrolytes. Other substances do not conduct electricity (non-electrolytes). We have seen that acids, bases and salts conduct electricity in solution, but many organic compounds, such as alcohols, glycerin and sugars, do not. Solutes also change the boiling and freezing points of the solvent. If we find a connection between these two kinds of effects, it may help explain what is happening in solutions.

Approach: Each student will take one solute and make up a solution of known concentration. If the freezing point is to be investigated, a solution of 1 mole per 1000 grams water is made by dissolving 1/10 mole in 100 grams (100 ml) water, a 1 molal solution. If the boiling point is to be investigated, a 4 molal solution is made by dissolving 4/10 mole in 100 grams water. Individual results will be shared with the class.

Procedure:
1. Measure the required amount of solute for your case. See the table and do not use the formula weight, but 1/10 or 4/10 depending on whether it is the freezing or boiling point. Mix with 100 grams (100 ml) of water.

2a. Boiling point: Heat the solution to boiling (the solute will dissolve readily as you heat) and record the boiling point to the nearest 0.2°C (that is, record 102.2 or 101.8, not 102 unless it is 102.0). If time permits, double the amount of solute and find the new boiling point.

2b. Freezing point: Assemble an ice/salt bath for your 250 ml beaker. Mix crushed ice and salt in a 600 or 800 ml beaker. Or use a pan filled with crushed ice and salt. Place a 100 or 250 ml beaker into the ice/salt bath. Stir carefully with a thermometer and record temperature to the nearest 0.2°C when solution freezes. The freezing point occurs when a slush forms. If solution does not freeze after some time of cooling, it may be "supercooled," that is, the temperature has fallen below the freezing point due to lack of an ice nucleus (like a supersaturated solution). Add a small chip of ice. Note: There is no

need to use the whole solution you make up. But you must have all solute dissolved before you begin cooling.

Report all data to the class and record data from classmates.

Questions:
1. What is the effect of solutes on the freezing and boiling points? When the amount of solute was doubled, what happened to the change in freezing and boiling points?

2. Explain the action of anti-freeze both in keeping your radiator from boiling and/ or freezing. Explain why salt is used on icy winter sidewalks. Why is salt ineffective if the weather becomes too cold?

3. How do electrolytes differ from non-electrolytes in their effect on boiling and freezing points? How could this be explained?

4. If the solute is interfering with the solvent trying to change phase (freeze or boil), how does this explain the direction of the changes in boiling and freezing point? (We say that the solute lowers the "vapor pressure" of the solvent.)

NOTE: Be sure that some of the students test molecular solutes and some ionic, so that a comparison can be made.

10-5

Experiment: Masses for Freezing and Boiling Point Changes

Substance	Formula	Formula Weight/Mass (g)	Amount for Freezing Point	Amount for Boiling Point
Sodium Chloride	$NaCl$	58.5	5.8 g	23.4 g
Potassium Nitrate	KNO_3	101	10 g	40 g
Calcium Chloride	$CaCl_2$	111	11 g	44.4 g
Dextrose, anhydrous	$C_6H_{12}O_6$	180	18 g	72 g
Citric Acid	$H_3C_6H_5O_7 \cdot H_2O$	210	21 g	84 g
	or $HOC(CH_2CO_2H)_2CO_2H$			
Glycerol/Glycerin	$C_3H_8O_3$	92	9.2 g	36.8 g

Experiment: Acids and Bases

Materials: Nitric Acid, HNO_3 6M
Hydrochloric Acid, HCl
Sulfuric Acid, H_2SO_4 6M
Acetic Acid, $HC_2H_3O_2$ or CH_3COOH 6M

Orange juice, lemon juice, tomato juice

Sodium Hydroxide, NaOH 6M
Calcium Hydroxide, $Ca(OH)_2$ 0.1M (saturated)
Ammonium Hydroxide, NH_4OH 6M

Distilled water, red and blue litmus paper, phenolphthalein

Observations: Arrange your observations neatly in your notebook in a table like the following:

Solution	Taste	Touch	Smell	Color	Litmus test		Phenolphthalein
					Red	Blue	

Procedure

I. Acids:

1. Nearly fill each of three test tubes with distilled water. Add about 5 drops of dilute nitric acid (6M) to one test tube of water and label. Use the dropper provided with the reagent and KEEP EACH DROPPER NEXT TO ITS BOTTLE. DO NOT MIX DROPPERS AND REAGENT BOTTLES. CONTAMINATION WILL RUIN LATER EXPERIMENTS. Do the same with the other acids. Shake tubes thoroughly.

2. Notice how the solution feels on the fingers. Rinse following contact. If you don't detect anything, add a few more drops and rub between the fingers.

3. Do you detect an odor? Color?

4. Using a clean stirring rod to dip into the test tubes, taste each solution *cautiously*. Wash the mouth out each time with water. DO NOT SWALLOW. Record the taste of each solution.

5. Place a few drops of each acid solution first on blue litmus paper and then on red.

6. Take a few ml of phenolphthalein in a small beaker. Make it pink by the addition of a drop or two of a dilute base and test each acid solution by adding a drop of the pink phenolphthalein solution. Shake or stir the solutions.

II. Bases:

7. Fill two test tubes half full of distilled water. Add 2 or 3 drops of NaOH to the first, likewise for KOH in the second and 5 or 6 drops of ammonium hydroxide to a third. Add a few ml Calcium Hydroxide to another. Shake the tubes and proceed as for acids. *Do not forget to rise your mouth well after each tasting.*

After all other tests, including litmus, are completed, introduce one or two drops of (colorless) phenolphthalein solution into each test tube.

III. Further Investigations:

8. Test your saliva with litmus. (An acid reaction is hard on your teeth; that generally means too much sugar.)

9. Test juices with litmus, also taste. You may also test other substances around the lab or at home. Use litmus, not taste.

10. What are the general properties of acids? Bases?

Experiment: Titration

Purpose: to find the concentrations of some household solutions: vinegar and ammonia water

Equipment: 2 burettes, burette clamp, ring stand, beakers, 250 ml Erlenmeyer flask

Materials: Standard solutions of 0.1M (or Normal) NaOH and 0.1M HCl, vinegar, household ammonia, phenolphthalein, methyl orange

Procedure:
A. Clean burettes by rinsing with tap water and then distilled water. Place a beaker beneath to catch the water.

B. Titrate the vinegar with the standard base (0.1M NaOH):

1. Pour about 25 ml vinegar into a small beaker. Rinse the left burette with a few ml vinegar, then fill about half full.
2. Repeat with the standard 0.1 M NaOH solution in the other burette. Pour some into a small beaker and fill the burette. (The NaOH is probably much weaker than the vinegar.)
3. Read both volumes and record the readings in your notebook.
4. Let about 4 ml vinegar run into the 250 ml Erlenmeyer flask.
5. Add a few drops phenolphthalein to the flask.
6. Gradually let the standard base flow into the flask, swirling as you do, to encourage complete mixing.
7. When the color change takes longer, slow the addition until you are adding it dropwise.
8. The end point comes when one drop base turns the flask pink and one drop acid turns the flask colorless. (However, because of the large difference in concentration, several drops may be needed for the base to neutralize one drop vinegar.)
9. Record final volumes of both burettes.

C. If you have time, repeat. If two are sharing one set, let the partner repeat.

D. If time permits, repeat the above procedure using household ammonia and 0.1M standard HCl. Methyl orange may be substituted for the phenolphthalein.

Calculations: Calculate the molarity of the vinegar (and the ammonia if done).

