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Science

Forensics and Applied Science Experiments

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Credits

Lab Writer

James R. Hurley
Director of Development, American Academy of Forensic Sciences
Shell Rock, Iowa

Introduction Writers

Gary Harris
Science Writer
Albuquerque, New Mexico

Robert Davisson
Science Writer
Albuquerque, New Mexico

Safety Reviewer

Robert S. Davis
Former Science Curriculum Assistance Specialist,
State of Alabama Department of Education
Mobile, Alabama

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Laboratory Safety

In the laboratory, you can engage in hands-on explorations, test your scientific hypotheses, and build practical lab skills. However, while you are working in the lab or in the field, it is your responsibility to protect yourself and your classmates by conducting yourself in a safe manner. You will avoid accidents in the lab by following directions, handling materials carefully, and taking your work seriously. Read the following safety guidelines before working in the lab. Make sure that you understand all safety guidelines before entering the lab.

Before You Begin

- **Read the entire activity before entering the lab.** Be familiar with the instructions before beginning an activity. Do not start an activity until you have asked your teacher to explain any parts of the activity that you do not understand.
- **Student-designed procedures or inquiry activities must be approved by your teacher before you attempt the procedures or activities.**
- **Wear the right clothing for lab work.** Before beginning work, tie back long hair, roll up loose sleeves, and put on any required personal protective equipment as directed by your teacher. Remove your wristwatch and any necklaces or jewelry that could get caught in moving parts. Avoid or confine loose clothing that could knock things over, catch on fire, get caught in moving parts, contact electrical connections, or absorb chemical solutions. Wear pants rather than shorts or skirts. Nylon and polyester fabrics burn and melt more readily than cotton does. Protect your feet from chemical spills and falling objects. Do not wear open-toed shoes, sandals, or canvas shoes in the lab. In addition, chemical fumes may react with and ruin some jewelry, such as pearl jewelry. Do not apply cosmetics in the lab. Some hair care products and nail polish are highly flammable.
- **Do not wear contact lenses in the lab.** Even though you will be wearing safety goggles, chemicals could get between contact lenses and your eyes and could cause irreparable eye damage. If your doctor requires that you wear contact lenses instead of glasses, then you should wear eye-cup safety goggles—similar to goggles worn for underwater swimming—in the lab. Ask your doctor or your teacher how to use eye-cup safety goggles to protect your eyes.
- **Know the location of all safety and emergency equipment used in the lab.** Know proper fire-drill procedures and the location of all fire exits. Ask your teacher where the nearest eyewash stations, safety blankets, safety shower, fire extinguisher, first-aid kit, and chemical spill kit are located. Be sure that you know how to operate the equipment safely.

While You Are Working

- **Always wear a lab apron and safety goggles.** Wear these items even if you are not working on an activity. Labs contain chemicals that can damage your clothing, skin, and eyes. If your safety goggles cloud up or are uncomfortable, ask your teacher for help. Lengthening the strap slightly, washing the goggles with soap and warm water, or using an anti-fog spray may help the problem.
- **NEVER work alone in the lab.** Work in the lab only when supervised by your teacher. Do not leave equipment unattended while it is in operation.
- **Perform only activities specifically assigned by your teacher.** Do not attempt any procedure without your teacher's direction. Use only materials and equipment listed in the activity or authorized by your teacher. Steps in a procedure should be performed only as described in the activity or as approved by your teacher.
- **Keep your work area neat and uncluttered.** Have only books and other materials that are needed to conduct the activity in the lab. Keep backpacks, purses, and other items in your desk, locker, or other designated storage areas.
- **Always heed safety symbols and cautions listed in activities, listed on handouts, posted in the room, provided on chemical labels, and given verbally by your teacher.** Be aware of the potential hazards of the required materials and procedures, and follow all precautions indicated.
- **Be alert, and walk with care in the lab.** Be aware of others near you and your equipment.
- **Do not take food, drinks, chewing gum, or tobacco products into the lab.** Do not store or eat food in the lab.
- **NEVER taste chemicals or allow them to contact your skin.** Keep your hands away from your face and mouth, even if you are wearing gloves.
- **Exercise caution when working with electrical equipment.** Do not use electrical equipment with frayed or twisted wires. Be sure that your hands are dry before using electrical equipment. Do not let electrical cords dangle from work stations. Dangling cords can cause you to trip and can cause an electrical shock. The area under and around electrical equipment should be dry; cords should not lie in puddles of spilled liquid.
- **Use extreme caution when working with hot plates and other heating devices.** Keep your head, hands, hair, and clothing away from the flame or heating area. Remember that metal surfaces connected to the heated area will become hot by conduction. Gas burners should be lit only with a spark lighter, not with matches. Make sure that all heating devices and gas valves are turned off before you leave the lab. Never leave a heating device unattended when it is in use. Metal, ceramic, and glass items do not necessarily look hot when they are hot. Allow all items to cool before storing them.

- **Do not fool around in the lab.** Take your lab work seriously, and behave appropriately in the lab. Lab equipment and apparatus are not toys; never use lab time or equipment for anything other than the intended purpose. Be aware of the safety of your classmates as well as your safety at all times.

Emergency Procedures

- **Follow standard fire-safety procedures.** If your clothing catches on fire, do not run; WALK to the safety shower, stand under it, and turn it on. While doing so, call to your teacher. In case of fire, alert your teacher and leave the lab.
- **Report any accident, incident, or hazard—no matter how trivial—to your teacher immediately.** Any incident involving bleeding, burns, fainting, nausea, dizziness, chemical exposure, or ingestion should also be reported immediately to the school nurse or to a physician. If you have a close call, tell your teacher so that you and your teacher can find a way to prevent it from happening again.
- **Report all spills to your teacher immediately.** Call your teacher rather than trying to clean a spill yourself. Your teacher will tell you whether it is safe for you to clean up the spill; if it is not safe, your teacher will know how to clean up the spill.
- **If you spill a chemical on your skin, wash the chemical off in the sink and call your teacher.** If you spill a solid chemical onto your clothing, brush it off carefully without scattering it onto somebody else and call your teacher. If you get liquid on your clothing, wash it off right away by using the faucet at the sink and call your teacher. If the spill is on your pants or something else that will not fit under the sink faucet, use the safety shower. Remove the pants or other affected clothing while you are under the shower, and call your teacher. (It may be temporarily embarrassing to remove pants or other clothing in front of your classmates, but failure to flush the chemical off your skin could cause permanent damage.)
- **If you get a chemical in your eyes, walk immediately to the eyewash station, turn it on, and lower your head so your eyes are in the running water.** Hold your eyelids open with your thumbs and fingers, and roll your eyeballs around. You have to flush your eyes continuously for at least 15 minutes. Call your teacher while you are doing this.

When You Are Finished

- **Clean your work area at the conclusion of each lab period as directed by your teacher.** Broken glass, chemicals, and other waste products should be disposed of in separate, special containers. Dispose of waste materials as directed by your teacher. Put away all material and equipment according to your teacher's instructions. Report any damaged or missing equipment or materials to your teacher.

- **Wash your hands with soap and hot water after each lab period.** To avoid contamination, wash your hands at the conclusion of each lab period, and before you leave the lab.

Safety Symbols

Before you begin working in the lab, familiarize yourself with the following safety symbols, which are used throughout your textbook, and the guidelines that you should follow when you see these symbols.

EYE PROTECTION

- **Wear approved safety goggles as directed.** Safety goggles should be worn in the lab at all times, especially when you are working with a chemical or solution, a heat source, or a mechanical device.
- **If chemicals get into your eyes, flush your eyes immediately.** Go to an eyewash station immediately, and flush your eyes (including under the eyelids) with running water for at least 15 minutes. Use your thumb and fingers to hold your eyelids open and roll your eyeball around. While doing so, ask another student to notify your teacher.
- **Do not wear contact lenses in the lab.** Chemicals can be drawn up under a contact lens and into the eye. If you must wear contacts prescribed by a physician, tell your teacher. In this case, you must also wear approved eye-cup safety goggles to help protect your eyes.
- **Do not look directly at the sun or any light source through any optical device or lens system, and do not reflect direct sunlight to illuminate a microscope.** Such actions concentrate light rays to an intensity that can severely burn your retinas, which may cause blindness.

CLOTHING PROTECTION

- **Wear an apron or lab coat at all times in the lab to prevent chemicals or chemical solutions from contacting skin or clothes.**
- **Tie back long hair, secure loose clothing, and remove loose jewelry so that they do not knock over equipment, get caught in moving parts, or come into contact with hazardous materials.**

HYGIENIC CARE

- **Keep your hands away from your face and mouth while you are working in the lab.**
- **Wash your hands thoroughly before you leave the lab.**
- **Remove contaminated clothing immediately.** If you spill caustic substances on your skin or clothing, use the safety shower or a faucet to rinse. Remove affected clothing while you are under the shower, and call to your teacher. (It may be temporarily embarrassing to remove clothing in front of your classmates, but failure to rinse a chemical off your skin could result in permanent damage.)
- **Launder contaminated clothing separately.**
- **Use the proper technique demonstrated by your teacher when you are handling bacteria or other microorganisms.** Treat all microorganisms as if they are pathogens. Do not open Petri dishes to observe or count bacterial colonies.
- **Return all stock and experimental cultures to your teacher for proper disposal.**

SHARP-OBJECT SAFETY

- **Use extreme care when handling all sharp and pointed instruments, such as scalpels, sharp probes, and knives.**
- **Do not cut an object while holding the object in your hand.** Cut objects on a suitable work surface. Always cut in a direction away from your body.
- **Do not use double-edged razor blades in the lab.**

GLASSWARE SAFETY

- **Inspect glassware before use; do not use chipped or cracked glassware.** Use heat-resistant glassware for heating materials or storing hot liquids, and use tongs or a hot mitt to handle this equipment.
- **Do not attempt to insert glass tubing into a rubber stopper without specific instructions from your teacher.**
- **Notify immediately your teacher if a piece of glassware or a light bulb breaks.** Do not attempt to clean up broken glass unless your teacher directs you to do so.

PROPER WASTE DISPOSAL

- **Clean and sanitize all work surfaces and personal protective equipment after each lab period as directed by your teacher.**
- **Dispose of all sharp objects (such as broken glass) and other contaminated materials (biological or chemical) in special containers only as directed by your teacher.** Never put these materials into a regular waste container or down the drain.

ELECTRICAL SAFETY

- **Do not use equipment with frayed electrical cords or loose plugs.**
- **Fasten electrical cords to work surfaces by using tape.** Doing so will prevent tripping and will ensure that equipment will not fall off the table.
- **Do not use electrical equipment near water or when your clothing or hands are wet.**
- **Hold the rubber cord when you plug in or unplug equipment.** Do not touch the metal prongs of the plug, and do not unplug equipment by pulling on the cord.
- **Wire coils on hot plates may heat up rapidly.** If heating occurs, open the switch immediately and use a hot mitt to handle the equipment.

HEATING SAFETY

- **Be aware of any source of flames, sparks, or heat (such as open flames, electric heating coils, or hot plates) before working with flammable liquids or gases.**
- **Avoid using open flames.** If possible, work only with hot plates that have an on/off switch and an indicator light. Do not leave hot plates unattended. Do not use alcohol lamps. Turn off hot plates and open flames when they are not in use.
- **Never leave a hot plate unattended while it is turned on or while it is cooling off.**
- **Know the location of lab fire extinguishers and fire-safety blankets.**
- **Use tongs or appropriate insulated holders when handling heated objects.** Heated objects often do not appear to be hot. Do not pick up an object with your hand if it could be warm.
- **Keep flammable substances away from heat, flames, and other ignition sources.**
- **Allow all equipment to cool before storing it.**

FIRE SAFETY

- **Know the location of lab fire extinguishers and fire-safety blankets.**
- **Know your school's fire-evacuation routes.**
- **If your clothing catches on fire, walk (do not run) to the emergency lab shower to put out the fire. If the shower is not working, STOP, DROP, and ROLL!**

CAUSTIC SUBSTANCES

- **If a chemical gets on your skin, on your clothing, or in your eyes, rinse it immediately and alert your teacher.**
- **If a chemical is spilled on the floor or lab bench, alert your teacher, but do not clean it up yourself unless your teacher directs you to do so.**

CHEMICAL SAFETY

- **Always wear safety goggles, gloves, and a lab apron or coat to protect your eyes and skin when you are working with any chemical or chemical solution.**
- **Do not taste, touch, or smell any chemicals or bring them close to your eyes unless specifically instructed to do so by your teacher.** If your teacher tells you to note the odor of a substance, do so by waving the fumes toward you with your hand. Do not pipette any chemicals by mouth; use a suction bulb as directed by your teacher.
- **Know where the emergency lab shower and eyewash stations are and how to use them.** If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher.
- **Always handle chemicals or chemical solutions with care.** Check the labels on bottles, and observe safety procedures. Label beakers and test tubes containing chemicals.
- **For all chemicals, take only what you need.** Do not return unused chemicals or solutions to their original containers. Return unused reagent bottles or containers to your teacher.
- **NEVER take any chemicals out of the lab.**
- **Do not mix any chemicals unless specifically instructed to do so by your teacher.** Otherwise harmless chemicals can be poisonous or explosive if combined.
- **Do not pour water into a strong acid or base.** The mixture can produce heat and can splatter.
- **Report all spills to your teacher immediately.** Spills should be cleaned up promptly as directed by your teacher.

Laboratory Techniques

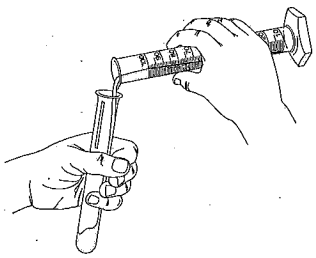


FIGURE A

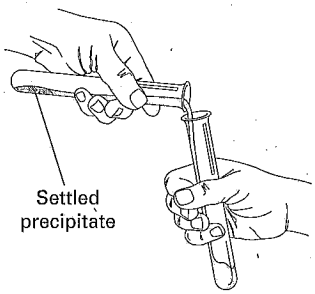


FIGURE B

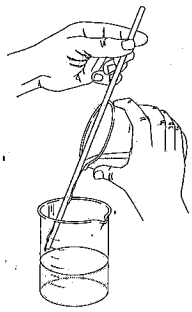


FIGURE C

HOW TO DECANT AND TRANSFER LIQUIDS

1. The safest way to transfer a liquid from a graduated cylinder to a test tube is shown in Figure A. The liquid is transferred at arm's length, with the elbows slightly bent. This position enables you to see what you are doing while maintaining steady control of the equipment.
2. Sometimes, liquids contain particles of insoluble solids that sink to the bottom of a test tube or beaker. Use one of the methods shown above to separate a supernatant (the clear fluid) from insoluble solids.
   - **a.** Figure B shows the proper method of decanting a supernatant liquid from a test tube.
   - **b.** Figure C shows the proper method of decanting a supernatant liquid from a beaker by using a stirring rod. The rod should touch the wall of the receiving container. Hold the stirring rod against the lip of the beaker containing the supernatant. As you pour, the liquid will run down the rod and fall into the beaker resting below. When you use this method, the liquid will not run down the side of the beaker from which you are pouring.

HOW TO HEAT SUBSTANCES AND EVAPORATE SOLUTIONS

1. Use care in selecting glassware for high-temperature heating. The glassware should be heat resistant.
2. When heating glassware by using a gas flame, use a ceramic-centered wire gauze to protect glassware from direct contact with the flame. Wire gauzes can withstand extremely high temperatures and will help prevent glassware from breaking. Figure D shows the proper setup for evaporating a solution over a water bath.

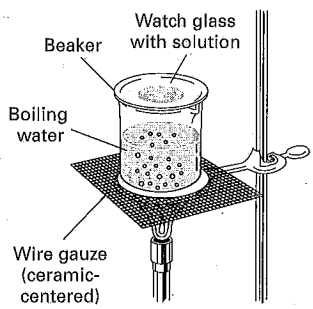


FIGURE D

3. In some experiments, you are required to heat a substance to high temperatures in a porcelain crucible. Figure E shows the proper apparatus setup used to accomplish this task.
4. Figure F shows the proper setup for evaporating a solution in a porcelain evaporating dish with a watch glass cover that prevents spattering.

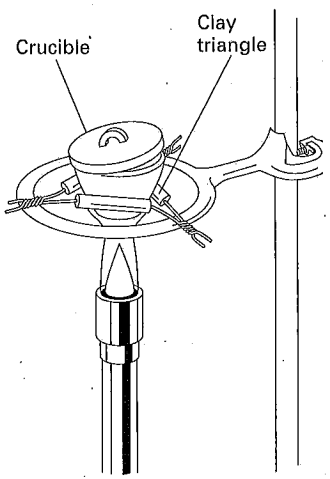


FIGURE E

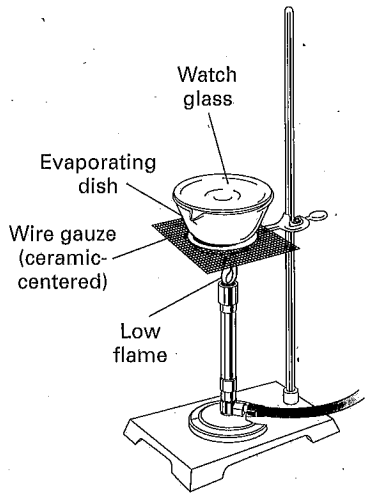


FIGURE F

5. Glassware, porcelain, and iron rings that have been heated may *look* cool after they are removed from a heat source, but these items can still burn your skin even after several minutes of cooling. Use tongs, test-tube holders, or heat-resistant mitts and pads whenever you handle these pieces of apparatus.
6. You can test the temperature of beakers, ring stands, wire gauzes, or other pieces of apparatus that have been heated by holding the back of your hand close to their surfaces before grasping them. You will be able to feel any energy as heat generated from the hot surfaces. DO NOT TOUCH THE APPARATUS. Allow plenty of time for the apparatus to cool before handling.