11th Grade Chemistry

Students at this stage in life are seeking to be clear about their place in the universe. The curriculum responds with Astronomy, locating us in the cosmos, and with Chemistry, raising the question of the structure of the universe on the most minute level. A small book illustrated this human place several years ago through a series of photos and drawings, taking us from a human being to the largest structures of the universe in one direction and to the smallest particles then known in the other (Philip Morrison, et al., *Powers of Ten*).

Two main questions weave their way through chemical history: Is the world continuous or particulate? Are there fundamental elements forming the foundation of the material world and if so, what are their relationships? How these questions have been resolved weaves through the history of chemistry from ancient times to modern. We are therefore faced with a huge task. We are not teaching a university course on the history of chemistry.

Still, we must deal with Aristotle, the alchemists, Dalton, Mendeleev, and the Rutherford-Bohr model. After discussing the deficiencies of this model, the next step would be to DeBroilie, Heisenberg, and Schroedinger. As a practical matter, it is better to leave further steps in atomic theory and the question of particulate or continuous until 12th Grade Chemistry. There is already too much for one main lesson. And it will be easier to handle the wave-particle duality of matter after the 12th Physics block, in which the wave-particle duality of light will be discussed. The characteristics of major elements and classes, chemical calculations, and the gas laws are necessary for understanding the historical developments. (It would be very helpful if the gas laws had already been studied in 9th Grade Physics.)

We do not want to short-change the artistic or spiritual nature of substances, in particular the seven metals. Student reports, each on a particular substance, can provide a window into the human connections and make the material more personal. I generally gave a sample report on one of the metals, usually iron, where many aspects can be readily characterized. Other ways to show the relationships of the major elements include a 7-pointed star with the planets and Julius' 12 modern elements with the associated 4 classical elements.

If a four-week block is possible, this would be a great blessing. Perhaps some extra periods can be absorbed from a track class. In any event it is clear that the block must move rapidly and efficiently.

Recitation Suggestions

John Donne, "No Man Is an Island..."
John Masefield, "Sea-Fever"

Student Report

One of the major elements. The 7 metals for the 7 planets should be included, also carbon, oxygen, hydrogen, sulfur, calcium, sodium, magnesium would be important. Reports must be short due to time limitations. A written version should give more details. Some artistic representation to show the element's character would be especially helpful to indicate human or spiritual aspects.

Course Outline

Greek philosophy
Alchemists
Phlogiston
Lavoisier, Priestley and oxygen
Laws of definite proportion, multiple proportions
Gas laws. Boyle, Charles, Kelvin
Dalton, Life and work
Dalton's atomic theory
Gay-Lussac and Avogadro
Kinetic theory of gases
Electrolysis and Faraday (optional demonstration)
The size of molecules and Avogadro's number
Chemical calculations
Ordering the elements. Mendeleev and others
The Rutherford-Bohr model, atomic spectra
Nuclear structure, subatomic particles, isotopes
Matter: What of "atoms" now?

References

Chemical Bond Approach Project, Chemical Systems
Keith, Francis. *Rudolf Steiner and the Atom*
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Lehrer, Tom. "The Elements" in *Too Many Songs* by Tom Lehrer, Pantheon Books
Lucretius. *De Rerum Natura*
Mason. *History of the Sciences*
McBride, J. Michael. *Freshman Organic Chemistry I*, Open Yale Courses
Mees, L.F.C. *Living Metals*
Morrison, Philip and Phylis. *Powers of Ten*, Scientific American Library, 1982
Pelikan, *The Secrets of Metals*
Steiner, Rudolf. *The Boundaries of Natural Science* CW 322
PSSC, *Project Physics*
Walker, Jearl. "The Amateur Scientist," *Scientific American,* December 1983, 164–170

Homework Assignment Topics

Boyle's Law
Temperature scales
Charles' Law
Molecular and formula weights/masses
Chemical equations: writing formulas, balancing
Weight relations
Volume relations. STP

Through the Block

Ancient Greek Thought
Aristotle sees continuous matter, intuitively clear.
Lucretius argues from experience: dust dancing in the sunlight. Brownian motion.
The Four Elements, character, as explanatory factors (will be gradually transformed into physical states of solid, liquid, gas, plasma)

Alchemists
goal, methods, contribution to evolution of chemistry. Three elements combine original idea with two modern (sulfur and mercury) with key role of salt recognized

Oxygen
the phlogiston sidetrack, van Helmont and air, Priestley, Lavoisier ("The Revolution does not need scientists. Off with his head." Lavoisier's experiment after death.)

Demonstration: combustion of wood shavings, iron filings, magnesium
Plunge burning magnesium into CO_2, note products of C and MgO, demonstrates O-R
Preparation and properties of oxygen

Boyle and the Revival of Atomism

Gas laws. Boyle, Charles, Kelvin

A simple review. Experiments done in 9th Grade Physics, laws should have been discussed then.

Laws of Definite Proportions and Multiple Proportions

Experiment: Copper and sulfur: a simple, clear and satisfying student class experiment

Demonstration: Copper dust in large evaporating dish, heated gently, gradually stronger. Gradual heating brings out a series of colorful compounds of Cu and O. With luck a change in weight between CuO and CuO_2 can be seen.

John Dalton

Strange personality, wore black, founded meteorology observing weather daily in his home town, where it rains every day. Color-blind. Develops atomic theory with flaw, hinders chemistry for years (until Avogadro's hypothesis recognized).

Kinetic Theory of Gases

Kinetic theory explains gas laws. Avogadro, Gay-Lussac, Molar Volume

Chemical calculations. Balancing equations, weight relations, volume relations

Demonstration

The size of molecules. Measurement of an oleic acid film on water allows an estimation of molecular size and also of Avogadro's Number

Ordering the Elements

Various proposals. 7 metals. Julius: a human ordering of the major elements.

Triads, Newlands and Mendeleev, modern periodic table

Chemical Combinations

Valance, ion formation, reactivity of the elements. Chemical families.

Demonstrations: Reaction of sodium, potassium and calcium with water. Combustion of calcium and magnesium. Activity of halogens

Ionic and covalent compounds

Exceptions and Questions

Many masses integral multiples of hydrogen, but several not.

- -Tellurium and Iodine out of order
- -Many holes
- -Radioactive elements
- -Regularity in valence, but no zero valance
- -Why lengths of 2, 8, 8, 18...?

J.J. Thomson and Electrons; Rutherford-Bohr Model, Neutrons
Experiment: Spectroscopy. Flame tests and/or hand spectroscopes.
Problems with the model, open questions: to be continued in 12th Grade.

Subatomic Particles
Is there an end?
Mass-energy: The 4 elements of Aristotle become the 4 states of matter: solid, liquid, gaseous, energy

Appendices

11-1 John Donne, "No Man is an Island"
Christopher Fry, "The Human Heart Can Go to the Lengths of God"
from *Sleep of Prisoners*
11-2,3,4 Experiment: The Composition of Copper Sulfide
11-5 Experiment: Compounds of Copper and Oxygen
11-6 Experiment: The Size of Molecules; Avogadro's Number
11-7 Boyle's Law
11-8 Charles' Law
11-9 Frits Julius: The Major Elements
11-10 The Seven Metals and Some Associations
11-11 The Seven Metals Star
11-12 Block Report

No Man Is an Island

No man is an island, entire of itself;
Every man is a piece of the continent,
A part of the main.
If a clod be washed away by the sea,
Europe is the less.
As well as if a promontory were,
As well as if a manor of thy friend's
Or of thine own were:
Any man's death diminishes me,
Because I am involved in mankind.
And therefore never send to know for whom the bell tolls;*
It tolls for thee.

– John Donne (1573–1631)
From Meditation XVII
Devotions upon Emergent Occasions

*that is, at a death

From "A Sleep of Prisoners"

by Christopher Fry

The human heart can go the length of God.
Dark and cold we may be, but this
Is no winter now. The frozen misery
Of centuries past breaks, cracks, begins to move;
The thunder is the thunder of the floes,
The thaw, the flood, the upstart Spring.
Thank God our time is now, when wrong
Comes up to meet us everywhere,
Never to leave us till we take
The longest stride of soul men ever took.
Affairs are now soul size. The enterprise
Is exploration into God.
Where are you making for? It takes
So many thousand years to wake,
But will you wake for pity's sake?

11-2,3,4

Experiment: The Composition of Copper Sulfide

(Laws of Definite Proportion and Conservation of Mass)

NOTES:
There are two sulfides of copper. CuS (cupric sulfide, copper II sulfide) transitions to copper I sulfide at 104°C. Cu_2S (cuprous sulfide, copper I sulfide) is stable until at least 1100°C, when it melts. Clearly we are obtaining Cu_2S in this experiment.

With a large class, students can work in pairs. Other amounts of sulfur can be added. For a small class, Case IV is necessary; otherwise cases can be omitted.

The results are clear and convincing.

EXPERIMENT:
Purpose: To see if Copper and Sulfur combine in fixed proportions. To see if mass is conserved in a chemical reaction.

Background:
Chemical changes result in new substances with new properties. For example, when Copper combines with Sulfur, a new substance, Copper Sulfide, is produced. A mixture of Copper and Sulfur can have any proportions desired. However if the Copper and Sulfur combine into Copper Sulfide is the ratio fixed, that is, in fixed proportions (by weight or mass), or is the ratio arbitrary or influenced by how much of each is present before the reaction? If the ratio is fixed, this would support a Law of Definite Proportions, or Law of Definite Composition. Through careful weighing of the reactants and products, the Law of Conservation of Mass may also be checked.

Equipment and Materials:
16 gauge Copper wire, powdered Sulfur, test tube, test tube holder, Bunsen burner, balance

Method:
The same mass of Copper wire will be heated with different amounts of Sulfur. The ratio of Copper to Sulfur in the initial mixture will thus be varied widely to see if a similar variation will show up in the product, Copper Sulfide. Students will be assigned different ratios. The results will be compared.

Note: Masses given are approximate. Obtain approximately the amounts for your Case and then measure as accurately as possible on a scale/balance.

	Mass of Copper (g)	Mass of Sulfur (g)	Ratio of Cu to S in Mixture
Case I	0.8	0.05	16.0
Case II	0.8	0.10	8.0
Case III	0.8	0.15	5.3
Case IV	0.8	0.20	4.0
Case V	0.8	0.30	2.7
Case VI	0.8	0.40	2.0
Case VII	0.8	0.60	1.3
Case VIII	0.8	0.80	1.0

Procedure:

1. Weigh a clean test tube.
2. Obtain 7.0 cm of 18 gauge Copper wire. Cut the wire into about 4 pieces and place into the test tube.
3. Weigh test tube plus wire.
4. Place a piece of smooth white paper on the scale, read the mass, then add the Sulfur for your case and reweigh.
5. Crease the paper and pour the Sulfur into the test tube with the Copper. Reweigh test tube.
6. Heat the test tube and contents over a Bunsen burner, gently, until you notice something happening inside the tube. Observe evidence of a chemical reaction. Observe any changes in the substances in the tube. You should also observe the results of the other members of the class. Record all observations.

If excess Sulfur appears after the reaction, heat until you are sure any reaction is finished, allowing liquid Sulfur to run back down the test tube over the wires. Then drive excess Sulfur away from the Copper Sulfide in the bottom of the tube by heating until the excess Sulfur vaporizes and condenses on the walls of the upper part of the test tube. Allow to cool and note any changes.

7. Reweigh.
8. Weigh a piece of smooth, white paper. Empty the sticks at the bottom of the tube onto the paper. If you do this quickly, the sticks won't get stuck on Sulfur which may have condensed on the sides of the tube.
9. Weigh paper plus compound.
10. Break the compound into pieces and remove any Copper from the center which may have remained unreacted.
11. If any Copper remains, weigh this Copper separately.
12. Arrange the test tubes and contents in a row, labeled from Case I to Case VIII. Compare the appearance of the contents and tubes as the amount of sulfur increases.

Data and Calculations:
You should make two tables of data, one for your own data and your calculations, the other for class data.

Own Data:

- Mass of test tube (g)
- Mass of test tube and Copper (g)
- Mass of test tube, Copper and Sulfur (g)
- Mass of test tube and contents after heating (g)
- Mass of paper (g)
- Mass of paper and sticks (g)
- Mass of copper unreacted (if any)

Calculations:

- Mass of Copper in mixture at start (g)
- Mass of Sulfur in mixture at start (g)
- Ratio of Copper to Sulfur in mixture
- Mass of sticks (after reaction) (g)
- Mass of Copper in compound (g)
- Mass of Copper Sulfide in compound (g)
- Mass of Sulfur in compound (g)
- Ratio of Copper to Sulfur in compound

Class Data:

Mass of Cu in mixture (g)	Mass of S in mixture (g)	Ratio of Cu to S in mixture	Mass of Cu n compound (g)	Mass of S in compound (g)	Ratio of Cu to S in compound

Questions:

1. Describe the contents of the test tubes. How do the contents change as more Sulfur is added? Does adding Sulfur always increase the amount in the compound? Explain.

2. Do Copper and Sulfur combine in definite proportions in this experiment?

3. a) How much Copper combines with 1 gram of Sulfur? With 2 grams? With 4 grams?
   b) Suppose we assign a "combining weight" of 1 gram to Sulfur for convenience in working chemical problems. What would be the "combining weight" of Copper?
   c) If we assigned a "combining weight of 16 grams to sulfur, what would be the combining weight of Copper?

4. Is the mass of the Copper and Sulfur the same before and after the reaction? If there is a small difference does this imply a loss or creation of matter? Why or why not?

Experiment: Compounds of Copper and Oxygen

NOTES:
Oxides of Copper listed in the *Handbook of Chemistry and Physics*:

Formula	Name	Color
Cu_4O	Copper Suboxide	olive green
Cu_4O	Copper I Oxide (cuprous oxide), Natural Cuprite	red, octagonal cubic
CuO	Copper II Oxide (cupric oxide), Natural Tenorite	black
$CuO_4 \cdot H_2O$	Copper Peroxide (decomposes at 60°C)	brown or brown-black

This experiment is probably best done as a demonstration. A good measurement of the mass ratio in CuO (copper II oxide or cupric oxide) should be possible.

Producing copper I oxide is problematic. If all CuO has not been transformed into Cu_4O, no comparison will be possible. It is perhaps best to simply stop with CuO, noting the beautiful colors of the series of oxide produced. The oxides appearing in the *Handbook of Chemistry and Physics* are listed above.

EXPERIMENT:

Purpose: To investigate compounds of copper and oxygen. To see the law of definite proportions expanded to substances that form more than one compound.

Background: In the last experiment we discovered that copper and sulfur form a compound in which copper and sulfur combine in the ratio of about 4 grams copper to 1 gram sulfur. In this experiment we seek to extend our experimental knowledge of combining weights to compounds of copper with oxygen. We will find evidence that oxygen forms more than one compound with copper.