HOW TO POUR LIQUID FROM A REAGENT BOTTLE

1. Read the label at least three times before using the contents of a reagent bottle.
2. Never lay the stopper of a reagent bottle on the lab table.
3. When pouring a caustic or corrosive liquid into a beaker, use a stirring rod to avoid drips and spills. Hold the stirring rod against the lip of the reagent bottle. Estimate the amount of liquid you need, and pour this amount along the rod, into the beaker. See Figure G.

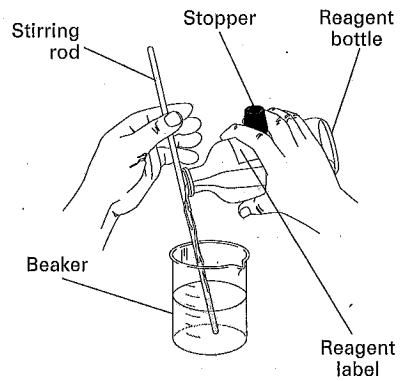


FIGURE G

4. Extra precaution should be taken when handling a bottle of acid. Remember the following important rules: Never add water to any concentrated acid, particularly sulfuric acid, because the mixture can splash and will generate a lot of energy as heat. To dilute any acid, add the acid to water in small quantities while stirring slowly. Remember the "triple A's"—*Always Add Acid* to water.

5. Examine the outside of the reagent bottle for any liquid that has dripped down the bottle or spilled on the counter top. Your teacher will show you the proper procedures for cleaning up a chemical spill.
6. Never pour reagents back into stock bottles. At the end of the experiment, your teacher will tell you how to dispose of any excess chemicals.

HOW TO HEAT MATERIAL IN A TEST TUBE

1. Check to see that the test tube is heat resistant.
2. Always use a test tube holder or clamp when heating a test tube.
3. Never point a heated test tube at anyone, because the liquid may splash out of the test tube.
4. Never look down into the test tube while heating it.
5. Heat the test tube from the upper portions of the tube downward, and continuously move the test tube, as shown in Figure H. Do not heat any one spot on the test tube. Otherwise, a pressure buildup may cause the bottom of the tube to blow out.

HOW TO USE A MORTAR AND PESTLE

1. A mortar and pestle should be used for grinding only one substance at a time. See Figure I.
2. Never use a mortar and pestle for simultaneously mixing different substances.
3. Place the substance to be broken up into the mortar.
4. Pound the substance with the pestle, and grind to pulverize.
5. Remove the powdered substance with a porcelain spoon.

HOW TO DETECT ODORS SAFELY

1. Test for the odor of gases by wafting your hand over the test tube and cautiously sniffing the fumes as shown in Figure J.
2. Do not inhale any fumes directly.
3. Use a fume hood whenever poisonous or irritating fumes are present. DO NOT waft and sniff poisonous or irritating fumes.

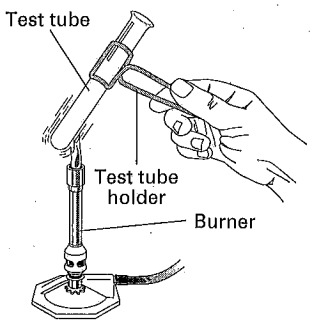


FIGURE H

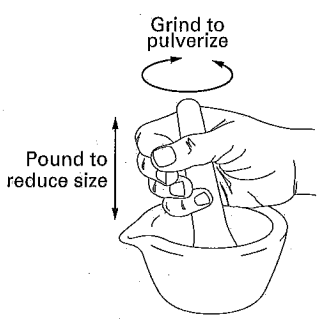


FIGURE I

FIGURE J

Name _____ Class _____ Date _____

Topic Introduction

An Introduction to Forensic Science

When most people think about forensic science, they recall crime dramas from television, in which a crime scene investigator seizes the smallest bits of evidence and ties them together to reconstruct the crime, enabling the investigator to identify even the most cunning criminal. For example, the evidence associated with a crime may be samples of hair, paint, glass, soil, blood, or plant material. A forensic scientist tests these pieces of evidence using various analytical procedures such as density tests, color tests, chromatography, and DNA tests.

Many of the scientists who work in forensics are involved in law enforcement work. But there's much more to forensics than that. Basically, **forensics** *is making knowledge and information available in a public forum, such as a court of law.* A *forensic scientist* is a person who applies scientific knowledge and techniques to the investigation of evidence for the purpose of identification.

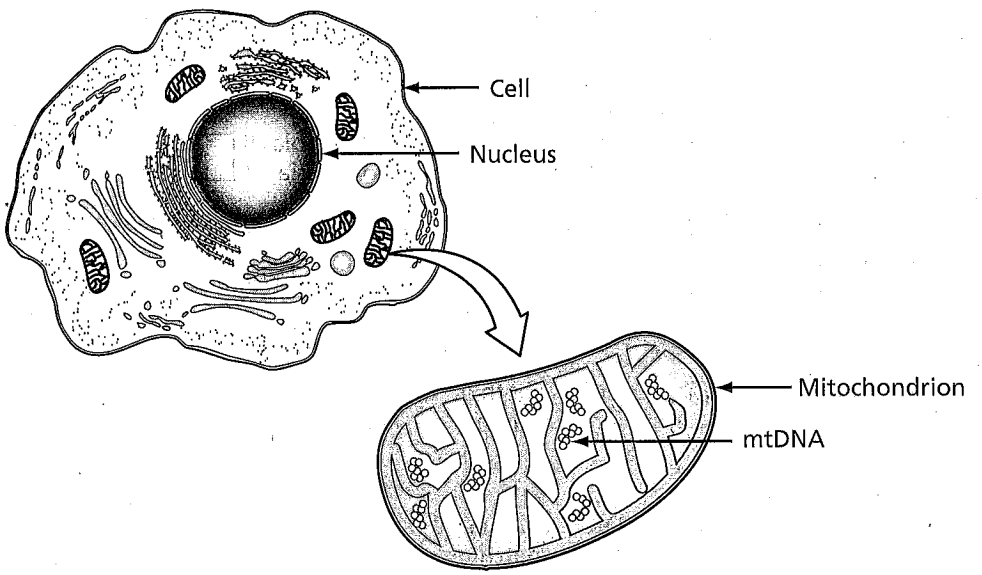
Sometimes, a single scientific technique can be applied to solve many different scientific problems as well as answer forensics questions. One example is the rapidly developing field of mitochondrial DNA analysis.

A Current Hot Topic: Forensic mtDNA Analysis

All cells contain mitochondria, shown below in **Figure 1,** which are small structures about the size of a bacterium. Mitochondria act as "power generators" for cells, making ATP. They are found in the cell material surrounding the nucleus, numbering from several to a thousand or more. They have their own DNA, and each mitochondrion contains several copies of its DNA.

FIGURE 1 A MITOCHONDRION WITH ITS DNA

Mitochondria contain their own DNA, referred to as mtDNA.



A person's mitochondria and mitochondrial DNA are always inherited from the mother, whereas nuclear DNA is inherited partly from the mother and partly from the father. One advantage of using mtDNA for forensic analysis is the fact that there are great numbers of mitochondria in each cell. This abundance allows a very small sample of material to provide a large mtDNA sample. Another advantage is that mtDNA exists in all types of cells and therefore any type of body tissue can be used, including bone.

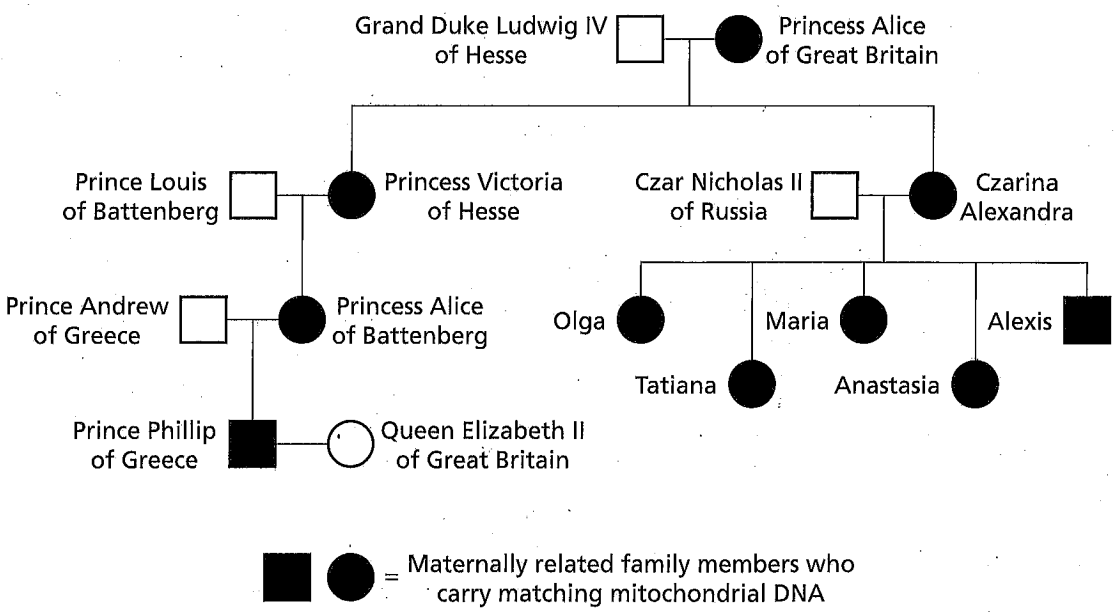
FORENSIC GENEALOGY

The very new technique of mtDNA analysis can aid in the identification of human remains, even solving mysteries that are nearly a century old.

In 1918, during the Russian Revolution, Czar Nicholas II, his wife Czarina Alexandra, and their children were executed. Many legends and rumors surrounded their deaths and the location of their grave. Years later, a woman in Paris claimed to be their daughter Anastasia, who had somehow escaped.

Investigators obtained mtDNA from a grave site rumored to be the place where the bodies of the czar's family were buried for the purpose of *forensic genealogy.* Using forensic genealogy, one attempts to establish family relationships between the living and the deceased. In this case, Prince Philip of Greece, the husband of Great Britain's Queen Elizabeth II, agreed to provide an mtDNA sample. Because he is a direct maternal descendant of the czarina's mother, he has the same mtDNA pattern as the czarina. His pattern matched those from the gravesite, proving that the site was the final resting place of the czar's family. A similar analysis disproved the claim of the woman from Paris. A diagram of the maternal lineage that connected these relatives is shown below in **Figure 2.**

FIGURE 2 PARTIAL GENEALOGY OF EUROPEAN ROYAL FAMILIES



MOLECULAR ANTHROPOLOGY

Mitochondrial DNA analysis is also being used to probe even older mysteries—those of human origins. Until recently, these studies have been done only on the physical characteristics of humans and their ancestors. In *molecular anthropology*, however, human characteristics can be studied genetically. A molecular anthropologist studies the similarities and differences of DNA and mtDNA of different groups of living humans to determine evolutionary and migratory patterns. Molecular anthropologists also study the mtDNA of modern humans and that of fossilized human remains in an effort to determine the early origins of the human race. Molecular anthropologists try to determine when and where the first humans lived and how and where those early humans migrated.

DISEASE AND MITOCHONDRIAL GENETICS

There are also applications of mtDNA analysis in medicine. To date, forensic investigations have found mutations in the genetic code of mtDNA that are related to disease. Some of these mutations may cause more than one disease or may cause different diseases to occur at different periods in a person's lifetime. Other investigations have found that certain toxins and drugs can cause mutations in mtDNA or interfere with its replication. One such relationship has been found with some of the drugs used to treat HIV/AIDS. The amount of mtDNA in these patients is smaller than normal, and these patients develop severe muscle weakness as a result.

Aging is the most common of all genetic diseases. Forensic investigators are trying to determine how the inherited genetics of mtDNA and any subsequent mutations affect the aging process. Current investigations into Parkinson's disease and Alzheimer's disease are attempting to determine if these diseases are related to mtDNA mutations.

Careers in Forensic Science

Mitochondrial DNA analysis is but one of many new technologies being developed for use in forensic science. With the rapid growth in this field, there are many different career opportunities in forensic science.

QUESTIONED DOCUMENT EXAMINATION

Forensic scientists who work in the area of questioned document examination determine who is the author of a document or how a document was created. Specifically, these scientists may try to determine whose handwriting is on the document, the machine (typewriter, copier, or fax) and the inks used to create the document, and the material on which the document is written. Researchers are now looking at ways to analyze the language patterns in a document, including particular words and phrases, the sentence construction, and verb tenses, to help identify the author of the document.

LATENT FINGERPRINTS RESEARCH

Many forensic analysts try to find fingerprints at a crime scene: this evidence is vital to many investigations. The old method of "dusting" for fingerprints is very time consuming, and some prints may be missed. New methods are being developed that allow an entire room, or even an entire house, to be scanned for fingerprints in a matter of hours. One of the new methods uses fumes, produced when dried "super glue" is burned, to make *latent*, or hidden, fingerprints easily visible so that they can be analyzed. Researchers in this area have to understand how particular chemicals react with the chemicals in a fingerprint.

TRACE EVIDENCE EXAMINATION

Glass fragments, paint chips, and gunpowder residue are examples of trace evidence. A forensic scientist in this area analyzes these very small samples by using both physical and chemical tests, which may destroy the sample. New research is underway to find ways to analyze very small samples. Some methods being investigated are sophisticated types of chromatography, laser scanning, and fluorescent imaging.

FIREARMS ANALYSIS

A gun's barrel leaves a set of scratches on the bullet fired from the gun. Because these scratches are unique to each gun, it is possible to identify the particular gun that fired a bullet. The firearms analyst compares these scratches to other scratched bullets in an attempt to match the bullet to a particular gun. Firearms analysts hope to create a computer database filled with gun scratch patterns. Then, the scratch pattern on a bullet fired from a gun would be scanned into a computer for comparison with the database of scratch patterns from specific weapons.

FORENSIC DENTISTRY

If a dead body has been badly burned or has decomposed, identification of the remains may be very difficult. In such cases, the only parts of the body left intact are often the jaws and teeth. A forensic dentist can identify human remains based on dental records, if the records exist. The forensic dentist may perform a dental exam during an autopsy, which may include X rays and charts of the teeth and the skull. In other cases, the forensic dentist may examine bite marks on a victim for comparison with the tooth patterns of a suspect. The examination of dental injuries that occurred during a crime is another task that may be required of the forensic dentist.

Topic Questions

1. Describe in one sentence what a forensic scientist does.

2. Where is mtDNA found, and how does it differ from the DNA in the nucleus?

3. What new method is being developed for determining the author of a document?

4. How can a firearms analyst tell what gun a certain bullet was fired from?

5. A corpse is discovered buried in a field. It may be a person who was reported missing a few years ago and is now feared dead. The body is decomposed and is not easily identifiable. Suggest a way that the body might be identified.

Name _____ Class _____ Date _____

Procedure Introduction

A Lesson on Chromatography

Green paint has been thrown all over several walls of a local business. The police have several suspects and have found some green paint at each of the suspects' homes. How can the police determine if any of the suspect samples match the paint thrown on the walls?

BACKGROUND

Chromatography is a technique used to separate a mixture of different substances based on the polarity of the molecules of the substances. It was originally developed in 1903 by a Russian botanist, Mikhail Tswett, who used this approach to separate colored plant pigments. The word means "to write with colors" and comes from the Greek words *chroma*, "color," and *graphein*, "to write."

There are several types of chromatography, each one depending on the nature of the substance in a mixture. In most types of chromatography, *polarity* is the basic principle at work. Water is the best example of a polar substance: its molecules have an uneven distribution of electrical charge, which means that one side of a water molecule strongly attracts the other side of the water molecule next to it. Polar substances have strong attraction to each other because of their molecules' ability to attract one another in this way, whereas nonpolar substances, such as oils, have a much stronger attraction for each other than for polar substances.

HOW CHROMATOGRAPHY WORKS

All kinds of chromatography involve two phases in contact with each other: a *mobile phase* and a *stationary phase*. **Table 1,** below, shows some examples of what forms these can take in different types of chromatography.