Method: Copper powder will be heated in air. When a change appears complete, the mass of the new compound will be found. The oxygen that has been added will be compared

with the original amount of copper to find the ratio of copper to oxygen in the copper oxide compound. An attempt will be made to add more oxygen to the compound by heating more strongly with thorough stirring. The dish plus copper oxide will be reweighed to see if further oxygen has been added.

Equipment and Materials: copper dust, evaporating dish, ring stand and ring, Bunsen burner, stirring rod, pestle, balance

Procedure:

1. Assemble apparatus. Heat an evaporating dish gently at first, then with a larger flame, for about 3 or 4 minutes. This preliminary heating will drive off any water or other material in the dish that might come off during the experiment. (What effect might omitting this step have on your results?)

2. After the evaporating dish has cooled to the touch, weigh it to the nearest 0.005 gram.

3. Adjust the weights on the balance to add 0.8 gram to the weight of the dish. Then add copper dust very gradually to make a thin layer across the bottom of the dish, until a new balance is obtained (approximately). (Note: Only a very small amount is needed.) Find the weight of the evaporating dish plus copper dust.

4. Place the dish on the ring and heat gently at first. Then as the dish warms up and the reaction progresses, heat more strongly until the copper dust takes on a uniform gray-black color. Stop heating.

Note evidence that copper forms more than one compound with oxygen. Record all observations in notebook.

5. After the dish cools, reweigh to find the mass of the dish plus the copper oxide.

6. Now make an attempt to add further oxygen through reheating the oxide with stirring, to allow complete access to the air.

7. After the dish has cooled to the touch, weigh.

Data:

a) Mass of evaporating dish (g)
b) Mass of evaporating dish and copper (g)
c) Mass of evaporating dish after first heating (g)
d) Mass of evaporating dish and copper oxide after final heating (g)

Calculations:

e) Mass of copper (g)
f) Mass of oxygen in first copper oxide (g)
g) Mass of oxygen in second copper oxide (g)
h) Ratio of copper to oxygen in first oxide (g)
i) Ratio of copper to oxygen in second oxide (g)

Questions:

1. It is a common belief that if you heat something, it has to lose weight. What evidence do you have that contradicts this popular belief?

2. What evidence from your observations might imply that copper forms more than one compound with oxygen?

3. According to your data, how much copper combines with one gram of oxygen in the first copper oxide? In the second oxide?

4. How much copper would combine with 16 grams of oxygen in the first copper compound? (This compound is known as Copper II Oxide.)

5. Compare the ratio of copper to oxygen in the two compounds. Are these ratios related in a simple way? For example, is the ratio approximately a simple whole number or fraction?

11-6

Experiment: The Size of Molecules; Avogadro's Number

Background: According to modern physical theory, substances cannot be broken down into smaller pieces forever. A limit is reached, and these smallest units are called atoms or, for compounds, molecules. How big are these tiny things? In this experiment we will find an estimate of the size of a molecule of a heavy organic acid, oleic acid. Oleic acid is known technically as 9,10-Octadecenoic acid and has the formula:

$$CH_3(CH_2)_7CH = CH(CH_2)_7CO_2H.$$

The molecular weight/mass is 282.5 g, its density, 0.8935 g/cc or about 0.9 g/cc.

In this experiment, a known solution of oleic acid and ethanol is dropped onto a pool of water. The oleic acid in the solution will spread out into a thin film. The alcohol dissolves in the water, so the film is made up of only of oleic acid. (It would be hard to measure out such a small amount of oleic acid without cutting it with alcohol.) The more oleic acid used, the larger the area of the oil slick. How thick is the oil slick? Put another way, how thin could it be? It could not be thinner than the thickness of one molecule of oleic acid:

Layer of oleic acid molecules on water would look like this: 88888888888

We first find the volume of a drop of the alcohol-oleic acid mixture. Knowing the percent oleic acid, we can find the amount of oleic acid in the oil slick. By measuring the diameter of the oil slick, the thickness of the oleic acid layer can be found. We assume that the layer is one molecule thick, a good assumption, since the oleic acid molecule has two ends, one water-loving (hydrophylic) and the other oily and avoiding contact with water (hydrophobic). Other substances will have molecules of different sizes, but still their size will be closer to the size of an oleic acid molecule than to some macroscopic object, like a baseball!

Equipment and Materials: 0.5% (= 5 parts per thousand) solution of oleic acid in ethyl alcohol (that is, 5 ml oleic acid mixed with 995 ml ethyl alcohol), lycopodium powder, large pan or tank, ruler, dropping bottle, graduated cylinder

Procedure:

1. Find the volume of one drop of the oleic acid mixture by finding how many drops are in a convenient volume, e.g., in 2 ml.

2. Make sure that the pan or tank is clean and oil-free. Add water to a depth of several centimeters.

3. Sprinkle lycopodium powder lightly on the water. Near the center is sufficient to make the oil film visible as the slick expands.

4. Let one drop of oleic acid mixture fall in the center of the pan.

5. Allow the surface to reach equilibrium (a few minutes).

6. Measure the (approximate) diameter of the oil slick. Estimate your uncertainty in measurement. Why should you only keep two significant figures in your calculations?

7. Wash the pan or tank with detergent to remove oil.

Calculations:

1. Size of one molecule. Find the thickness of the oil film. This is an estimate of the size of one oleic acid molecule. To do this, we must assume a shape for the molecules. For simplicity we will assume that they are spheres, although this does not really fit their shape. (They are actually linear and arrange themselves with the hydrophylic end at the water, the hydrophobic sticking up, like a diving duck with its rump in the air. With this assumption, a far closer estimate of Avogadro's Number can be obtained.)

The volume of oleic acid on the surface of the pan, V, is the volume of one drop times the fraction of oleic acid in the solution. Set this V equal to the volume of a disc:

$$V = \frac{\pi d^2 h}{4}$$

Solve for h and substitute your measured value of d and, for V, use the average volume of a drop which was found in Procedure Step 1. Express your answer (and all the following large numbers) in scientific notation. (Recall that 1 ml = 1 cm^3.)

2. Volume of one molecule. For simplicity, assume that the molecule is a cube and calculate its volume ($V=s^3$)

3. Mass of one molecule. Find the mass of one molecule from the volume and the density of oleic acid, which is 0.9 grams/cm^3. Recall that density = mass divided by volume, or d = m/V.

4. Total mass of oleic acid in the oil film. Again, use d = m/V. You found the volume of oleic acid in calculation 1.

5. Number of molecules in the film. Using the total mass (from calculation 4) and the mass of one molecule (calculation 3), calculate the number of molecules in the film (simply divide).

6. Avogadro's Number. The number of molecules in one mole can be found from our calculations of the mass of one molecule and the gram formula weight, using a simple ratio. Set the ratio of one molecule to its weight equal to the ratio of Avogadro's Number to the gram formula weight. Solve this equation for Avogadro's number, N_0.

Questions:
1. What difference in Avogadro's number would result if we assume in calculation 2 that molecules are spheres? If molecules are long and skinny, with a thickness of many times smaller than the length?

2. What errors in measurements influence the calculation of N_0? Does the difference between your result and the expected value seem reasonable in the light of the experimental errors? The assumptions?

Experiment Notes: The Size of Molecules
Oleic acid is a convenient oil. Because it is a linear molecule with hydrophylic and hydrophobic ends, it dissolves readily in alcohol and will also spread out on water in a monomolecular layer. See the article by Jearl Walker in *Scientific American* for details. Oleic acid has a density of 0.8935 grams/cc, approximately that of water. Immiscible with water, the hydrophylic end allows it to spread out on the water surface in a monomolecular layer, the hydrophylic end at the water surface.

The suggestion in the directions to imagine the molecules as cubes or spheres is clearly unrealistic. This is the reason the estimate of Avogadro's number is so far off, although clearly a very large number nevertheless. Actually we have long linear chains, one CH_2 unit thick.

If we make use of our knowledge of the molecular architecture, we can produce a far better result.

The carbon-hydrogen bond length is about 1 Ångstrom. So across the molecule we have at most several Ångstroms. One Ångstrom is 10exp-8 centimeters, or 0.00000001 cm. If we take the thickness of a molecule as about 4 x 10exp-8 cm, we have an area of about 4π x 10exp-16 cm²/molecule. Dividing the area of the oil slick by this number gives us an estimate of the number of molecules in the slick. The area of the slick is typically somewhat over 100 cm², perhaps more like 150 cm². So the number of molecules would be:

Slick area/area per molecule = 150 cm^2/ 12 x 10exp-16 cm^2/molecule
= 12 x 10exp+18 molecules

The mass of oleic acid is found from the volume of oleic acid-alcohol mixture, namely, 1 drop or about 1/20 cc, which contains 5% oleic acid, or about 1/400 cc or about 1/400 gram oleic acid (since its density is about 1.0g/cc). The formula weight of oleic acid is 283 grams/mole. So 1/400 gram is 1/44 of 283 grams/mole or (1/400)/283 = 8 x 10exp-6 moles.

Avogadro's Number is then:

$$N = \frac{\text{Number of molecules}}{\text{Molecular mass}}$$

$$= \frac{\text{12 x 10exp + 18 molecules}}{\text{8x10exp-6 moles}}$$

= 1.5 x 10exp + 24 molecules/mole

This value compares favorably with the accepted value of 6.02 x 10exp + 24

Further Experiments
There two experiments in 9th Grade Physics which would be good in the discussion of gas laws if they were not performed then: Boyle's Law and Charles' Law. It would be extremely helpful if they had already been done then and could simply be recalled, as time to cover the topics in 11th Grade is quite limited. If they have not been done, they could be squeezed in.

11-7

Boyle's Law

The Relationship between Pressure and Volume of a Gas

Purpose: To find the relationship of pressure and volume of a gas

Equipment: syringe with stand, bricks, scale, ruler

Background: According to Boyle's Law, the volume of a gas varies inversely with the pressure.

Approach: We will use a sample of air trapped in the syringe. Pressure is varied by setting bricks on top of the syringe. The total pressure is atmospheric pressure plus the pressure exerted by the bricks. Volume and pressure can then be compared, their product calculated, and a graph made showing volume as a function of pressure.

Procedure:
Measure the diameter of the syringe and find its area.
Weigh a brick with the scale (in pounds). Note: 2.2 lb = 1 kg
Assemble the syringe and stand. Be sure that the syringe is air-tight.
Record the height of the syringe plunger/piston.
Place half and full bricks, one at a time, on top of the syringe, measuring the height in the tube after each addition.
Calculate the total pressure in the cylinder.
Calculate pressure times volume, pV.
Plot volume as a function of pressure on graph paper.

Calculations:

Area of piston = $\pi d^2/4$
Pressure of brick (lb/in^2) = weight of brick/area of piston
Total pressure in the cylinder = p (atmosphere) + p (bricks)

Data: Include your data and that of all classmates:

V (cm)	# bricks	p of bricks	Total p	pV

Graph: Graph volume as a function of total pressure.

Conclusions: Describe the appearance of your graph. How do the values of pV compare? Is this product approximately constant? What is this relationship called in mathematics? Do your graph and your data confirm Boyle's Law? Explain. What errors could influence your results. Are you still convinced of the validity of the Law? Why?

Charles' Law

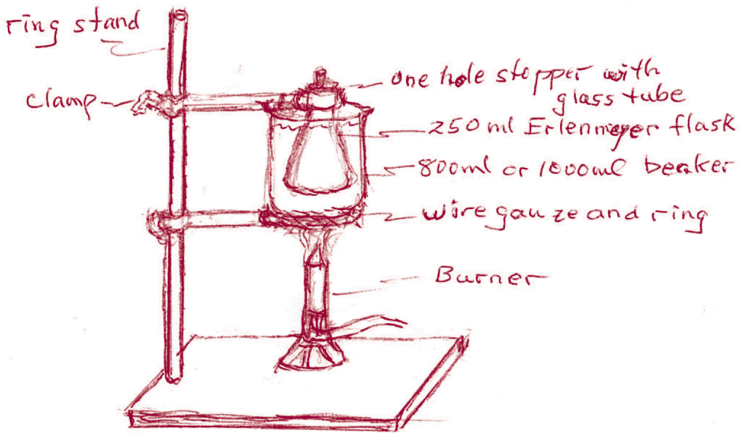
An Air Thermometer

Purpose: To understand temperature scales and the behavior of gases when their temperature is changed

Method: In this experiment, a flask of air will be heated to the boiling point, which we call 100°C. After waiting for the air in the flask to also rise to this temperature, it will be plunged into ice water, water which has come to equilibrium with the ice and thus has a temperature of the freezing point, which we call 0°C. To do this without losing or gaining air, a finger will be kept tightly over the top of the glass tube. The clamp will be removed from the ring stand, and clamp, flask and stopper with tube will all be plunged into the ice water. The finger can then be removed, allowing ice water to flow into the flask as the air contracts.

Comparing the original the volume of air in the flask with the new volume, we can see how much the air contracted. Suppose that we cooled the air further? If we assume that the air continues to contract by the same amount for each degree Celsius the temperature declines, we can calculate the temperature when the volume would shrink to zero. This temperature is known as "Absolute Zero," a temperature considerably lower than 0°C. We can estimate this temperature by graphing the Volume of air in the flask as a function of Temperature.

Procedure:



1. Prepare an ice bath by filling a pneumatic trough or other container with ice and adding enough water to cover the ice.

2. Using a dry Erlenmeyer flask, insert a short glass tube into a rubber stopper to fit the flask, and insert the stopper into the flask.

3. Place a ring and wire gauze on a ring stand, an 800 or 1000 ml beaker on the gauze, and lower the 250 ml flask into the beaker, holding it in place with a clamp attached to the ring stand. The flask must not touch the beaker. (Why?) Then fill the beaker with water to the neck of the flask.

4. Heat the water to boiling with a Bunsen burner and continue heating for at least 5 minutes to assure that the air in the flask has reached the temperature of the boiling water, which we call 100°C.

5. Make sure that the stopper is held tightly in the flask.

6. Now place your finger firmly over the end of the glass tube and plunge the flask, tube down, into the ice-water bath. Remove your finger and observe. Leave the flask in the bath for several minutes. What is happening inside the flask? Why?

7. When the flask is ice-cold, adjust the water level in the flask to that in the ice water, keeping the tube end under water at all times. This equalizes the pressure inside and outside the flask. Why is this important?

8. Now place your finger over the end of the tube and turn the flask right side up on the table. Remove the stopper and measure the water with a graduated cylinder. Call the temperature of the ice water 0°C.