TABLE 1 SOME TYPES OF CHROMATOGRAPHY

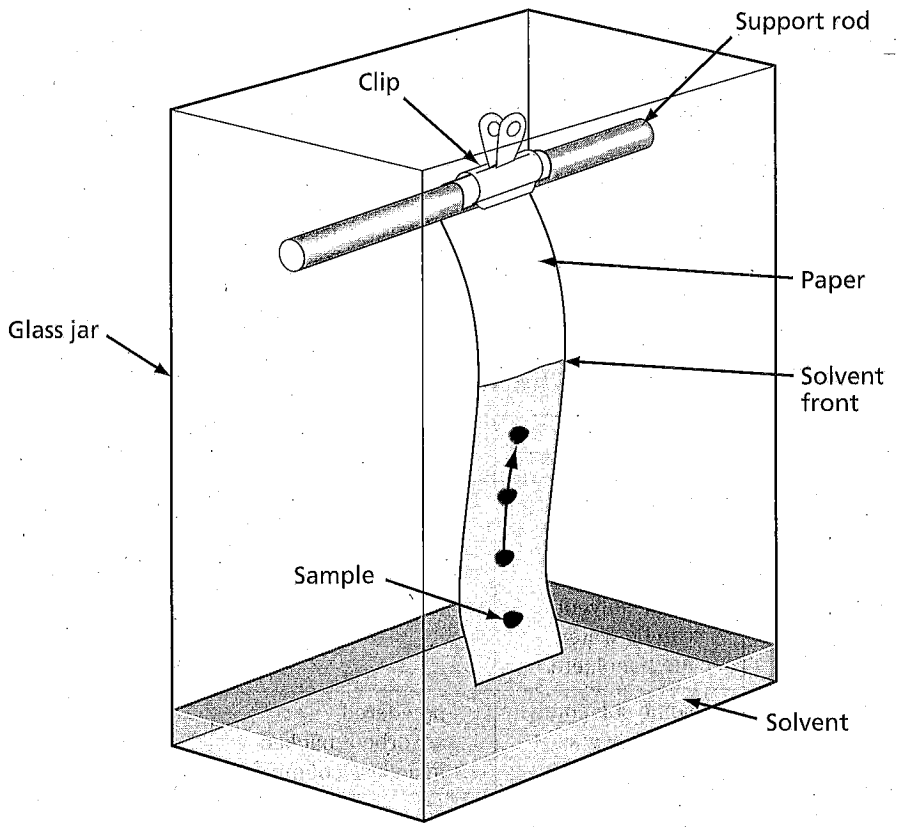
Category	Mobile phase	Stationary phase	Separating principle
Paper chromatography	some solvent; can be water, methanol, etc.	paper	polarity of mixture components relative to mobile phase
Thin-layer chromatography	some solvent; can be water, methanol, etc.	silica gel plate	polarity of mixture components relative to mobile phase
Column chromatography	some solvent; can be water, methanol, etc.	powdered adsorbent packed in a glass column	polarity of mixture components relative to mobile phase

The mobile phase is a solvent that dissolves some or all of the substances to be separated in the mixture. The stationary phase on which the mixture is placed is often some type of solid material such as chromatography paper or a thin layer of a gel coating a glass or plastic plate. As the mobile phase moves through or across the stationary phase, the stationary phase separates the components of the mixture. The result of the process is called a *chromatogram*, named for the colored bands produced when the separation involves a mixture of colored substances.

PAPER CHROMATOGRAPHY

A paper chromatogram is produced by placing a sample of the mixture to be separated near one end of a piece of chromatography paper (the "stationary phase"). The paper is placed into a container so that the paper hangs free without touching the walls of the container. A solvent, the "mobile phase," is placed into the container. The solvent level should not be higher than the sample spot or the mixture will dissolve in the solvent instead of traveling up the paper. A diagram showing the setup for paper chromatography is shown below in **Figure 1.**

FIGURE 1 EXPERIMENTAL SETUP FOR PAPER CHROMATOGRAPHY



While the paper is in contact with the solvent, the solvent moves upward through the paper. Substances in the sample mixture are dissolved by the solvent and move along the paper with the solvent. As the solvent moves through the paper, the molecules of the dissolved substances are attracted to both the solvent and the paper. The strengths of these attractions are determined by how polar the substance is. Polar substances will have a greater attraction to one of the phases than substances that are nonpolar. Because these attractions are different for each substance in a mixture, each substance moves through the paper at a different rate. The substances with a greater attraction to the solvent move faster and farther along the paper. Those with a greater attraction to the paper move more slowly, and consequently, not as far as other substances. Polar solvents tend to work best with substances that are also polar, such as water-based inks and dyes. A less-polar solvent will tend to work best with nonpolar or weakly polar substances, such as oil-based inks and dyes.

In addition, large molecules tend to move more slowly than small molecules because the large molecules cannot easily pass through the stationary phase material. The result of the differences in attraction and size cause the various substances to separate into distinct areas on the paper. The paper is removed from the solvent before the solvent reaches the end of the paper opposite the solvent. The paper is then allowed to dry, producing a permanent record that can be analyzed or processed further.

For a given mixture, the choice of the solvent used for the mobile phase can affect the results obtained. The solvent used for the mobile phase should dissolve most or all of the components of the mixture. A polar solvent is more likely to give good results with substances that are polar. Likewise, a nonpolar solvent is more likely to give good results with nonpolar substances. Water, methanol, and acetic acid are examples of highly polar solvents. Petroleum ether, cyclohexane, and methylene chloride are examples of solvents that are nonpolar.

HOW TO USE CHROMATOGRAPHY

Paper chromatography is often used as a tool for comparing the makeup of two or more mixtures. If the chromatogram is the same for each mixture, then the mixtures are probably the same. If the chromatograms are different, then the mixtures are probably different. Often, different samples to be tested are placed on the same piece of chromatography paper. This way, the conditions that create the chromatogram are the same for all the mixtures.

Not every solvent will give good results. A chromatogram produced using a particular solvent may drive all the components of the mixture up the paper too quickly, and another solvent may not cause the particular components of a mixture to travel up the paper at all. The right solvent for a mixture will give clear and consistent separation between the mixture's components.

Name _____ Class _____ Date _____

A Lesson on Chromatography *continued*

1. In chromatography, what are the functions of the mobile and stationary phases?

2. Red dye can be made from a mixture of yellow dye and magenta (a deep purplish red) dye. How could you determine if a particular red dye is made from a single dye or from a mixture of yellow and magenta dyes?

3. Two mixtures are compared using chromatography. Why is it desirable to place samples of both mixtures on the same paper when making the chromatogram?

4. A paper chromatogram is made for a particular mixture. The colored bands that result from the chromatography run are so close to each other that they overlap, making the chromatogram difficult to interpret. What change or changes could be made to increase the separation between the colors? Explain.

Name _____ Class _____ Date _____

Forensics Lab

The Athletic Rivals

The Case

Jason scowled at the broken windshield glass on the parking lot pavement. "Kyle's gonna pay for this," he muttered. His car had been vandalized sometime during the day.

Rivals for the role of starting quarterback on the football team, Kyle and Jason have been steadily growing more at odds with each other. "Those threatening notes I've gotten—and I know it was Kyle who wrote them—said something like this might happen," he told the campus police officer who had come to the scene, "and now it has. At least we know who did it."

"Hold on a minute," Officer Harlow said, "do you have proof that Kyle wrote the note you're referring to?"

Jason hesitated a moment. "Well, no, but who else could it be?"

"If we can find some way to prove Kyle threatened to do this, then you could file charges against him. Until then, I don't know what else you could do."

"So how do we do that?" Jason asked.

"You give me that threatening note, and I'll talk to Kyle," said officer Harlow.

Officer Harlow made a search of Kyle's locker and found two pens that look like they could have been used to write the note that Jason turned over as evidence. Kyle denies writing the note and any involvement in the vandalism.

The two pens and the note threatening vandalism to Jason's car, have been turned over to you, forensic lab analyst. Your job is to prepare paper chromatograms for Kyle's two suspect pens and for the ink extracted from a threatening note to see if there is a pigment match.

OBJECTIVE

Determine by examination of pigments through chromatography whether a suspect pen could have been used to write a threatening note.

MATERIALS

- open-ended capillary tubes (3)
- chromatography paper (6 strips)
- dropper bottle of distilled water
- dropper bottle of methanol
- segment of threatening note
- suspect pens
- thumbtacks (6)

EQUIPMENT

- 25 × 200 mm test tubes (6)
- test tube rack
- #4 no-hole rubber stoppers (6)
- single hole puncher
- 10 mL graduated cylinder
- spot plate
- scissors
- thumbtacks (6)

SAFETY 

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- Methanol is poisonous. Wear protective gloves when handling methanol. (Notify your teacher if you are allergic to latex.) Avoid prolonged exposure to vapors and use in the hood or a well-ventilated area, as directed by instructor. Keep methanol away from heat and flames, as it is flammable.
- In the event methanol gets on skin or clothing, wash the affected area immediately at the sink with copious amounts of water, keeping affected clothing away from skin. In the event of a chemical spill, notify the instructor immediately. Spills should be cleaned up promptly as directed by the instructor.
- Handle all glassware with caution. In the event of a cut or puncture from broken glass or scissors, notify the instructor immediately.

Procedure

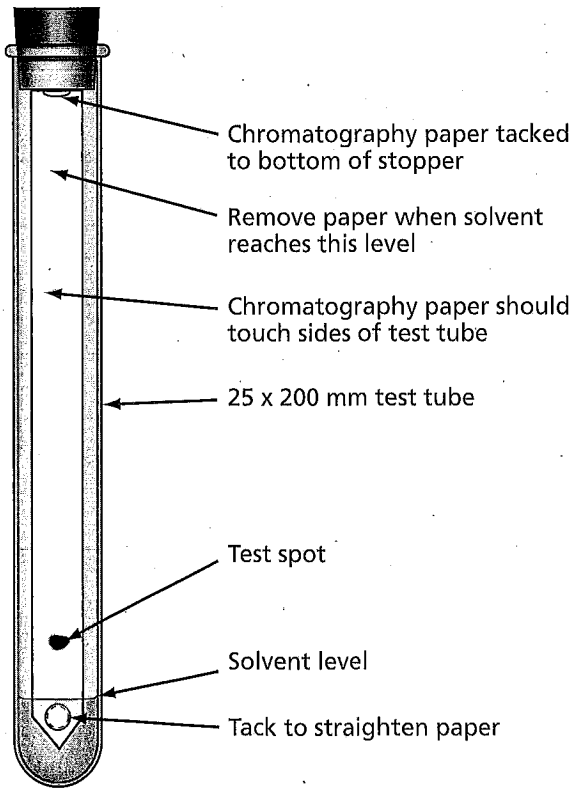
Some inks are water soluble and others dissolve in methanol, so you will need to make six chromatographic runs: inks from suspect pen 1, suspect pen 2, and the note will each be tested once with water, and once with methanol, as solvents.

1. Cut a length of chromatography paper so that it extends the entire length of a test tube. Bend the top of the paper at a right angle and tack it to the bottom of the rubber stopper. Push a thumbtack through the paper near the bottom to make it hang straight down in the tube so that the solvent can travel upward (take care not to puncture your fingers).
2. Repeat step 1 until you have made six paper/test tube setups. Each paper segment should be of identical length and width, and make sure that the segments do not touch the sides of the test tubes.
3. To extract ink from the note, use a hole puncher to punch about 40 holes in the note from areas containing ink. Place half of these small circles into a spot plate well, and then add a few drops of water (for the water run).
4. Place the rest of the punched holes containing ink into another spot well, and add methanol (for the methanol run) to dissolve and remove the ink from the paper.
5. Using a capillary tube, remove some of the water-based note ink solution. Spot this solution onto one of the paper lengths, about 2 cm above where the solvent level will be. Repeat this spotting process (allowing each spot to dry before applying another on top of it) several times to build up a concentration of note pigment that will yield good results.
6. To prepare chromatograms for the two suspect pens, simply mark spots about 3 mm in diameter directly onto a chromatography strip for each pen, about 2 cm above where the solvent level will be, as in the chromatogram prepared by spotting in step 5.

The Athletic Rivals *continued*

7. Repeat steps 5 and 6 to spot the methanol-based ink solution and ink from the two suspect pens onto three additional strips of chromatography paper, respectively. Be sure to keep track of which chromatogram was spotted with the water-based ink solution and which was spotted with the methanol-based ink solution.
8. Place 8 mL of water into each of three test tubes. Place 8 mL of methanol into each of another three test tubes.
9. A diagram of the chromatography setup is shown in **Figure 1** below. Place the stoppers with attached paper lengths into the test tubes. Be sure to place the methanol-ink spotted chromatograph into one of the test tubes with methanol as the solvent, and the water-ink spotted chromatograph into one of the test tubes with water as the solvent. Make sure the ink spot on each chromatography strip does not touch the solvent (water or methanol).
10. Allow the solvent to move up the paper and separate the pigments in the ink (this process may take up to 30 minutes). Stop the runs by removing the papers from the test tubes when the solvent level has risen to within a few centimeters of the bottom of the stoppers, and allow the chromatograms to dry overnight. Dispose of materials as directed by your teacher.

FIGURE 1 PAPER CHROMATOGRAPHY SETUP



Postlab Questions

1. Are the pigments of the note ink and the order of these pigments consistent with the pigments and order of pigments of the suspect pen inks?

2. If the note pigments match one of the suspect pens, how exactly does this help answer the question of whether Kyle wrote the note?

3. What factors could affect the accuracy of your results? How could your procedure have been improved in order to control for these factors?

4. What additional tests could be conducted to make the results of the case more certain?

Name _____ Class _____ Date _____

Forensics Lab

The Questionable Autograph

The Case

"I've been ripped off! What can I do now?" Juan complained. "I was so excited to win an online auction for a ticket stub autographed by my favorite ballplayer, but I really don't think it's authentic."

"What makes you think so?" Ms. Pierson asked.

"I heard he signed an endorsement with a certain brand of pen to sign autographs with only their pens, and this doesn't look like it was signed with that type of pen—it looks like it was just signed with a regular ballpoint pen! I contacted the online auction company with my complaint and they told me they were just about to ban the seller because of complaints, and that an investigation of mail fraud was underway. That's when I called you," Juan said.

"You called the right person," Ms. Pierson said. "As a U.S. Postal Inspector, it's my job to investigate all reports of mail fraud. I'll need to take that ticket stub back to the lab so that we can analyze the ink to see if it comes from the right kind of pen. The ticket stub will have to be destroyed in the process, though."

"Well, all right, if that's the only way to get my money back," Juan said, as he reluctantly handed over the evidence.

Ms. Pierson has turned the signed ticket stub over to you, forensic lab analyst, to compare by thin layer chromatography (TLC) the ink from the questioned item with ink from the type of pen the athlete would have used.

OBJECTIVE

Determine by examination of pigments through thin layer chromatography if an autograph was written with a particular type of pen.

MATERIALS

- open-ended capillary tubes (2)
- thin layer chromatography plates (2)
- dropper bottles of distilled water and methanol
- suspect autographs, and ink samples from an authentic pen

EQUIPMENT

- 2-oz. glass bottles with caps (2)
- graduated cylinder, 10 mL
- ruler
- single-hole puncher
- spot plates
- teasing needle or pushpin

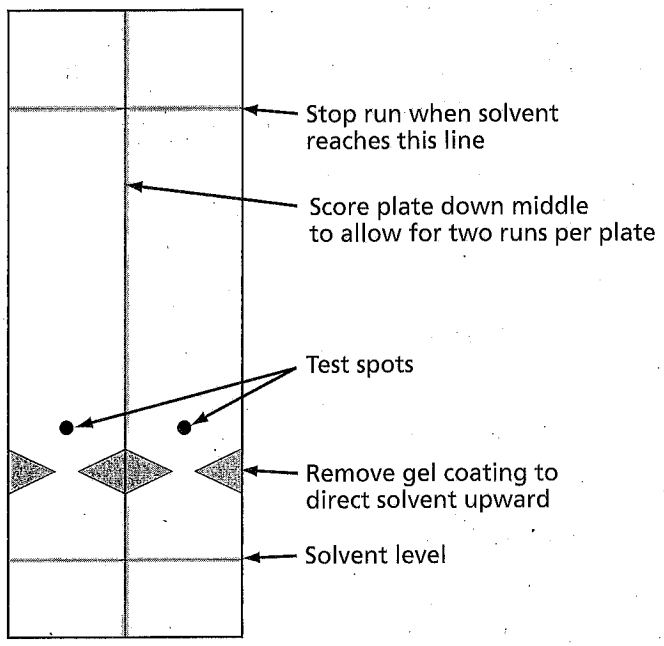
SAFETY

- Methanol is poisonous. Wear protective gloves when handling methanol. (Notify your teacher if you are allergic to latex.) Avoid prolonged exposure to vapors and use in the hood or a well-ventilated area, as directed by instructor. Keep methanol away from heat and flames, as it is flammable.
- In the event methanol gets on skin or clothing, wash the affected area immediately at the sink with copious amounts of water, keeping affected clothing away from skin. In the event of a chemical spill, notify the instructor immediately. Spills should be cleaned up promptly as directed by the instructor.
- Handle all glassware with caution. If you cut or puncture yourself from broken glass or scissors, notify the instructor immediately.

Procedure

Some inks are water soluble and others dissolve in methanol, so you will need to conduct four thin layer chromatography (TLC) runs: two (one for the suspect ink and one for the authentic ink) using water as the solvent, and another two of the same samples using methanol as the solvent. Refer to **Figure 1** below for aid in the TLC setup.

FIGURE 1 THIN LAYER CHROMATOGRAPHY PLATE SETUP



The Questionable Autograph *continued*

1. Score two TLC plates in half lengthwise by scratching a line on the TLC gel coating with the teasing needle or pushpin, to allow two runs per plate. Also scratch off some of the plate coating from the sides of the plate below the test spots, as shown in **Figure 1** on the previous page. This will help the solvent to migrate more directly upward so as to achieve better dye separation on the plate.
2. To extract ink from an autograph, use a hole puncher to punch about 40 holes from areas containing ink. Place half of these small circles into a spot plate well and then add a few drops of water to dissolve and remove the ink from the paper.
3. Place the rest of the paper punches containing autograph ink into another spot plate well, and add a few drops of methanol to dissolve and remove the ink from the paper.
4. Repeat steps 2 and 3 with ink samples from the authentic pen.
5. You will use one of the TLC plates to run the suspect and authentic inks side by side with water as the solvent, and the other TLC plate to run the suspect and authentic inks side by side with methanol as the solvent. Use a capillary tube to spot some of the suspect ink onto the TLC plates (about 1 cm above where the solvent level will be in the bottom of bottle. Allow the initial spots to dry, then place more ink on top of the previous spots. Repeat this process a few times to build up a concentration of pigment that will yield good results.
6. Use a different capillary tube to place authentic ink on the other side of the TLC plates in the same way as you did the suspect ink in step 5. Be sure to keep track of which side on each plate is being used for which ink sample.
7. Place 5 mL of solvent into each of the two bottles: one with water and one with methanol. It is important for both runs to have the test spots be 1 cm above the solvent level and not immersed or even touching the solvent initially.
8. Place the TLC plates, as upright as possible, into the bottles, screw on the caps, and allow the solvents to move up the plates and separate the pigments in the ink. Observe the process carefully, as it may take just a few minutes, or up to 30 minutes, for the solvent to move to the top of the plate. When the solvent level has risen to within a centimeter of the top of the plate, remove the plate from the bottle. Allow the TLC plates to dry overnight before examining them.
9. Dispose of materials as instructed by your teacher.

Postlab Questions

1. Are the pigments contained in the suspect and authentic inks similar?

2. If the two inks tested are identical, does this prove with certainty that the autograph is authentic?

3. What factors could affect the accuracy of your results? How could your procedure have been improved in order to control for these factors?

4. What additional tests could be conducted in order to make the results of the case more certain?

Name _____ Class _____ Date _____

Procedure Introduction

A Lesson on Spectroscopy

You enter your chemistry laboratory and find a note left by your research assistant that reads, "Use these for your analysis." There are two flasks containing yellow solutions nearby. One is labeled with the concentration but does not state the identity of the chemical compound, and the other is labeled with the identity of the chemical compound but not the concentration. How would you determine the identity of the first solution and the concentration of the second solution?

BACKGROUND

The technique known as *spectroscopy* was perfected in the 1850s and was publicly announced to the scientific community in 1859. The fundamental principle behind spectroscopy is that each element will emit or absorb a different pattern of electromagnetic waves. Spectroscopy was first used as a means of identifying chemical elements.

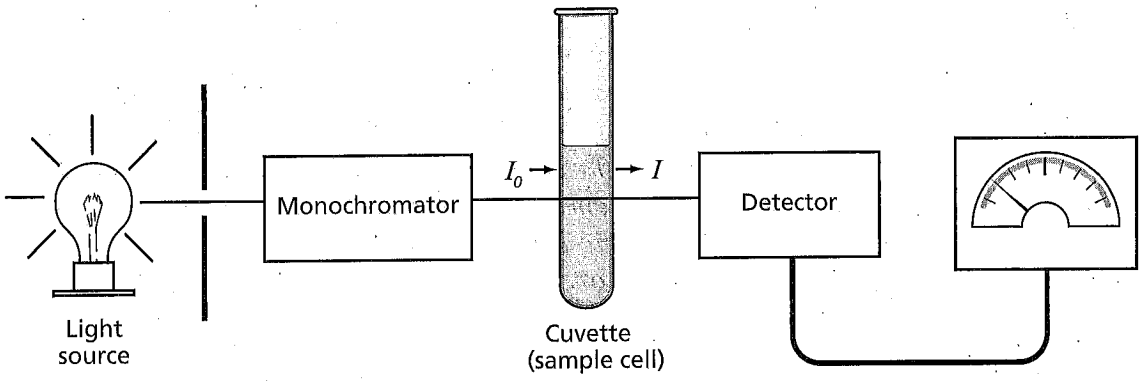
The range of light waves (electromagnetic spectrum) emitted by an element heated to incandescence consists of a set of bright lines at wavelengths unique to that particular element. When white light passes through a gas containing the same element, the spectrum produced has dark lines at exactly the same wavelengths as a spectrum produced by incandescence. In either case, as the amount of the element present increases, the intensity of the bright lines increases or the dark lines become darker.

SPECTROPHOTOMETRY: VISIBLE-LIGHT SPECTROSCOPY

Spectroscopy also works on liquid solutions of pure substances, which absorb electromagnetic radiation only at certain wavelengths. *Spectrophotometry* is a type of spectroscopy that relies on the absorption of electromagnetic radiation, at or near the range of visible light, at specific wavelengths through a certain substance, often a substance in solution. So, using spectrophotometry to analyze a solution requires a source of light that can be adjusted to a known wavelength and a means of measuring the intensity of the light after the light has passed through the solution.

A special type of test tube called a *cuvette* holds the solution being analyzed. Cuvettes have flat parallel sides, and transmit light very uniformly. This way, the conditions under which samples are analyzed can be as controlled as possible from one test to the next. On many spectrophotometers, you can set the meter to display the measured light intensity as either percent transmittance, which is a measure of how much light of the measured wavelength came through the solution, or as absorbance, which is the opposite: the amount of light that the solution absorbed, which did not pass through.

FIGURE 1 SPECTROPHOTOMETER SCHEMATIC



A basic schematic of a spectrophotometer is shown above in **Figure 1.** A light source, (a), emits light, which passes through a monochromator, (b). The monochromator filters the light so that only light of the desired frequency will pass through the sample chamber, (c), containing a cuvette with the solution to be tested. I_0 in **Figure 1** above represents the intensity of the light as it enters the sample. The intensity of the light, I, is measured by a detector, (d). The difference between I_0 and I is displayed on a meter, (e), as the absorbance, or transmittance, depending on what the machine has been set to measure.

Absorbance, A, is the logarithm of the ratio of the light intensity entering the sample, I_0, to the light intensity emerging from the sample, I.

$$A = \log (I_0/I)$$

So, the more light a substance lets through, the closer I will be to I_0 and the lower the absorbance value will be. Note that absorbance is a number without units and that it can have any positive value. The percent transmittance, $\%T$, of a solution is 100% multiplied by the ratio of the light intensity emerging from the sample to the light intensity falling on the sample.

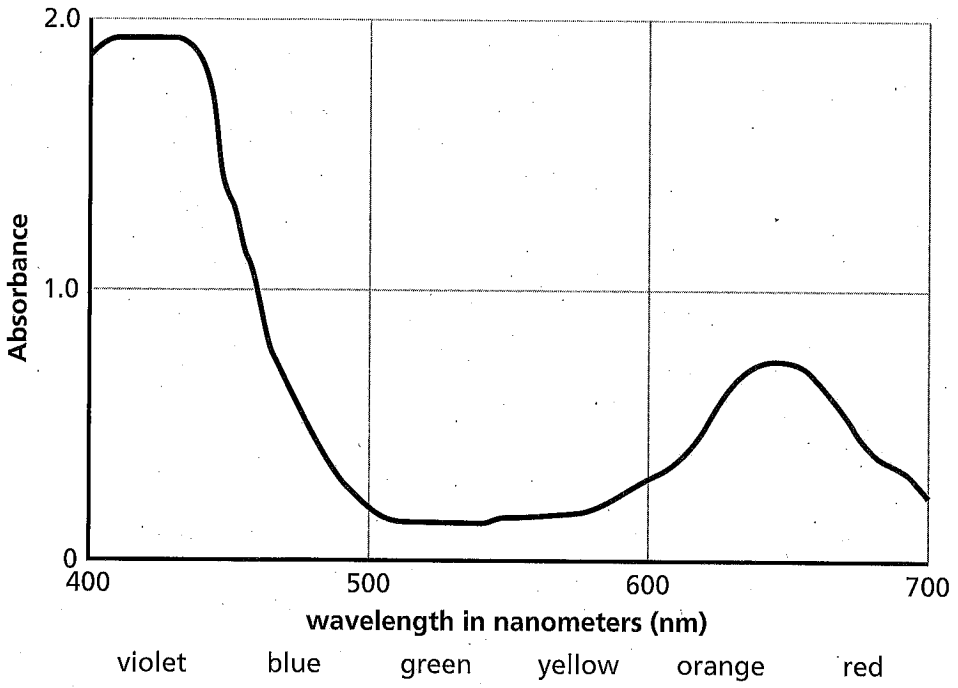
$$\%T = 100 \times (I/I_0)$$

The equation above reflects the fact that the more light that passes through the sample, the higher the percent transmittance will be. Absorbance can be found from percent transmittance using the equation below.

$$A = \log\left(\frac{100\%}{\%T}\right)$$

After setting a certain wavelength and before taking measurements, a spectrophotometer must be calibrated by placing a cuvette containing the solvent used to make the solution into the sample compartment. The spectrophotometer is then set to read zero absorbance (or 100% transmittance). This cancels out any absorption by the cuvette or by the solvent itself and controls for any variation in light intensity at different wavelengths. This calibration, or "zeroing out," is done to ensure that any light absorption measured by the spectrophotometer will be due only to the substance being measured.

FIGURE 2 ABSORPTION SPECTRUM OF A LEAF PIGMENT EXTRACT



How to Use Spectrophotometry

IDENTIFYING A SUBSTANCE BY ABSORPTION CURVE

Spectrophotometry can be used to identify an unknown substance. If data is taken for absorbance readings over a range of wavelengths and plotted as a graph of absorbance versus wavelength, they produce an absorption curve that is characteristic of that substance. An example of such an absorption spectrum is shown in **Figure 2** above. An absorption curve can be plotted for an unknown substance and compared with that of a known substance suspected to be the same as the unknown substance. If their absorption curves match, they are probably the same. The height of the absorbance peaks may vary from sample to sample based on concentration; the unique identifying factor, however, is the wavelength at which these peaks occur in an absorption spectrum.

MEASURING CONCENTRATION BY USING BEER'S LAW

A spectrophotometer can also be used to measure concentration. The relationship between absorbance and concentration is *Beer's law*, which can be expressed as $A = abC$, where A is the measured absorbance of the solution, a is the *absorptivity* of the substance, b is the length of the light path through the substance, and C is the concentration of the substance in solution. Absorptivity, a, is a constant for a given substance, and b is a constant for a given spectrophotometer. This means that a and b can simply be disregarded during an experiment using the same substance in solution and the same spectrophotometer.

A Lesson on Spectroscopy *continued*

This leaves a simple proportionality between absorbance and concentration:

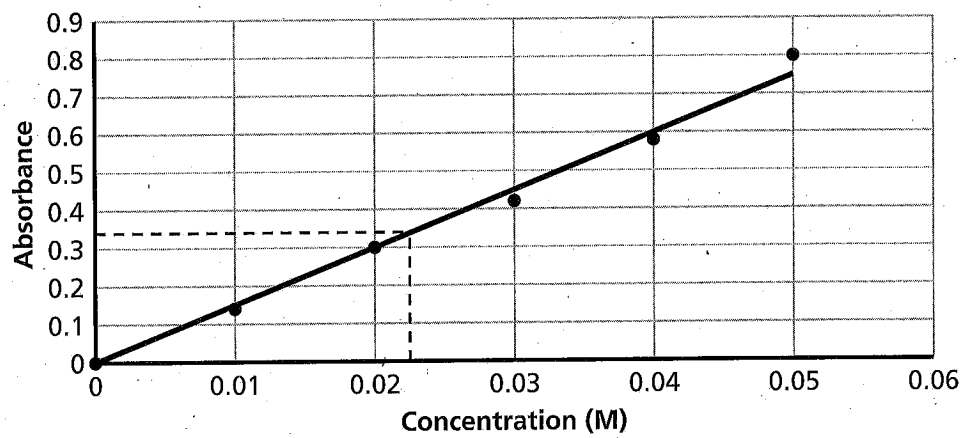
$$A \propto C.$$

This equation reflects the simple linear relationship between absorbance and concentration: the more concentrated a solution, the more light it will absorb (and the darker it will appear).

To use spectrophotometry to determine the concentration of a substance, it is necessary to compare measurements to a standard curve. To create such a curve, you measure the absorbance of solutions of known concentrations at the substance's wavelength of maximum absorption. Absorbance is usually used instead of percent transmittance because absorbance is directly proportional to concentration and thus should result in a straight line, whereas transmittance is not. These data are plotted to produce a plot of absorbance versus concentration, an example of which is shown below in **Figure 3.**

A straight line is drawn through the data points as best as it can fit them: this reflects the linear relationship of absorbance versus concentration stated by Beer's law. The line must also pass through the origin of the plot, reflecting the fact that zero concentration must result in zero absorbance. Note that the individual data points may deviate slightly in either direction from the line. Data points often do not fit a line exactly because of errors that occur in procedure and measurement. However, if a straight line fit is possible, the plot can be used to determine unknown concentrations. For most substances in solution, Beer's law is only valid for absorbance values up to about 1. Beyond that range, inaccuracies tend to invalidate Beer's law.

FIGURE 3 AN EXAMPLE OF A BEER'S LAW STANDARD GRAPH



After a plot is done, the absorbance value of the unknown is determined using the same wavelength as the one used for the known concentrations. The concentration of the unknown can then be found by *interpolating* on the straight line in the standard plot. What this means is that after you take an absorbance reading of the unknown solution, you find where that absorbance occurs on the Beer's law plot. Then, you trace down to the x-axis from that point on the line to find the concentration that would be expected to provide that absorbance. For example, from the Beer's law graph in **Figure 3,** from an absorbance reading of 0.34, you would interpolate a concentration value of about 0.023 M.

IDENTIFYING A SUBSTANCE BY PARTICLE SETTLING RATE CURVE

A solid such as soil suspended in a liquid produces a condition called *turbidity:* this means that the liquid will appear cloudy. The cloudy appearance is the result of light reflected in random directions by the solid particles and light being absorbed by the solid particles. The amount of light that passes through such a liquid is a function of the amount of solid material suspended in the liquid. Spectrophotometry can therefore be used to measure absorbance in such a mixture.

Because much of the light passing into a turbid liquid is scattered rather than absorbed, the absorption spectrum produced is relatively flat with few, if any, peaks. An identifying absorbance curve, with peaks at various wavelengths, therefore cannot be obtained for a suspension as it can for a solution. Recall that a suspension is not a stable mixture: after having been mixed, it settles out upon standing. The turbidity of a suspension of a solid in liquid is related to its concentration of particles per liter, as well as how thoroughly it is mixed. Therefore, after you mix a suspension and measure its turbidity in a spectrophotometer, the rate of the mixture's settling can be measured by taking several absorbance readings over time.

As you have learned, density is a good way to identify a substance or compare two substances to see if they are the same. The speed at which the particulate substance in the water settles to the bottom of a container after being shaken up is also related to its density. Exact density determinations are hard to obtain in this way, but a settling rate curve can be used to compare two solids to see if they have the same density.

Topic Questions

1. If a substance has low absorbance, will its transmittance be low or high? Explain your answer.

2. You have two solutions of copper sulfate, one a deep blue and the other much paler. Is the first or second likely to be more concentrated? Is the first or second likely to have higher absorbance?

3. Two absorbance curves have peaks at the same wavelengths, but all of the absorbance values are greater on one of the two curves. Are the two curves plots of the same substance? Explain.

4. Why are absorbance values used instead of percent transmittance values when determining the concentration of a substance in solution?

5. You have two soil samples, both of the same particle size distribution, and you want to compare them to see if they might have come from the same place. How might spectrophotometry be used to accomplish this?

Practice Problems

1. The ratio of I_0 to I for a particular sample is 3:1. What would be the absorbance reading given by the sample?

2. What would be the percent transmittance of the sample mentioned in item 1?

3. What would be the absorbance reading of a sample that had a percent transmittance of 80.%?

4. At a wavelength of 490 nm, one sample of a solution has an absorbance of 0.27 and a second sample has an absorbance of 0.81. The sample with the absorbance of 0.81 is found to have a molar concentration of 0.54 M. What is the molar concentration of the sample with the 0.27 absorbance?

Name _____ Class _____ Date _____

Forensics Lab

The Fast-Food Arson

The Case

Everyone in town's been talking about the big fire at Junior's. It was *the* place to go after football games and the softball tournament, so most folks had been there many times.

Not many people knew that Preston had been fired the night before by the manager. Those who did had overheard Preston mutter, "I'll get even for this," under his breath as he stormed out at closing time.

When the fire had been put out just before sunrise, the arson investigation team had brought Aladdin, their dog partner, to the scene. Aladdin's keen sense of smell swiftly found the spot where the fire started, in a storage area near the back door. A few milliliters of a liquid accelerant, which may have been used to start the fire, were recovered at the scene.