9. A "250 ml" flask is only approximately 250 ml in volume. Furthermore, there was a stopper in the top of the flask. To determine the actual original volume of air in the flask, fill the flask with water, insert the stopper, remove the stopper, and empty the remaining water into a graduated cylinder. (If you are using a 100 ml graduated cylinder, you will have to pour in only about 1/3 of the water at a time, then add them together to find the total.)

Data: Record all data and observations in your notebook.

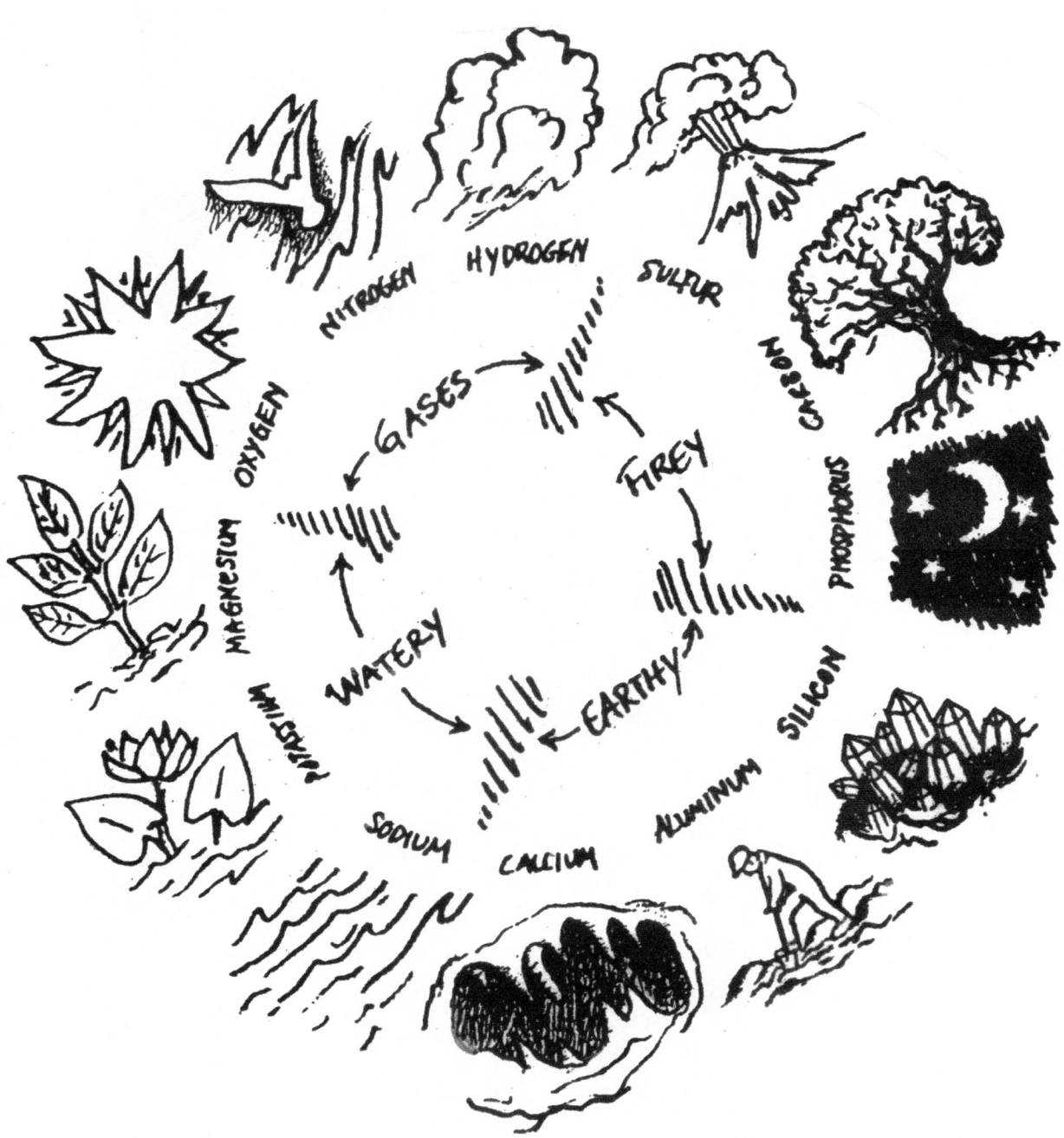
Calculations: Calculate the volume of air in the flask at the freezing point.

Graph: Plot your results for the volume and temperature of air on graph paper, allowing room on the graph to show the temperature at which the volume of air would become zero. You will need a horizontal axis which includes values of temperature (°C) from about -300 to +100. Place your vertical axis at 0°C and let the units run from 0 ml at the x axis up to 300 ml. Plot your values for the volume of air at 0°C and at 100°C. Connect your two data points with a straight line and extend the line to the left to lower temperatures until the line intersects (meets) the Temperature (x) axis. This value of the temperature is known as "Absolute Zero" or 0°Kelvin.

Questions:

1. According to your graph, what should be the volume of air in your flask at a room temperature of about 20°C? Explain how this apparatus could be used as a thermometer. What are the disadvantages of such a thermometer?
2. What temperature is absolute zero on your graph? How close are you to the accepted value of approximately -273°C (0°K)?
3. State Charles' Law in °C and in °K.

Frits Julius: The Major Elements



From Frits Julius, *Chemistry*

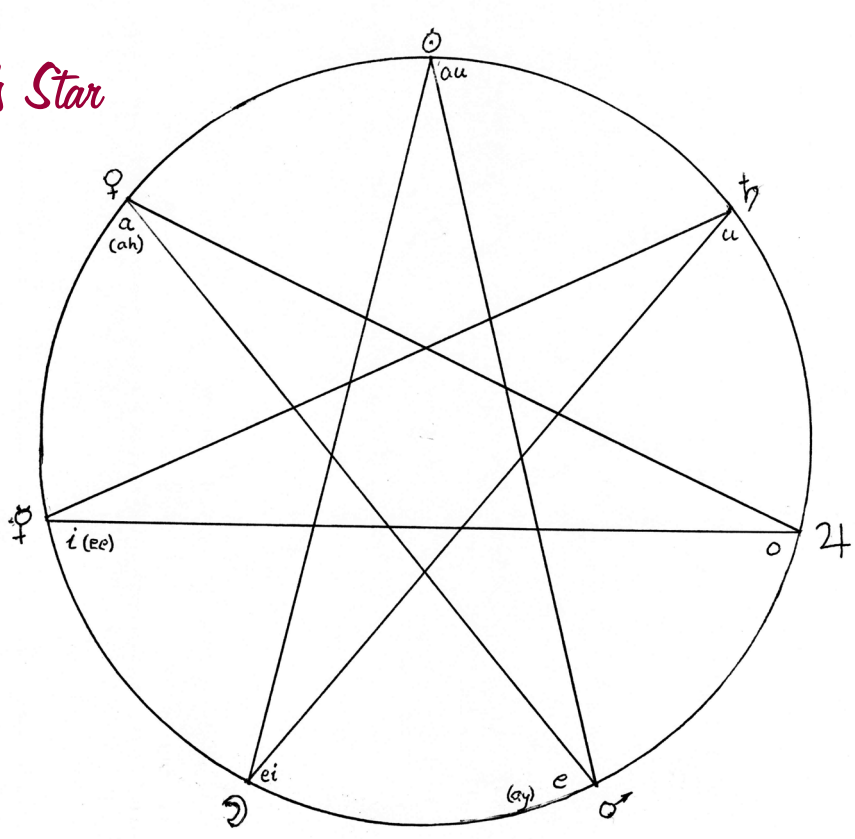
11-10

The Seven Metals and Some Associations

Metal	Planet	Day	Vowel	Color	Tree
Gold	Sun	Sunday	au (ow)	White	Ash
Silver	Moon	Monday	ei (ai)	Violet	Cherry
Iron	Mars	Tuesday	e (ay)	Red	Oak
Mercury	Mercury	Wednesday	i (ee)	Yellow	Elm
Tin	Jupiter	Thursday	o (oh)	Orange	Maple
Copper	Venus	Friday	a (ah)	Green	Birch
Lead	Saturn	Saturday	u (you)	Dark Blue	Beech, Pine, Cyprus

11-11

The Seven Metals Star



Block Report

The purpose of this research report is to learn as much as possible about one particular substance (element), so that the student will become to some extent an expert on it, and be able to understand its significance for chemistry and civilization in general. We will focus first of all on the common metals.