Now it's up to you, county forensic lab analyst. The arson team has brought you their sample, and a court-ordered search of Preston's garage has turned up five petroleum mixtures. Your job is to see if the sample from the scene matches any of the mixtures in the garage.

OBJECTIVE

Compare accelerant from a crime scene with samples from a suspect's garage using spectroscopy absorbance curves.

MATERIALS

- sample of crime scene accelerant
- distilled water
- graph paper
- optical wipes, lint free

EQUIPMENT

- pipets (2)
- spectrophotometer, with accompanying cells

SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- Do not touch or taste any chemicals. Know the location of the emergency shower and eyewash station and know how to use them.

- In the event a chemical gets on skin or clothing, wash the affected area immediately at the sink with copious amounts of water, keeping affected clothing away from skin. In the event of a chemical spill, notify the instructor immediately. Spills should be cleaned up promptly as directed by the instructor.
- In the event that you cut or puncture yourself with broken glass, notify your teacher immediately. Broken glass should be cleaned up as directed by your teacher.

Procedure

1. Create a data table in which to record absorbance values (ranging from 0.0 to 1.0) for wavelengths over the range 400 nm to 650 nm, in increments of 10 nm.
2. Follow the manufacturer's directions for the amount of time the spectrophotometer should warm up. Set the machine to display absorbance values. Fill a clean cell with distilled water using a pipet. Wipe any water from the outside of the cell using lint-free wipes. Place the cell in the sample compartment of the spectrophotometer.
3. Adjust the wavelength of the spectrophotometer to 400 nm. Adjust the calibration knob on the spectrophotometer until the absorbance reading for distilled water is zero. This way, the spectrophotometer will give a reading only for any substance that is added to pure water (in this case, the accelerant sample), so the water in the solution will not factor into the actual data you collect.
4. Remove the cell containing distilled water from the spectrophotometer, and place it to the side for the time being, as you will need it in a minute. Using a different pipet, fill a clean, empty cell with accelerant solution. Wipe any solution from the outside of the cell using lint-free wipes. Place the cell in the sample compartment of the spectrophotometer. Measure the absorbance value of the accelerant solution at 400 nm. Record this value in your data table.
5. Remove the cell containing the accelerant solution from the spectrophotometer. Increase the wavelength with which the spectrophotometer will measure the absorbance to 410 nm. Insert the cell with distilled water into the sample compartment. Adjust the calibration knob until the absorbance reading for distilled water is zero at 410 nm. Remove the cell and place the cell with accelerant in the sample compartment. Measure the absorbance of this solution at 410 nm, and record the absorbance value in your data table.
6. Repeat steps 3–5 over the range of 420 to 650 nm by increments of 10 nm. Each time you change the wavelength that the spectrometer reads, you must rezero the spectrophotometer with the cell containing distilled water prior to recording the absorbance value of the crime scene accelerant.
7. When all data collection is complete, dispose of all solutions as directed by your teacher.

Analysis

1. **Graphing Data** After you have completed taking your data, plot the data on a piece of graph paper. Label the x-axis "Wavelength" and divide the axis into 10 nm increments from 400 nm to 650.nm. Label the *y*-axis "Absorbance" and mark it in equal intervals from zero to a convenient value slightly above your highest absorbance value. Then, plot the absorbance value for each wavelength on your graph and draw a smooth curve through the data points.
2. **Analyzing Data** Your teacher will provide you with a table giving the absorbance characteristics for the five suspicious petroleum mixtures from Preston's garage. Based on your results, do you think the accelerant obtained from the crime scene matches any of the substances found in Preston's garage? If so, indicate which, and what parts of your graphed absorbance data match the absorbance characteristics listed in the table given.

3. **Analyzing Methods** Why is an established procedure so important in analysis of this type?

Conclusions

1. **Drawing Conclusions** Should the police continue to investigate the possibility that Preston started the fire? What other investigations can be made to determine whether Preston started the fire?

Name _____ Class _____ Date _____

Forensics Lab

The Untimely Death

The Case

When Darlene went to the hospital for knee surgery after an accident on the softball field, her parents never suspected she wouldn't survive the operation.

The coroner has determined that Darlene had no conditions that could have caused her death during the surgery, so suspicion has shifted to the anesthesia administered. The anesthetic used during the operation may be safely used only in concentrations of 0.020 M or less. If it can be shown that the anesthetic was used at a concentration higher than this, then the anesthesiologist who gave Darlene the anesthetic would be liable for a malpractice suit.

Darlene's family has hired you, freelance chemical forensic investigator, to provide their legal team with hard evidence as to the cause of this tragedy. You have acquired a sample of the suspect anesthetic and will use a spectrophotometer to determine the concentration of anesthetic to see if it is greater than the safe amount. You will do so by interpolating from a graph of absorbance values of known concentrations.

OBJECTIVE

Determine the concentration of a solution using interpolation and Beer's Law.

MATERIALS

- sample of 0.050 M anesthetic
- sample of suspect anesthetic
- distilled water
- graph paper
- lint-free optical wipes
- grease pencil

EQUIPMENT

- spectrophotometer, with accompanying cells
- pipet (2)
- graduated cylinder, 10 mL
- small beakers (4)

SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- Do not touch or taste any chemicals. Know the location of the emergency shower and eyewash station and know how to use them.
- If you get a chemical on your skin or clothing, wash it off at the sink while calling to the teacher. Notify the teacher of a spill. Spills should be cleaned up promptly, according to your teacher's directions.
- In the event that you cut or puncture yourself with broken glass, notify your teacher immediately. Broken glass should be cleaned up as directed by your teacher.

Procedure

MAKING STANDARD SOLUTIONS

1. Your teacher will provide you with a beaker of 0.050 M standard solution of the anesthetic. Label this beaker "0.050 M" with a grease pencil. Using a clean pipet, transfer 10 mL of this solution into one of the 10 mL graduated cylinders.
2. If you "overshoot" the 10 mL mark on the graduated cylinder, use the pipet to transfer solution out of the graduated cylinder, then pipet a smaller amount into the graduated cylinder, and repeat if necessary until you get as close as possible to the 10 mL mark. Accuracy is very important in making standard solutions.
3. Empty the 10 mL of solution into an empty beaker. Shake as many of the last remaining drops as you can into the beaker. Set aside the graduated cylinder you just used, and do not use it again for the experiment.
4. Take a clean 10 mL graduated cylinder and measure exactly 10 mL of distilled water into it as you did with the solution, taking care to get as close as possible to the 10 mL mark.
5. Empty as much as possible of the 10 mL of distilled water into the beaker containing the 10 mL of solution you measured. Swirl the beaker gently to mix as thoroughly as possible. Label this beaker "0.025 M."
6. Repeat from step 1, but this time take 10 mL of the solution you just diluted, and dilute it with 10 mL of distilled water as you did before (Use a different clean graduated cylinder for each dilution.). Label this dilution "0.0125 M." Repeat once more, diluting 10 mL of the 0.0125 M solution, which you just made, with another 10 mL of distilled water, and label this solution "0.00625 M."

READING ABSORBANCE VALUES

1. Create a data table in which to record absorbance values for concentrations of known anesthetic concentrations 0.050 M, 0.025 M, 0.0125 M, and 0.00625 M.
2. Follow the manufacturer's directions for the amount of time the spectrophotometer should warm up. Set the machine to display absorbance values. Fill a clean cell to the fill line with distilled water using a clean pipet. Wipe any water from the outside of the cell using lint-free optical wipes. Place the cell in the sample compartment of the spectrophotometer.

3. Set the machine to display absorbance values, adjust the wavelength to the wavelength your teacher specifies, and zero the machine so that it reads 0.00 A. This way, the spectrophotometer will give a reading only for any substance that is added to pure water (in this case, the anesthetic sample), so that the water in the solution will not factor into the actual data you collect.
4. Use a pipet to fill a clean cell to the fill line with the 0.050 M standard solution. Wipe the cell clean with a wipe, insert it into the spectrophotometer, and record in your data table the absorbance reading it gives.
5. Repeat step 4 with the 0.025 M, 0.0125 M, and 0.00625 M dilutions of the standard solution, recording in your data table each absorbance reading.
6. Obtain a sample of the suspect anesthetic of unknown concentration and find the absorbance value for this unknown in the same way as you did in steps 4 and 5.
7. When all data collection is complete, dispose of all solutions as directed by your teacher.

Analysis

1. **Graphing Data** The relationship between concentration and absorbance is known as Beer's law, which states that the more solute that is present in a solution, the more light will be absorbed by the solution, and also that this is a linear relationship. The first data point on your graph should be at a concentration of 0.00 M and absorbance of 0.00 A, because if the concentration of the solute in a solution is zero, then no light passing through the solution will be absorbed by the solute.

   On a sheet of graph paper, label the x-axis "Concentration" and mark it in equal intervals from 0.00 M to 0.050 M. Label the y-axis "Absorbance" and mark it in equal intervals from 0.00 A to a convenient value slightly above your highest absorbance value (which should not be above 1).

   Plot the concentration and absorbance values for your four standard solutions, and use a ruler to draw the best straight line through the four points and the origin of the graph. It is important that your line pass through the origin: zero concentration should result in zero absorbance. This is your *Beer's law standard graph*, which will allow you to relate absorbance to concentration in a solution of unknown concentration.
2. **Interpolating Data** Mark the absorbance of the suspect solution on the y-axis of your Beer's Law standard graph, and use a ruler to draw a horizontal line from the point where it intersects the *standard line.* Then use your ruler to draw a vertical line down from this intersection to the x-axis. This process is called *interpolation.* The point of intersection with the x-axis is your estimate of the concentration of the suspect anesthetic. Clearly indicate this concentration on your graph.

3. **Analyzing Methods** Why is preparation of the dilutions of the standard solution such an important part of an analysis like this one? Why would a defense attorney want to create doubt about how the standard solutions were made?

4. **Analyzing Methods** For a Beer's Law interpolation, drawing a straight line through the data points is necessary because the Beer's Law relationship is a linear one. Why is drawing a straight line still acceptable even if the data points do not fit exactly on it?

Conclusions

1. **Drawing Conclusions** Based on your results, do you believe the anesthesia was the cause of death in the patient? Explain.

2. **Drawing Conclusions** What further tests or data analysis could be done in order to further eliminate doubts about the outcome of this procedure?

Name _____ Class _____ Date _____

Forensics Lab

INQUIRY LAB

The Assault at the Flower Shop

The Case

Staci has been attacked and robbed while returning to her car after closing her flower shop. As Staci left her shop after working quite late, she was attacked from behind by one person and wrestled to the ground. The day's cash receipts were stolen by a second person. In the course of the attack, Staci and her assailant ended up wrestling in an area where a fresh mix of special mulching soils had been dumped, and the composition of this unique soil may now be crucial to resolving the case.

Although Staci was unable to identify her attackers, she gave investigating officers the names of two former employees, Christine and Jen, who were recently fired by Staci and left their jobs vowing some form of revenge. They were located the following morning, and each denies any involvement in the attack and robbery. When questioned as to why some jeans in each of their laundry piles waiting to be washed had soil on the knees and seats, both Christine and Jen stated that they had been doing some yardwork the previous day. After the police looked at their yards, however, this claim seemed doubtful to the officers. Because the soil on Christine's and Jen's pairs of jeans is the only piece of evidence investigators have at this point, the soil needs to be analyzed to see if it is the same kind of soil as the mulching soil from the flower shop.

Your task as forensic lab analyst is to carefully analyze samples of the soils from each suspect's clothing and the flower shop mulching soil to see if a match can be made. You will gather soil settling rate data using a spectrophotometer and plot a curve. Your lab group will be responsible for testing only one of the three soils and will then compare your results with the work of others. Each type of soil will give a certain shape of curve, so comparing the curves will enable you to match soil types.

Objective

Plot a soil-settling rate curve of spectrophotometer data to determine if soil from suspect clothing matches that from a crime scene.

MATERIALS

- soil sample from either Christine's clothing, Jen's clothing, or the flower shop
- distilled water
- weighing paper
- graph paper
- wipes, lint free

EQUIPMENT

- spectrophotometer, with accompanying cells
- digital balance
- graduated cylinder, 10 mL
- wire mesh

SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- In the event that you cut or puncture yourself with broken glass, notify your teacher immediately. Broken glass and spilled soil should be cleaned up as directed by your teacher.

Procedure

Soil samples must be prepared for testing by passing them through wire mesh to remove debris and achieve uniform particle size among all the samples. This way, soil settling rates will be affected only by particle density—which will be the important factor in identifying the type of soil—and not particle size, which may differ throughout samples regardless of where they came from. Also, the masses of the soil samples tested must be equal. About 0.50 g is a good amount, but make sure whatever mass you use is the same for each sample.

After the spectrophotometer warms up, set the wavelength to 500 nm. Fill a spectrophotometer cell to the fill line with distilled water, and place it in the sample compartment. Use the calibrating knob to adjust the absorbance reading until it reads zero. This way, the absorbance of water itself will not be a factor in the measurements you make of the absorbance of soil samples.

Place your weighed soil sample into an empty spectrophotometer cell, and add distilled water to the fill line. Wipe the outside of the cell clean with a wipe. Just before inserting it into the spectrophotometer, cap the cell and vigorously shake it for two minutes. Allow any bubbles to rise to the top. To obtain a settling rate curve, take and record absorbance readings every one minute until five minutes after the absorbance value becomes stable. Initially the muddy water will cause most of the light to be absorbed, resulting in absorbance readings close to 1.00 or greater, but as the soil particles settle to the bottom of the test tube, the absorbance values will decrease. Each type of soil has a characteristic settling rate curve, and you are conducting this test to see if there is a match between either (or both) suspects and the soil known to have come from the floral shop crime scene.

1. Create a procedure that will allow you to plot the settling rate curve for the soil sample assigned to you. See the introduction pages on Spectroscopy, pp. 51–57, for hints. Discuss your procedure with your teacher for approval.
2. If your procedure is approved, carry out the experiment you have designed. Create a data table to record absorbance values and the time of each.

Postlab Questions

1. Plot the absorbance values on the y-axis versus time (in minutes) on the x-axis. Discuss and compare your settling rate curve with lab groups analyzing the other suspect or crime scene samples.
2. Based on the class's total results, do you believe that the soil on either suspect's clothing came from the crime scene?

3. Explain, in your own words, why it was necessary to sift the soil samples through wire mesh before testing them.

4. Why is an established procedure so important in analysis of this type?

5. What other kinds of tests might be conducted on soil samples?

6. Generally, in what type of situation would soil type be of greatest value as evidence?

Name _____ Class _____ Date _____

Forensics Lab

INQUIRY LAB

The Neighborhood Burglaries

Prerequisite

- "Blood Typing" lab on pages 83–87

The Case

CITY OF OAKWOOD
POLICE DEPARTMENT
Oakwood, Missouri 65432-1221

December 18, 2005

Caitlin Noonan
Research and Development Division
BioLogical Resources, Inc.
101 Jonas Salk Dr.
Oakwood, MO 65432-1101

Dear Ms. Noonan,

We have recently had yet another series of burglaries. This time, all the victims have been residents of the same neighborhood. We were able to obtain some stained cloth samples from the last crime scene. According to the victim, he came home to find the burglar in his living room. The burglar broke a window to escape and was apparently cut by the glass. We believe that the cloth samples, which were found among the broken glass, are stained with the burglar's blood.

We are trying to solve this case as quickly as possible. Many of the residents in the area are concerned for their property and their safety. So far we have four suspects. All of them were seen near the crime scene, and all of them have cuts that could have been made by broken glass. We have blood samples from all four suspects and from the latest victim as well. Unfortunately, our forensics expert called in sick early this week and will not be able to complete blood-typing tests until next week. We need your research company to complete the necessary blood tests to help us narrow down our list of suspects. We will provide you with the stained cloth samples and the blood samples that we have collected. Please let me know what you find.

Sincerely,

Roberto Morales

Roberto Morales
Chief of Police
City of Oakwood Police Department

BioLogical Resources, Inc. Oakwood, MO 65432-1101

M E M O R A N D U M

To: Team Leader, Forensics Dept.

From: Caitlin Noonan, director of Research and Development

Chief Morales has sent the blood samples he described in his letter, along with a list of tests that need to be completed. Please have your research teams examine the stain on the cloth to determine whether it is indeed blood. Then complete a blood-typing test for the crime-scene stain samples, the victim, and each of the four suspects.

Chief Morales told me that he was very pleased with the work your team did on the last burglary case. I congratulate you on your previous success and encourage you to complete this project with the same exemplary skill and determination that you have demonstrated thus far.

Proposal Checklist

Before you start your work, you must submit a proposal for my approval. **Your proposal must include the following:**

_____ • the **question** you seek to answer

_____ • the **procedure** you will use

_____ • a detailed **data table** for recording results

_____ • a complete, itemized list of proposed **materials** and **costs** (including use of facilities, labor, and amounts needed)

Proposal Approval: _____

(Supervisor's signature)

SAFETY 

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.
- Never use electrical equipment around water or with wet hands or clothing. Never use equipment with frayed cords.
- Wash your hands before leaving the laboratory.
- Under no circumstances are you to test any blood other than the simulated blood samples provided by your teacher.

Procedure

When you finish your analysis, prepare a report in the form of a business letter to Chief Morales. **Your report must include the following:**

_____ • a paragraph describing the **procedure** you followed to examine the crime-scene blood sample and to complete blood-typing tests on all six blood samples

_____ • a complete **data table** used for recording results

_____ • your **conclusions** about how the results indicate whether the crime-scene sample is indeed blood, and which, if any, of the other samples matches the blood type of the crime-scene sample

_____ • a completed **invoice** (see page 92) showing all materials, labor, and the total amount due

DISPOSAL

- Dispose of waste materials according to instructions from your teacher.
- Place used toothpicks in the waste disposal container indicated by your teacher.
- Place broken glass, unused simulated blood, unused antiserums, and used cloth squares in the separate containers provided.
- Wash reusable materials such as glassware and lab utensils, and return them to the supply area.

File: City of Oakwood Police Department

MATERIALS AND COSTS

(Select only what you will need. No refunds.)

I. Facilities and Equipment Use

Item	Rate	Number	Total
facilities	$480.00/day		
personal protective equipment	$10/day		
compound microscope	$30.00/day		
microscope slide with coverslip	$2.00/day		
scissors	$1.00/day		
ruler	$1.00/day		
hot plate	$15.00/day		
blood-typing tray	$5.00/day		
test tube	$2.00/day		
test-tube rack	$5.00/day		

II. Labor and Consumables

Item	Rate	Number	Total
labor	$40.00/hour		
4 stained cloth samples	provided		
vial of "Victim blood"	provided		
vial of "Suspect 1 blood"	provided		
vial of "Suspect 2 blood"	provided		
vial of "Suspect 3 blood"	provided		
vial of "Suspect 4 blood"	provided		
vial of anti-A typing serum	$20.00 each		
vial of anti-B typing serum	$20.00 each		
vial of anti-Rh typing serum	$20.00 each		
toothpicks	$0.10 each		
distilled water	$0.10/mL		
wax pencil	$2.00 each		
Fines			
OSHA safety violation	$2,000.00/incident		
	Subtotal		
	Profit Margin		
	Total Amount Due		

Name _____ Class _____ Date _____

Topic Introduction

An Introduction to Environmental Chemistry

You've heard of "environmental" issues. Air pollution, water pollution, endangered animal species, and global warming may come to mind. The environment we live in—the air we breathe, the water we drink, and even the soil in which our food is grown—is subject to chemical changes that can affect health, climate, and many other important concerns. Consequently, there are many opportunities for chemistry to be applied in solving environmental problems.

Environmental chemistry is simply the study of the chemical makeup of the environment and chemical changes that take place in the environment. One area of environmental chemistry uses organisms such as bacteria and fungi to help solve environmental problems, such as cleaning up various kinds of chemical pollution.

A CURRENT HOT TOPIC: BIOREMEDIATION

"Remediation" means finding a remedy, or solution, for an existing problem; *bioremediation* is the use of biological materials to solve an existing problem. Problems such as groundwater contamination, chemical spills, and oil spills are a few examples in which the use of bioremediation is proving effective.

One type of bioremediation uses bacteria and fungi to remove substances from the environment as they grow. Often, they take in chemicals as food sources or as nutrients or trace substances that help them grow. In most cases, they chemically change a substance into final products that are safe and do not pollute the environment. One of the main advantages of bioremediation is that once the nutrients are used up, the organisms die and thus do not create additional pollution. Most of the organisms used for bioremediation are ones that already exist in the environment, so they are natural to the environment.

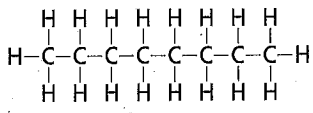
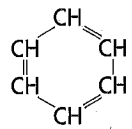
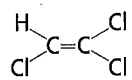
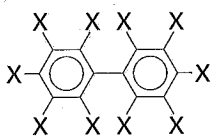
BIOAUGMENTATION

Most bioremediation involves *bioaugmentation*, which simply means adding organisms to the environment to help solve an environmental problem. Typically, one or more organisms are added to an area for the purpose of removing unwanted chemicals. Bacteria are the most commonly added organisms, but other organisms such as yeasts, algae, and fungi may also be used. Certain plant species have been found to remove toxic chemicals from soil and water. One plant example is locoweed, which can remove selenium from contaminated soils. In some cases, enzymes alone may be effective.

Certain kinds of chemicals are more *biodegradable* than others, as you probably know. This just means that some chemicals are easier to change into harmless chemicals than others are. This limitation applies to bioaugmentation, too: some chemicals cannot be easily changed by bioaugmentation into harmless ones. **Table 1** on the next page shows some classes of compounds with differing potentials for degradation.

TABLE 1 BIODEGRADATION POTENTIAL FOR CLASSES OF COMPOUNDS

Organic compounds closer to the top of this table are more biodegradable than compounds closer to the bottom.

Compound class	Example
Straight-chain hydrocarbon compounds	 *Octane*
Aromatic compounds	 *Benzene*
Chlorinated straight-chain compounds	 *Trichloroethylene (TCE)*
Chlorinated aromatic compounds	 X = H or Cl *Polychlorinated biphenyl (PCB)*

High potential

Low potential

BIOSTIMULATION AND BIOVENTING

Sometimes, the presence of certain naturally occurring organisms is a benefit to the environment. Research in the area of *biostimulation* is done to identify the particular nutrients that will encourage the growth of such organisms. One nutrient that is used in biostimulation is similar to ordinary fertilizer. Fertilizer supplies a source of nitrogen compounds, which are needed by most organisms but can be relatively scarce in many types of soil. Research has found that, in some cases, nutrients alone are not sufficient for some organisms' growth: they may also require a suitable surface, or substrate, to thrive, whereas others may need certain vitamins or minerals.

Microorganisms that are beneficial to the environment can also be helped by providing them with oxygen where they may otherwise have difficulty obtaining it. *Aerobic* organisms require oxygen to live, whereas *anaerobic* organisms are poisoned by the presence of oxygen. *Bioventing*, a variation of biostimulation, provides oxygen to aerobic organisms. Research in this area involves finding practical and economical methods of providing useful aerobic microorganisms with an abundant oxygen supply.

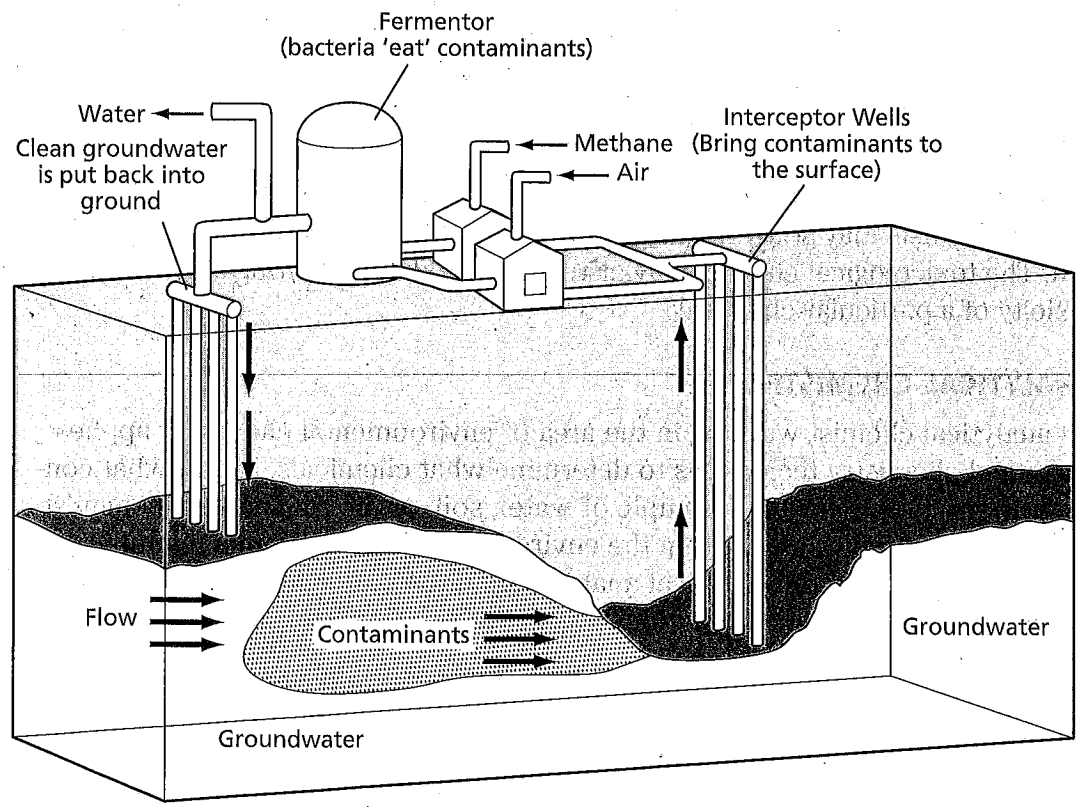
COMPOSTING AND BIOREACTORS

Gardeners make compost from weeds, plant trimmings, and grass clippings. These materials are allowed to "ferment" in a large pile, which causes the starting materials to break down. The resulting mixture of organic materials can be returned to the garden. Often, it will provide a good source of nutrients and trace elements, increasing plant growth.

Composting can also treat some materials contaminated with unwanted or hazardous chemicals. Composting includes a combination of several bioremediation techniques: biostimulation, bioventing, and bioaugmentation. Contaminated material is mixed with uncontaminated compost, bacteria, nutrients, and enough water to make the mixture slightly damp. The mixture is placed in a warm environment and aerated. After a period of time, the bacteria have converted the unwanted materials into harmless products. The composted mixture can then be used in a garden or placed in a landfill.

Bioreactors can perform some of the same tasks that composting accomplishes. A *bioreactor* is a large tank in which contaminated material is treated with microorganisms and enzymes. The materials in a bioreactor are usually kept mostly liquid. Bioreactors are used to remove pollutants from solid wastes, water, and soil. A diagram of a bioreactor being used to clean up contaminated groundwater is shown in **Figure 2** below. Treating large quantities of material with a bioreactor may be more expensive than other methods of bioremediation but may be the only alternative for some kinds of contamination.

FIGURE 2 A BIOREACTOR CLEANING UP CONTAMINATED GROUNDWATER



BIOFILTERS

A *biofilter* removes toxic or otherwise harmful materials from wastewater or gases before the water or gases are released into the environment. Wastewater treatment is probably the oldest example of the use of a biofilter. In a typical wastewater treatment, sewer water is passed slowly through a porous rock filter before it leaves the wastewater treatment facility. Bacteria growing on the rock break down various organic compounds contained in the wastewater. This process allows the output of a wastewater treatment plant to be safe enough to send out into the environment.

The treatment of organic gases, such as benzene vapor, is the main focus of current biofilter research. There are various types of filters that can be used, such as porous soil and compost, but all biofilters use microorganisms to break down the gas. A large part of this research involves finding organisms that will break down the gases. Once an organism is found, more work is done to find out how to keep it alive and effective.

Careers in Environmental Chemistry

In addition to the field of bioremediation, there are many other careers in chemistry that deal with environmental issues. Just a few are listed below.

ECOLOGICAL/ENVIRONMENTAL BIOCHEMISTRY

An ecological chemist studies the interaction between organisms and their environment and how chemicals in the environment affect these interactions. Of special interest to chemists in this field are chemicals that either do not occur naturally or that have become more concentrated in the environment because of pollution.

TOXICOLOGICAL CHEMISTRY

Toxicological chemistry is the study of the chemistry of toxic chemicals. Toxicological chemists may study how a chemical affects the tissues of a certain organism. The toxicological chemist may also be involved in measuring and assessing the toxicity of a particular chemical.

ANALYTICAL CHEMISTRY

An analytical chemist working in the area of environmental chemistry applies analytical chemistry techniques to determine what chemicals, and in what concentrations, are present in a sample of water, soil, or air. An analytical chemist may analyze samples taken from the environment or those from a manufacturing plant. The results of the chemical analysis are most often used to aid in determining whether government regulations regarding the chemicals are being followed.

Topic Questions

1. Describe in one sentence the purpose of bioremediation.

_____

_____

2. What types of organisms can be used for bioremediation? What type of organism is most commonly used?

_____

_____

3. What is the main advantage of using biological organisms to remove unwanted chemicals from the environment?

_____

4. How does composting differ from the use of a bioreactor?

_____

_____

_____

5. A particular organism used for bioremediation is anaerobic. Would this organism be suitable for use in bioventing? Explain.

_____

_____

6. Name and describe the branch of environmental chemistry that might be used to measure the concentration of a pollutant in a sample of air from the atmosphere.

_____

_____

_____

Name _____ Class _____ Date _____

Environmental Chemistry Lab

Extraction of Copper from Its Ore

Most metals are combined with other elements in Earth's crust. A material in the crust that is a profitable source of an element is called an ore. Malachite (MAL uh KIET) is the basic carbonate of copper. The green corrosion that forms on copper is due to chemical weathering. *Chemical weathering* is the process by which material such as rocks breaks down as a result of chemical reactions. This green corrosion has the same composition that malachite does. The reactions of malachite are similar to those of copper carbonate.

In this investigation, you will extract copper from copper carbonate using heat and dilute sulfuric acid. The process you will be using will be similar to the process in which copper is extracted from malachite ore.

OBJECTIVES

Perform an extraction of copper from copper carbonate in much the same way that copper is extracted from malachite ore.

Hypothesize how this process can be applied to extract other metallic elements from ores.

MATERIALS

- copper(II) carbonate (about 15 g)
- iron filings (about 5 g)
- sulfuric acid, dilute (about 100 mL)

EQUIPMENT

- beaker, 500 mL
- Bunsen burner
- funnel
- test-tube holder
- test-tube rack
- test tubes, 13 mm × 100 mm (2)

SAFETY

- Put on a lab apron, safety goggles, and gloves.
- In this lab, you will be working with chemicals that can harm your skin and eyes or stain your skin and clothing. If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher. If you get a chemical in your eyes, immediately flush it out at the eyewash station while calling to your teacher.

Procedure

1. **CAUTION: Wear your laboratory apron, gloves, and safety goggles throughout the investigation.** Fill one of the test tubes about one-fourth full of copper carbonate. Record the color of the copper carbonate.
2. Light the Bunsen burner, and adjust the flame.
3. Heat the copper carbonate by holding the test tube over the flame with a test-tube holder, as shown in the figure on the next page. **CAUTION: When heating a test tube, point it away from yourself and other students. To prevent the test tube from breaking, heat it slowly by gently moving the test tube over the flame.** As you heat the copper carbonate, observe any changes in color.
4. Continue heating the test tube over the flame for 5 min.
5. Allow the test tube to cool. Observe any change in the volume of the material in the test tube. Then, place the test tube in the test-tube rack. Insert a funnel in the test tube, and add dilute sulfuric acid until the test tube is three-fourths full. **CAUTION: Avoid touching the sides of the test tube, which may be hot. If any of the acid gets on your skin or clothing, rinse immediately with cool water and alert your teacher.**
6. Allow the test tube to stand until some of the substance at the bottom of the test tube dissolves. After the sulfuric acid has dissolved some of the solid substance, note the color of the solution.
7. Use the second test tube to add more sulfuric acid to the first test tube until the first test tube is nearly full. Allow the first test tube to stand until more of the substance at the bottom of the test tube dissolves. Pour this solution (copper sulfate) into the second test tube.
8. Add a small number of iron filings to the second test tube. Observe what happens.
9. Clean all of the laboratory equipment, and dispose of the sulfuric acid as directed by your teacher.

Analysis

1. **Explaining Events** Disregarding any condensed water on the test-tube walls, what substance formed in the first test tube? Write the balanced chemical equation of the reaction that occurred. Explain any change in the volume of the new substance relative to the volume of the copper carbonate.

2. **Explaining Events** When the iron filings were added to the second test tube, what indicated that a chemical reaction was taking place? Explain any change to the iron filings. Explain any change in the solution.

Conclusions

1. **Drawing Conclusions** Why was sulfuric acid used to extract copper from copper carbonate? Write the balanced equation for the reaction that occurs.

Extension

1. **Analyzing Data** Suppose that a certain deposit of copper ore contains a minimum of 1 percent copper by mass and that copper sells for $0.30/kg. Approximately how much could you spend to mine and process the copper from 100 kg of copper ore and remain profitable?

Name _____ Class _____ Date _____

Environmental Chemistry Lab

Effects of Acid Rain on Plants

Acid precipitation is one of the effects of air pollution. When pollutants that contain nitrogen or sulfur react with water vapor in clouds, dilute acid forms. These acids fall to Earth as acid precipitation.

Often, acid precipitation does not occur in the same place where the pollutants are released. The acid precipitation usually falls some distance downwind—sometimes hundreds of kilometers away. Thus, the sites where pollutants that cause acid precipitation are released may not suffer the effects of acid precipitation.

Coal-burning power plants are one source of air pollution. These power plants release sulfur dioxide into the air. Sulfur dioxide reacts with the water vapor in air to produce acid that contains sulfur. This acid later falls to Earth as acid precipitation.