The report should include:

1. An oral report of 5 to 10 minutes in length.
2. A written report with proper references. Suggested length: minimum of 3 to 5 pages.
3. You may also be able to make a small artistic presentation of the nature or significance of the element chosen, which may be a picture, poem, music, dance, sculpture...

Sources. You are encouraged to consult at least one book and also articles or encyclopedias and chemistry books, as well as an internet search.

Topics which may be included in your report:

1. Ancient myths or associations with your element
2. History of discovery and use
3. Geography of production, reserves, extraction, processing
4. Importance in human civilization, technology
5. Physical properties
6. Chemistry
7. Role in human organism, in plants or animals
8. Uses in medicine or poisonous aspects

Any common themes or patterns of behavior appearing in the above survey (1–8)

12th Grade Chemistry

The 12th Grade is the time to take a wider view of the human enterprise, to explore human individual responsibility and possibilities. Thus the Geography block becomes Economics, the History through Art block addresses Architecture. The Biology block surveys Zoology, with the human the central character as the summing up of the other species. Rudolf Steiner's suggestion for 12th Grade Chemistry may be seen in the context of these other subjects. For the 12th Grade Chemistry block, Rudolf Steiner recommended presenting the chemistries of the four levels of being. These levels are the mineral, plant, animal and human. How shall we handle this challenge? Here is how I came out.

I began the block with an introduction to minerals and crystals. The difference between the chemistry of minerals and that of living organisms is clear enough. Growth is through the setting down of layers on the crystal lattice. The crystal types, the symmetries, the resulting actual forms in nature can be introduced. Growth is entirely from the surrounding solution. Form results from the internal character of the substance and from the external situation.

Both plants and animals govern growth in conjunction with the genetic endowment, the living or etheric forces, and the external environment. The central role of enzymes is characteristic. Still there are clear differences which can be emphasized, for example, the chlorophyll with magnesium as the central atom in contrast to hemoglobin with Iron. In general, plants grow until external circumstances limit further expansion. Animals have characteristic sizes and lifespans, to a large extent independent of the environment, in other words, determined internally rather than externally. Plants concern themselves with photosynthesis and the transformation of its products. Animals, by contrast, are constantly carrying out a vast array of complex and highly varied biochemical processes. The positions in the oxygen cycle are clearly complementary. The major portion of the block would be taken up with biochemistry. Discussion of steriochemistry and factors affecting rates of reaction would be appropriate.

If students have studied series in geometry or projective geometry, the contrast between arithmetic, geometric and hypergeometric series can be referred to. The arithmetic series grows stepwise as a crystal; the geometric ever expanding, as a plant. The third expands, then closes in on itself, as an animal.

What about humans? Much as the higher animals, humans carry out a great variety of chemical reactions in transforming, breaking down, and producing new substances. Since the beginning of the 20th Century, humans have also carried out nuclear transformations

on a large scale through nuclear reactors. It would be well to explain how we obtain energy from this source and the biochemical effects of the resulting pollution and potential environmental disasters. The discussion of alternative energy sources and methods of limiting use would not be out of place, especially if these issues have not been addressed in other classes or in high school forums.

With the inclusion of crystallography, biochemistry and nuclear chemistry, I believe that the block is addressing major l2th Grade issues and carrying out as best we can Steiner's mandate. The actual content and weighting depends on what is contained in other 11th and 12th Grade blocks.

The Rutherford-Bohr Model Failures and Modern Atomic Theory
These questions remain from 11th Grade Chemistry and must be addressed now. De Broglie, Heisenberg, Schroedinger are introduced and the modern view of atomic and molecular structure. The students have experienced the wave-particle duality of light, so that meeting it again with matter is no great surprise. In my experience, students today accept these paradoxes better than their elders of the previous generation. And the wave-particle duality and the associated wave equation point to the structure of the atoms, molecules and periodic table. Students have studied calculus, so that an introduction to the wave equation may be possible, especially in response to student questions.

Continuous or Particulate?
And what of matter? Is it in the end continuous or particulate? The answer as of 2012 is continuous. Matter's wavelike character means that discrete independent particles are unrealistic abstractions.

References

Edwards, Lawrence. *Projective Geometry*
Ege, Seyhan. *Organic Chemistry*
Pauling, Linus. *General Chemistry*

Appendices

12-1 Wordsworth, "Ode on Intimations of Immortality"
12-2 Psalm 8: 1, 3-9
12-3 The Shadow
12-4 Four Levels of Being
12-5 Chromatography of Natural and Synthetic (or Processed) Substances

Some Block Notes

Wave-particle nature of matter. De Broglie, Heisenberg, Schroedinger
Rudolf Steiner cautions against associating the electronic charge with all matter, thus slipping an evil (Luciferic) element into everything. While we cannot avoid describing the modern view, we can also indicate the potential for evil with help from an old radio show, "The Shadow." The reference to evil and the gruesome laughter come together with the total uncertainty of The Shadow's position, since he is invisible. To make things even more bewildering, these wave/particles also have a spin or magnetic moment, so once again electricity and magnetism are intimately connected.

Shells, subshells, orbitals
Convenient models are made from balloons: round for s-orbitals, oblong for p-orbitals. Balloons which blow up to about 3" x 9" are convenient. Two twisted and combined in the center produce a picture of hybrid orbitals found in carbon (well to be discussed prior to biochemistry). Three treated the same way (in three different colors) show relations of the three p-orbitals. Modern Periodic Table.

Mineralogy
Crystal, symmetry, classifications, origins, jewelry

Biochemistry
Photosynthesis. Catalysts. Steriochemistry. Some important systems in animal and human.

Nuclear Chemistry
Stable and unstable nuclei. Natural radioactivity. Disintegration series. Nuclear power, nuclear weapons, fallout

Ode: Intimations of Immortality

A Passage from Recollections of Early Childhood

Our birth is but a sleep and a forgetting:
The Soul that rises with us, our life's Star,
Hath had elsewhere its setting,
And cometh from afar;
Not in entire forgetfulness,
And not in utter nakedness,
But trailing clouds of glory do we come
From God, who is our home:
Heaven lies about us in our infancy!
Shades of the prison-house begin to close
Upon the growing Boy,
But He beholds the light, and whence it flows,
He sees it in his joy;
The Youth, who daily farther from the east
Must travel, still is Nature's Priest,
And by the vision splendid
Is on his way attended;
At length the Man perceives it die away,
And fade into the light of common day.

– William Wordsworth (1807)

Psalm 8

King James and Revised Standard Versions

O Lord, our Lord,
How majestic is Thy name in all the earth!