In this investigation, you will create a chemical reaction that produces sulfur dioxide. The same acids that result from coal-burning power plants will form. You will see the effects of acid precipitation on living things—in this case, plants.

OBJECTIVES

Perform a chemical reaction that produces sulfur dioxide, a component of acid precipitation.

Hypothesize the effects acids containing sulfur will have on plants.

MATERIALS

- clear plastic bags, large (2)
- houseplants of the same type, potted (2)
- sodium nitrite, 2 g
- sulfuric acid, 1 M (2 mL)

EQUIPMENT

- beaker, 50 mL
- twist tie or tape

SAFETY

- Put on a lab apron, safety goggles, and gloves.
- In this lab, you will be working with chemicals that can harm your skin and eyes or stain your skin and clothing. If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher. If you get a chemical in your eyes, immediately flush it out at the eyewash station while calling to your teacher.

Procedure

1. Place 2 g of sodium nitrite in a beaker. Place a plant and the beaker inside a plastic bag. Do not seal the bag. **CAUTION: Steps 2–4 should be carried out only under a fume hood or outdoors.**
2. Carefully add 2 mL of a 1 M solution of sulfuric acid to the beaker. Immediately seal the bag tightly, and secure the bag with a twist tie or tape. **CAUTION: Because this reaction produces sulfur dioxide, a toxic gas, the bag should have no leaks. If a leak occurs, move away from the bag until the reaction is complete and the gas has dissipated.**
3. Seal the same type of plant in an identical bag that does not contain sodium nitrite or sulfuric acid.
4. After 10 minutes, cut both bags open while keeping the plants and bags under the fume hood. Stay at least 5 m from the bags as the sulfur dioxide gas dissipates. Keep the plants and bags under the fume hood.
5. Predict the effects of the experiment on each plant over the next few days. Record your predictions.
6. Observe both plants over the next three days. Record your observations in a data table like the one shown below.

SAMPLE DATA TABLE

Day	Control plant	Experimental plant
1	normal	normal
2	normal	slightly wilted
3	normal	very wilted

Analysis

1. **Analyzing Models** In what ways is this a realistic model of acid precipitation?

_____

_____

2. **Analyzing Models** In what ways is this experiment not a realistic simulation of acid precipitation?

_____

_____

_____

_____

Conclusions

1. **Examining Data** How closely did your predictions about the effects of the experiment on each plant match your observations?

2. **Drawing Conclusions** What does this experiment suggest about the effects of acid precipitation on plants?

Extension

1. **Analyzing Models** Would you expect to see similar effects occur as rapidly, more rapidly, or less rapidly in the environment? Explain your answer.

2. **Building Models** Acid precipitation is damaging to plants because the sulfur dioxide contained in the water vapor clogs the openings on the surfaces of plants and interferes with photosynthesis. What kind of a safe model would demonstrate the damaging effects of acid precipitation in the form of water vapor on plant photosynthesis? Would this model be a realistic simulation of acid precipitation?

Name _____ Class _____ Date _____

Environmental Chemistry Lab

PROBEWARE LAB

Wetlands Acid Spill

An accident has recently occurred at a local wetlands refuge. A truck carrying drums of various chemicals overturned, and one of the drums ended up in a pond. On impact, the drum burst open, spilling its contents into the water. Markings on the drum indicate that it contained hydrochloric acid. Unfortunately, the markings that give its concentration are unreadable. Before cleanup crews can add a neutralizing agent to the water, they must first know the molar concentration of the HCl acid.

As an analyst for the EPA, you are responsible for determining the concentration of the unknown acid. A sample has been collected from the damaged drum. You will perform an acid-base titration to determine the moles of NaOH needed to neutralize the moles of HCl in the sample of acid collected.

The NaOH solution is of a known concentration and is the titration standard. Hydrogen ions from the HCl react with hydroxide ions from the NaOH in a one-to-one ratio to produce water in the overall reaction:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \longrightarrow H_2O(l) + Na^+(aq) + Cl^-(aq)$$

In an acid-base titration involving HCl and NaOH, the initial pH of the acidic solution is very low. As the NaOH solution is added, the pH will change gradually. When the equivalence point is reached and all of the HCl has reacted, the pH change will be very rapid and the overall pH of the solution will go from acidic to basic. As additional NaOH is added, the pH will change gradually and level off.

A pH sensor will be used to monitor the pH of the solution during the titration. The volume of NaOH added to reach the equivalence point will be used to determine the molarity of the unknown HCl. The data collected will resemble the graph shown below.

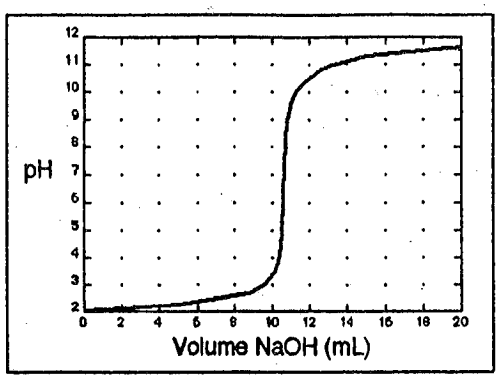


FIGURE 1

OBJECTIVE

Measure pH changes.

Graph pH-volume data pairs.

Identify the equivalence point of a titration curve.

Calculate the concentration of an unknown HC1 solution.

MATERIALS

- HCl solution, unknown concentration
- NaOH solution, ~0.1 M
- water, distilled

EQUIPMENT

- beaker, 250 mL
- buret, 50 mL
- LabPro or CBL2 interface
- magnetic stirrer (if available)
- pipet, 10 mL
- pipet bulb or pump
- ring stand
- stirring bar
- TI graphing calculator
- utility clamps (2)
- Vernier pH sensor

SAFETY 

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- Avoid wearing contact lenses in the lab.
- If any substance gets in your eyes, notify your instructor immediately, and flush your eyes with running water for at least 15 minutes.
- If a chemical is spilled on the floor or lab bench, alert your instructor, but do not clean it up yourself unless your teacher says it is OK to do so.
- Secure loose clothing and remove dangling jewelry. Don't wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Pour 50 mL of distilled water into a 250 mL beaker. Use a pipet bulb (or pipet pump) to transfer 10 mL of the HCl solution into the 250 mL beaker. **CAUTION: Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin.**

3. Place the beaker on a magnetic stirrer and add a stirring bar. If no magnetic stirrer is available, you will need to stir the beaker with a stirring rod during the titration.

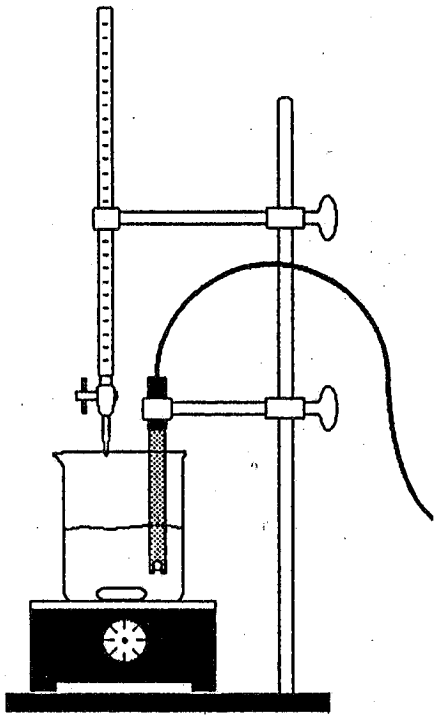


FIGURE 2

4. Plug the pH sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
5. Use a utility clamp to suspend a pH sensor on a ring stand as shown in **Figure 2.** Position the pH sensor in the HCl solution, and adjust its position so that it is not struck by the stirring bar.
6. Obtain a 50 mL buret, and rinse with a few milliliters of the ~0.1 M NaOH solution. Dispose of the rinse solution as directed by your teacher. Use a utility clamp or buret clamp to attach the buret to the ring stand as shown in **Figure 2.** Fill the buret a little above the 0.00 mL level with ~0.1 M NaOH solution. Drain a small amount of NaOH solution so that it fills the buret tip *and* leaves the NaOH at the 0.00 mL level of the buret. Record the precise concentration of the NaOH solution in your data table. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*

DATA COLLECTION

7. Turn on the calculator, and start the DATAMATE program. Press CLEAR to reset the program.

8. Set up the calculator and interface for the pH sensor.
   a. Select SETUP from the main screen.
   b. If CH 1 displays PH, proceed directly to Step 9. If it does not, continue with this step to set up your sensor manually.
   c. Press [ENTER] to select CH 1.
   d. Select PH from the SELECT SENSOR menu.
9. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select EVENTS WITH ENTRY from the SELECT MODE menu.
   c. Select OK to return to the main screen.
10. You are now ready to perform the titration. This process goes faster if one person adjusts and reads the buret while another person operates the calculator and enters the data on the volume of solution.
   a. Select START to begin data collection.
   b. Before you have added any NaOH solution, press [ENTER] and type in "0" as the buret volume in mL. Press [ENTER] to save the first data pair for this experiment.
   c. Add a small amount of NaOH titrant (enough to raise the pH about 0.15 units). When the pH stabilizes, press [ENTER] and enter the current buret reading (to the nearest 0.01 mL). You have now saved the second data pair for the experiment.
   d. Continue adding NaOH solution in amounts that raise the pH by about 0.15 units, and enter the volume reading from the buret each time. When a pH value of approximately 3.5 is reached, add and record only one drop at a time. Enter a new buret reading after each drop. (Note: It is important that all changes in volume in this part of the titration be equal; that is, one-drop increments.)
   e. After a pH value of approximately 10 is reached, again add larger increments that raise the pH by about 0.15 pH units, and enter the buret level after each increment.
   f. Continue adding NaOH solution until the pH value remains constant.
11. Press [STO▶] when you have finished collecting data.
12. Examine the data on the displayed graph. As you move the cursor right or left on the graph, the volume (X) and pH (Y) values of each data point are displayed below the graph. Go to the region of the graph with the largest increase in pH. Find the NaOH volume just *before* this jump. Record this value in the data table. Then record the NaOH volume *after* the drop producing the largest pH increase was added.
13. Print a copy of the graph of pH versus volume.

14. (optional) Using the "Graphical Analysis" software, print a copy of the NaOH volume and pH data for the titration.
15. Dispose of the beaker contents as directed by your teacher. Rinse the pH sensor, and return it to the pH storage solution.

DATA TABLE

Concentration of NaOH	M
Volume of NaOH added *before* largest pH change	mL
Volume of NaOH added *after* largest pH change	mL

Volume of NaOH added at equivalence point	mL
Mole NaOH	mol
Mole HCl	mol
Concentration of HCl	mol/L

Analysis

1. **Examining Data** Use your data table to locate the equivalence point. The equivalence point is characterized as the region of greatest pH change. Determine the volume of NaOH added directly before and after the largest pH change. Add the two volumes together, and divide by two. Record the result in your data table as the volume of NaOH added at the equivalence point.
2. **Organizing Data** Using the volume of NaOH titrant added, calculate the number of moles of NaOH used to neutralize the HCl. Record the results in your data table.
3. **Organizing Data** Based on the equation for the neutralization reaction given in the introduction, calculate the number of moles of HCl used. Record the results in your data table.
4. **Organizing Data** Calculate the concentration of HCl used in this titration. Remember that you began with 10.0 mL of the unknown HCl solution. Record the results in your data table.

Conclusions

1. **Drawing Conclusions** The drum containing the HCl carried 189 L of acid. The entire contents of the drum were released into the pond at the accident site. According to the results of your titration, what concentration and volume of NaOH would need to be added to neutralize the acid? _____

Name _____ Class _____ Date _____

Environmental Chemistry Lab **PROBEWARE LAB**

How Do Pollutants Affect a Lake?

In this lab, you will design and conduct an experiment to determine how pollutants such as fertilizers and detergents affect the quality of water in a lake.

BACKGROUND

Lakes provide a home for a wide variety of organisms, including aquatic plants, fish, and a variety of arthropods, mollusks, and other invertebrates. The quality of the water in a lake affects the ability of these organisms to survive, grow, and reproduce. Aquatic organisms are sensitive to both the pH and the dissolved oxygen (DO) content of lake water. Organisms do best in lakes where the pH is between 6 and 9. A pH that is too high or too low can cause tissue damage and can increase the toxicity of compounds such as iron, ammonia, and mercury. Aquatic organisms are sensitive to the DO content of the lake water because they need oxygen to carry out cellular respiration. Cellular respiration provides these organisms with the energy they need to survive, grow, and reproduce.

As rainwater runs off agricultural and residential lands, it often carries pollutants, such as fertilizers, detergents, and fecal material from farm animals, into lakes. Pollutants can have many effects on a lake. Some pollutants are toxins, some change the pH of the lake, and some are actually rich sources of nutrients. Nitrates and phosphates, which are present in fertilizers and laundry detergents, are nutrients that are beneficial in small amounts for algae and plants.

However, when excess nutrients are present, a sudden massive growth of algae called an *algal bloom* may result. The development of an algal bloom in a lake often causes the death of many aquatic plants and animals.

1. What characteristics of lake water affect the health of aquatic organisms?

_____

_____

_____

2. How do pollutants such as nitrates and phosphates get into lake water?

_____

_____

_____

_____

3. Aquatic organisms require nitrates and phosphates to live. Under what circumstances do these nutrients become pollutants?

_____

_____

SAFETY

- Wear safety goggles, gloves, and an apron at all times.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.

OBJECTIVES

Develop a hypothesis about how common pollutants affect the quality of lake water.

Design and **conduct** an experiment to test your hypothesis.

Identify relationships between common pollutants and the pH and DO content of lake water.

Evaluate your results.

POSSIBLE MATERIALS

- "lake water" containing several different species of algae (100 mL)
- CBL system
- DO calibration bottle
- DO probe
- electrode filling solution
- fertilizer (nitrate) solution (10 mL)
- fluorescent lights or grow lamp
- lab apron
- laundry detergent (phosphate) solution (10 mL)
- link cable
- pH probe
- plastic graduated pipets (3)
- rinse bottle of deionized water
- safety goggles
- sheet of white paper
- small jars or 50 mL beakers (3)
- TI graphing calculator
- wax pencil

Procedure

FORMING A HYPOTHESIS

Based on what you have learned, form a hypothesis about how fertilizers and detergents might create an unhealthy environment for aquatic organisms.

1. What characteristics of the lake water might be changed by the presence of excess nitrates and/or phosphates?

_____

_____

_____

2. Write your own hypothesis. A possible hypothesis might be "The presence of excess nitrates changes the pH of the lake water to a level that is harmful to aquatic organisms."

_____

_____

COMING UP WITH A PLAN

Plan and conduct an experiment that will determine what changes the pollutants in the lack cause that might be harmful to the organisms living there. Limit the number of conditions you choose for your experiment to those that can be completed during the time your teacher has allotted for this lab. Consult with your teacher to make sure that the conditions you have chosen are appropriate.

3. Write out a procedure for your experiment on a separate sheet of paper. As you plan the procedure, make the following decisions.
   - Decide what pollutant(s) you will use.
   - Decide what characteristics of the "lake water" you will observe or measure.
   - Select the materials and technology that you will need for your experiment from those that your teacher has provided.
   - Decide where you will conduct your experiment.
   - Decide what your control(s) will be.
   - Decide what safety procedures are necessary.
4. Using graph paper or a computer, construct tables to organize your data. Be sure your tables fit your investigation.
5. Have your teacher approve your plans.

PERFORMING THE EXPERIMENT

6. Put on safety goggles and a lab apron.
7. Implement your plan, using the equipment, technology, and safety procedures that you selected. Instructions for using CBL probes to measure pH and dissolved oxygen are included on the next page.
8. Record your observations and measurements in your tables. If necessary, revise your tables to include variables that you did not think of while planning your experiment.
9. When you have finished, clean and store your equipment. Recycle or dispose of all materials as instructed by your teacher.

SETTING UP AND USING THE PH PROBE

10. Plug the pH probe into the Channel 1 input of the CBL unit. Use the black cable to connect the CBL unit to the graphing calculator.

11. Turn on both the CBL unit and the calculator. Start the CHEMBIO program and go to the MAIN MENU.

12. Select SET UP PROBES. Enter "1" as the number of probes. Select pH from the SELECT PROBE menu. Enter "1" as the channel number.

13. Select USE STORED from the CALIBRATION menu.

14. Return to the MAIN MENU and select COLLECT DATA. Select MONITOR INPUT for the DATA COLLECTION menu. The CBL unit will display pH readings on the calculator.

15. Remove the pH probe from its storage solution. Use the rinse bottle filled with deionized water to carefully rinse the probe, catching the rinse water in a 500 mL beaker.

16. Submerge the pH probe in your sample of "lake water." When the pH reading stabilizes, record the pH in your table. Rinse the pH probe with deionized water between each reading.

17. After the final reading, rinse the pH probe with deionized water and return the probe to its storage solution. Dispose of the rinse water as instructed by your teacher. Press "+" on the calculator.

SETTING UP AND USING THE DISSOLVED OXYGEN (DO) PROBE

18. Plug the DO probe into the Channel 1 input of the CBL unit. Use the black cable to connect the CBL unit to the graphing calculator.