Thou whose glory above the heavens is chanted
by the mouth of babes and infants,
Thou hast founded a bulwark because of Thy foes,
to still the enemy and the avenger.

When I consider Thy heavens, the work of Thy fingers,
The moon and the stars which Thou hast ordained;
What is man that Thou art mindful of him,
And the son of man that Thou dost care for him?

Yet Thou hast made him a little lower than the angels,
And hast crowned him with glory and honor.
Thou hast given him dominion over the works of Thy hands;
Thou hast put all things under his feet,
All sheep and oxen,
Yes, and the beasts of the field,
The birds of the air, and the fish of the sea,
Whatever passes along the paths of the sea.

O Lord, our Lord,
How majestic is Thy name in all the earth!



The Shadow



"Who knows what evil lurks in the hearts of men? The Shadow knows!" The opening lines of the "Detective Story" radio program captivated listeners and are instantly recognizable even today. It first went on the air in l930 and continued until 1954. Originally the narrator of the series of macabre tales, the eerie voice know as The Shadow, became so popular to listeners that "Detective Story" was renamed "The Shadow," and the narrator became the star of the old-time mystery series.

A figure never seen, only heard, The Shadow was an invincible crime fighter. Lamont Cranston, a wealthy young man, had learned, during his travels in the Far East, to make himself invisible. He possessed many gifts which enabled him to overcome any enemy. Besides his tremendous strength, he could defy gravity, speak any language, unravel any code, and become invisible with his famous ability to "cloud men's minds."

Each show began with The Shadow, in his gruesome, sinister and unique voice, intoning, "Who knows what evil lurks in the hearts of men? The Shadow knows. Huh, huh, huh ... ha, ha, ha ..." and the voice would trail off in a penetrating, unforgettable snicker.

Along with his team of operatives, The Shadow battled adversaries with chilling names like The Black Master, Kinds of Crime, The Five Chameleons and, of course, The Red Menace. When The Shadow surprised a crook, he would first laugh his hideous laugh. The crook would scream and shoot, but always miss, since The Shadow was invisible.

At the end of a program the sign-off was: "The weeds of crime bear bitter fruit. The Shadow knows. (and then the hideous laugh) Huh, huh, huh ... ha, ha, ha ..."

The Shadow's exploits were also avidly followed by readers in *The Shadow* magazine, which began in 1931, following the huge success of the radio program. The magazine was published by Street & Smith, who had also sponsored the radio program. Over the course of 18 years, Street & Smith published 325 issues, each one containing a novel about the sinister crime fighter. These stories were written by Maxwell Grant, a fictional name created by the publishing company. Although several people wrote under the pseudonym, Walter B. Gibson wrote most of the stories, 282 in all.

Most of the novels published have been reprinted in paperback, and The Shadow adventures remain popular today, with comic books, magazines, toys, games, CDs and cassettes of the old-time radio shows, and books bringing top dollar among collectors the world over.



RKO Orson Welles: The 22-year-old Orson Welles funded his theatrical productions with his radio work, including a year on the Mutual Network's "super hero" program as The Shadow (1936–1937).

The similarity to the electron, an entity which you may try to pin down to a location, but always is somewhere else, would seem easy to grasp, together with the appeal to the emotions of the gruesome laughter. Furthermore there is the eerie connection to evil, hinting at the potential of the special power of electricity to be harnessed for good or to degenerate into evil. Naturally Lamont Cranston had the choice to fight crime or to be a criminal himself. Perhaps some chemistry teachers also have the power to cloud men's minds and disappear while laughing hideously. For sure, when things get too complex, some students may feel like someone has clouded their minds.

Four Levels of Being

Some Possible Correlations or Correspondences

Level	*State*	*Element*		*Food*	*Aristotelian Cause*
Mineral	Solid	C	Earth	Salt	Material
Plant	Liquid	O	Water	Carbohydrate	Efficient
Animal	Gas	N	Air	Protein	Formal
Human	Fire/Plasma	H	Fire	Fat	Primal

12-5

Chromatography of Natural and Synthetic (or Processed) Substances

Purpose: to compare visually natural and artificial, processed or refined substances

Materials: 0.5 % silver nitrate solution, 0.1% sodium hydroxide solution, Whatman filter paper #1, 15 cm diameter

Suggested substance pairs for testing:

Rose hips	vs	Vitamin C
Orange juice	vs	Orange Kool-Aid, Tang, Orange Funny-face
Fresh milk	vs	Sour milk
Whole wheat bread	vs	White bread
Molasses	vs	White sugar
Honey	vs	Corn syrup
Organic potato	vs	Conventional potato
Apple cider	vs	Vinegar
Spinach	vs	Green food color
Grape juice	vs	Grape Kool-Aid or drink

Procedure:
Three steps are required. The paper is sensitized about 4 hours prior to the actual chromatography. The substance to be tested must be prepared, generally about 1 hour or more ahead of time, and allowed to steep in mild lye solution. Then the prepared substance is allowed to make a chromatogram on the sensitized paper.

Step I. Sensitization.
Prepare 2 filter paper circles as follows:

1. Punch a hole in the center of a piece of Whatman #1 (fast) filter paper. (A slower paper might work better, but would make it difficult to complete the experiment during classtime.)
2. Mark with a pencil 1" and 2" from the center.
3. Make a wick from #4 paper, cut from another sheet.
4. Pour some 0.5% silver nitrate solution ($AgNO_3$) into a watch glass resting in a petri dish.
5. Place the filter disk with wick on top of the dish. Stop when the solvent reaches the first mark (1").

Step II. Preparation of Sample.
Each student will be assigned a substance to prepare. You will work in pairs so that you will be able to compare your substance with another similar substance which has been grown or processed differently. For example, one pair will have an orange or orange juice paired with an orange drink mix.

For solids and milk, and extracts or dyes: Mix 1 gram (or 1 ml = ¼ teaspoon) with 50 ml 0.1% sodium hydroxide solution (NaOH). Grind first with a mortar and pestle if necessary. Use 100 ml beakers to mix substance and NaOH.

For liquids: Mix 25 ml of sample liquid with 5 ml 0.1% sodium hydroxide solution (NaOH). (The sodium hydroxide assists in dissolving substances.) Use a 100 ml beaker to prepare samples. Label beaker, using pencil on the etched glass oval. Let stand for one hour or for as long as you have time. Record any conditions which you think might influence the experiment.

Step III. Making the Chromatogram.
1. Label your disks with the substances being tested, one for yours and one for your partner's substance. Print clearly in pencil at the outer edge of the disk. Your classmates will have to be able to read your printing easily at a distance.
2. Make a new wick, fat, at least 1/8" in diameter to speed movement of solvent through the filter paper, one wick for each disk.
3. Each member of a pair will do one chromatogram of each substance the pair is testing. There are enough petri dishes and watch glasses to let you run all the tests simultaneously.
4. Decant the liquid from your sample into the watch glass. Do not stir up the dregs, which will clog the wick.
5. Put the filter disk on the dish and let the solvent expand until it reaches the second mark (2"). Save disks for comparison with those of your classmates. Record observations of progress and comparisons.

Notes on Chromatography
The procedure follows the recommendations of "The Circular Chromatographic Method According to E.E. Pfeiffer: Practical Instructions" Biochemical Research Laboratory, Threefold Farm, Spring Valley, NY.

Complex inorganic substances, like long-chain hydrocarbons, also produce more complex pictures than simple chemical substances. Dr. Gerhardt Schmidt: "They do it also."



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