19. Turn on both the CBL unit and the calculator. Start the CHEMBIO program and go the the MAIN MENU.

20. Select SET UP PROBES. Enter "1" as the number of probes. Select D.OXYGEN from the SELECT PROBE menu. Enter "1" as the channel number.

21. Select POLARIZE PROBE. Press ENTER to return to the CALIBRATION menu. You must allow the DO probe to polarize for 10 minutes before you can use it.

22. Select MANUAL ENTRY from the CALIBRATION menu. Enter the intercept (KO) and slope (K1) values for the DO calibration provided by your teacher.

23. After 10 minutes have passed, remove the DO probe from its storage solution. Submerge the probe in your sample of "lake water."

24. Select COLLECT DATA from the MAIN MENU. Select MONITOR INPUT from the DATA COLLECTION menu. Press ENTER.

25. Gently move the probe up and down about 1 cm in the sample. Be careful not to agitate the water, which will cause oxygen from the atmosphere to mix into the water. Continue moving the probe until the DO reading stabilizes. Record the DO concentration in your table.

26. Repeat steps 23 and 24 for each sample. Rinse the probe with deionized water between each reading.

27. After the final reading, rinse the DO probe with deionized water and return the probe to its storage solution. Press "+" on the calculator. Dispose of the rinse water as instructed by your teacher.

SETTING UP THE CBL SYSTEM FOR BOTH PROBES

To use both the pH probe and the DO probe, replace steps 12 and 20 with step 29, and replace steps 13 and 21 with steps 31 and 32.

28. Plug the pH probe into the Channel 1 input of the CBL unit. Plug the DO probe into the Channel 2 input. Use the black cable to connect the CBL unit to the graphing calculator.

29. Select SET UP PROBES. Enter "2" as the number of probes. Select pH from the SELECT PROBE menu. Enter "1" as the channel number.

30. Select MORE PROBES from the SELECT PROBE menu. Select D.OXYGEN from the SELECT PROBE menu. Enter "2" as the channel number.

31. Select POLARIZE PROBE. A message will appear. Select MANUAL ENTRY from the CALIBRATION menu. Enter the intercept (K0) and slope (K1) values for the dissolved oxygen calibration provided by your teacher. A message will appear concerning the sensors. Press ENTER. Leave the dissolved oxygen probe connected to the CBL for 10 minutes so that the probe can polarize.

32. Select COLLECT DATA from the MAIN MENU. Select MONITOR INPUT. Select either CH1 or CH2 from the SELECT A CHANNEL menu to monitor the probe reading. Use the CH VIEW button on the CBL to switch channels. Press TRIGGER on the CBL to quit monitoring. To view the other channel, select it from the SELECT A CHANNEL menu. To quit, choose QUIT from the SELECT A CHANNEL menu.

Analysis

1. Summarizing Data Summarize your findings and observations.

2. **Describing Events** Share your results with your classmates. Which hypotheses were supported?

3. **Identifying Relationships** How might an algal bloom contribute to a decrease in dissolved oxygen in the "lake water"?

Conclusions

1. **Drawing Conclusions** What conclusions can you draw from your results? from class results?

2. **Evaluating Models** Was your experiment a good model for how pollutants might affect lake water? Explain why or why not, and give examples of what might be missing from your model.

Name _____ Class _____ Date _____

Environmental Chemistry Lab

PROBEWARE LAB

Evaluating Fuels

Calorimetry is a technique that uses an instrument called a *calorimeter* to measure the energy as heat released by materials when they burn. In an ideal calorimeter, a sample is burned in a pure oxygen environment inside a container called a reaction chamber. Surrounding the reaction chamber is a water-filled container. When the sample burns, energy flows into the water, raising its temperature. By measuring the temperature change and the mass of the water, the energy released can be calculated.

Fuels contain varying amounts of energy. For fossil fuels, the most important fuels are those that are the most economical, are the cleanest to burn, and produce the largest amount of energy per unit mass. Amount of energy produced per unit mass is known as the *energy content* of a fuel. Technicians at coal-burning power plants sample fuel from suppliers and test it for energy content and pollutants. The coal with the highest energy content, the least moisture, and the fewest pollutants is the most valuable.

In this lab, you will burn different fuels to find out their energy content. You will use temperature readings, the mass of the heated water, and the specific heat of water to determine the amount of energy flowing into the water. The *specific heat* of a substance is the amount of energy as heat needed to raise 1 g of the substance 1°C. The energy gained by the water, measured in joules, is determined by the equation

$$E = mc_w\Delta T,$$

where E is energy, m is the mass of the water in grams, c_w is the specific heat of water, and ΔT is the temperature change of the water in degrees Celsius. The specific heat of water is a constant equal to 4.184 J/(g°C). Using this data, the amount of energy per gram of fuel burned can be determined.

OBJECTIVES

Use a temperature probe to measure changes in water temperatures generated by burning fuels.

Evaluate the fuel samples to determine which one releases the greatest amount of energy per unit mass.

MATERIALS

- fuels (1–4)

EQUIPMENT

- balance
- CBL system
- clamps, utility (2)
- crucibles (1–4)
- flame lighter
- flasks, 250 mL (1–4)
- link cable
- oven mitt or tongs
- ring stand
- temperature probe
- TI graphing calculator

SAFETY

- Wear safety goggles, gloves, and an apron at all times.
- Be very cautious with the fuels and the flame lighter. Before igniting the fuels, be sure all other combustible materials are cleared away from the setup.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.

Procedure

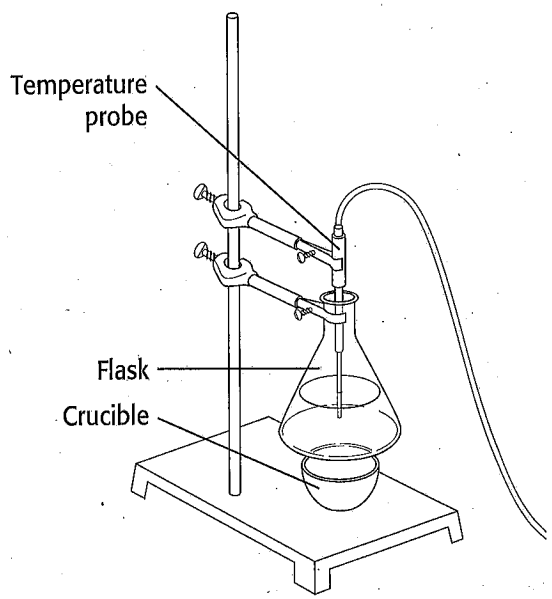
SETTING UP THE CBL SYSTEM

1. Connect the CBL unit to the graphing calculator, using the link cable. Press the ends of the link cable firmly into the CBL unit and the calculator. Connect the temperature probe to the Channel 1 input.
2. Turn on the graphing calculator and CBL unit. Start the CHEMBIO program. Go the the MAIN MENU.
3. Select SETUP PROBES. Enter "1" as the number of probes. From the SELECT PROBE menu, select TEMPERATURE. Enter "1" as the channel number.

ASSEMBLING THE CALORIMETRY APPARATUS

4. Connect a utility clamp to the ring stand. Place the crucible on the base of the ring stand.
5. Find the mass of the empty flask. Record the mass in **Table 1.** Add approximately 100 mL of water to the flask. Find the mass of the flask and the water. Record this mass in **Table 1.**
6. Secure the water-filled flask to the clamp. Adjust the clamp so that the base of the flask is approximately 2–3 cm higher than the top of the crucible, as shown in **Figure 1.** Use another utility clamp to suspend the temperature probe in the water. The probe should not touch the sides or bottom of the flask.

FIGURE 1 POSITION OF THE CRUCIBLE, FLASK, AND PROBE



PREPARING FUEL SAMPLES

7. Prepare your solid fuel samples in small piles.
8. Fill the crucible with a fuel sample. Do not overfill the crucible or pack down the fuel. Record the fuel type in **Table 2.**
9. Place the filled crucible on the balance, and measure its mass. Record the value in **Table 2.** Place the crucible on the base of the ring stand.

COLLECTING DATA

10. Select COLLECT DATA from the MAIN MENU. On the DATA COLLECTION MENU, select MONITOR INPUT. The temperature in degrees Celsius will be displayed on the calculator. Record this initial water temperature in **Table 1.** While you are changing or preparing fuel samples for testing, if the graphing calculator goes into sleep mode, press the ON button to turn it on.
11. Use the flame lighter to ignite the fuel sample. **CAUTION: When using an open flame, tie back long hair and keep loose clothing away from the flame.** Allow the fuel to burn for 3–5 minutes while it heats the water in the flask.
12. Use tongs or an oven mitt to remove the flask from the heat source. Swish the flask to mix the water. Take a final temperature reading, and record it in **Table 1.** When you are finished with data collection, press "+" to end.
13. Find the mass of the crucible containing the burned fuel sample. Record this final crucible and fuel mass in **Table 2.**
14. Dispose of the burned fuel sample according to your teacher's instructions.
15. Repeat steps 8–13 for additional fuel samples as directed by your teacher.
16. Clean up your work area, and wash your hands before leaving the lab.

TABLE 1 WATER MASS AND TEMPERATURE CHANGE

Trial	Empty flask mass (g)	Flask + water mass (g)	Water mass (g)	Initial water temperature (°C)	Final water temperature (°C)	Water temperature change (°C)
1						
2						
3						
4						

TABLE 2 MASS CHANGE FOR BURNED FUEL

Trial	Fuel type	Initial crucible + fuel mass (g)	Final crucible + fuel mass (g)	Fuel mass change (g)
1				
2				
3				
4				

TABLE 3 ENERGY CALCULATIONS

Trial	m, Water mass (g)	c_w, Specific heat of water (J/g•°C)	ΔT, Water temperature change (°C)	$mc_w\Delta T$, Energy absorbed by water (J)	Fuel mass change (g)	Amount of energy in fuel (J/g)
1						
2						
3						
4						

Analysis

1. **Organizing Data** Calculate the fuel mass change in **Table 2** by substracting the final crucible and fuel mass from the initial crucible and fuel mass. Enter the values in Table 2 and in column 6 of **Table 3.**

2. **Organizing Data** Calculate the water mass in **Table 1** by subtracting the empty flask mass from the flask and water mass. Enter the values in **Table 1.**

3. **Organizing Data** Calculate the temperature change of the water in **Table 1** by subtracting the initial water temperature from the final water temperature. Record the results in the last column of **Table 1** and column 4 of **Table 3.**

4. **Organizing Data** Calculate the energy absorbed by the water for each fuel tested, using the equation $E = mc_W\Delta T$. Use the data columns 2, 3, and 4 of **Table 3,** and record your results in column 5.

5. **Analyzing Results** Using the data in **Table 3,** find the fuel energy content by dividing the energy absorbed by water by the fuel mass change. Record these values in the last column in **Table 3.**

6. **Analyzing Results** Rank the fuels tested from least to greatest amount of energy absorbed by the water.

_____

_____

7. **Analyzing Results** Rank the fuels tested from least to greatest fuel energy content.

_____

_____

Conclusions

1. **Evaluating Methods** Which of the fuel rankings—the one from Analysis question 6 or 7—is more useful? Explain your answer.

2. **Evaluating Models** In an ideal calorimeter, all of the released energy is captured by the water. In the calorimeter you used, where did energy flow in addition to the water?

3. **Drawing Conclusions** Based on energy content, which of the fuels tested do you think is the best?

4. **Applying Conclusions** What other information, besides energy content, should be considered when determining what makes the best fuel? Given these considerations, which of the fuels tested do you think is the best? Explain.

Extension

Research and Communication Investigate a bomb calorimeter or other type of calorimeter, and prepare a presentation that describes how it works. Include a diagram or model in your presentation.

Name _____ Class _____ Date _____

Topic Introduction

An Introduction to Biological Chemistry

Chemistry is the study of the composition, properties, and structure of matter and the changes that it undergoes. The kinds of matter that chemists study is not limited to things such as metals, gases, and solutions in beakers. Chemists also study the matter that makes up living things. Life processes are chemical and physical changes such as those you have studied in other science courses. These processes include digestion and cell reproduction. **Biological chemistry,** *or biochemistry, is the study of the chemistry of biological processes.* Scientists who work in this field are called *biochemists.*

Knowing how drug molecules interact with biological molecules allows chemists to design new and potentially more effective drugs. Still, biochemists have much to do in order to understand and prevent diseases such as cancer and AIDS, as well as genetic diseases such as sickle-cell anemia and cystic fibrosis. Many biological processes involve large, complex molecules such as DNA. *Genes,* which determine an organism's traits, are made up of DNA. As of 2004, researchers have discovered that the human body contains about 20,000 to 25,000 genes. Understanding how genes determine traits allows chemists to modify traits of organisms. You will learn about some of these modifications in the next section.

A Current Hot Topic: Genetic Engineering

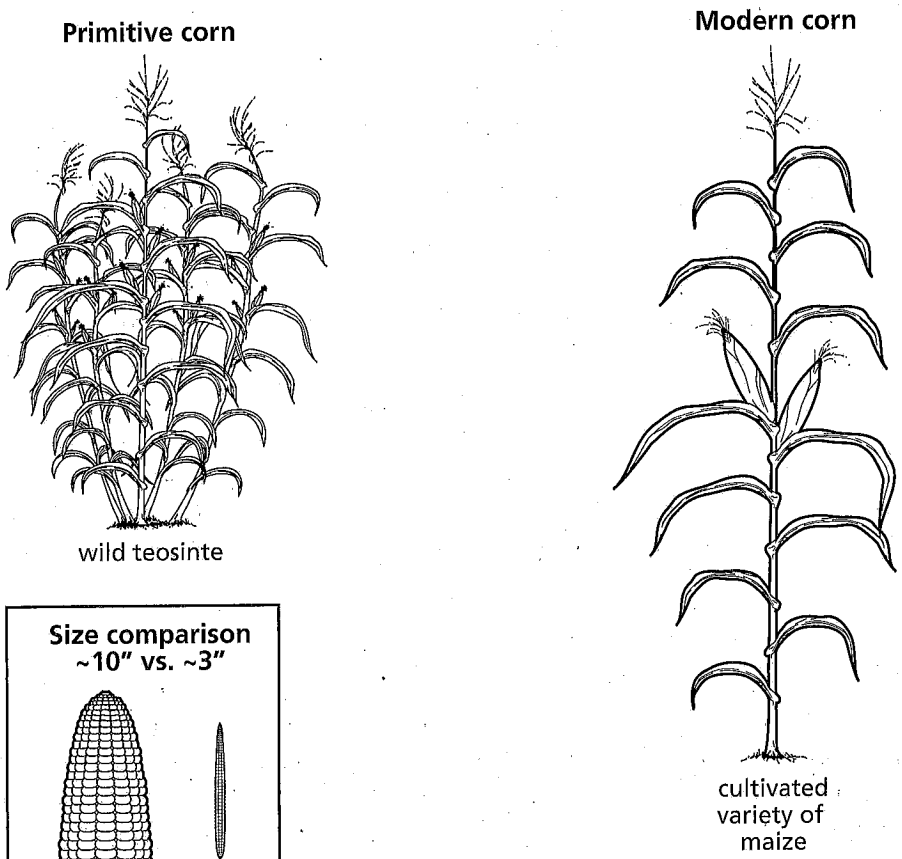
During the twentieth century, research by biochemists has shown how the genetic code determines the traits of an organism. This knowledge has created a new branch of science called genetic engineering. **Genetic engineering** *is the modification of the DNA of an organism in order to change the traits of an organism.* The results can include improving existing traits, eliminating undesirable traits, or adding new traits, often by transferring a gene from a different organism.

EARLY GENETIC MODIFICATION

People have carried out simple forms of genetic engineering for thousands of years. For example, both plants and animals have been crossbred to bring out useful traits, such as greater yields of grain or milk, over the course of generations. Corn, for example, originated as a tall grass with small seed heads that looked like wheat. Thousands of years of crossing corn plants produced the corn with large "ears" that we know today. **Figure 1** on the next page compares the modern cultivated maize plant and the wild grass, *teosinte,* which maize is believed to be derived from. Likewise, modern dogs are descended from wolves. Thousands of years of selective breeding has produced a huge variety of dog breeds, many of which hardly resemble wolves at all!

FIGURE 1: PRIMITIVE WILD CORN AND MODERN CULTIVATED CORN

Maize (corn), shown on the right, is believed to be derived from the wild grass *teosinte*, shown at left. The heavy seed cob of cultivated corn is much larger than the cob of teosinte due to many generations of selective cultivation.



Maize, right, is believed to be derived from the wild grass teosinte (left), its heavy seed cob being equivalent to teosinte's miniscule ear (left box)

MODERN GENETIC MODIFICATION

In modern genetic engineering, scientists may insert human genes into bacteria to make them synthesize important hormones such as insulin and human growth hormone. These hormones can then be harvested from the bacteria and given to patients who need them. Other genes can make bacteria produce useful drugs that are difficult to synthesize in the laboratory. Plants and fungi can also be genetically engineered to produce hormones and drugs. **Table 1** on the next page lists several examples of modern genetic engineering. Some of these, such as the production of hormones by bacteria and herbicide-resistant plants, are already used commercially. Other examples of genetic engineering are still being developed.

TABLE 1: SOME APPLICATIONS OF GENETIC ENGINEERING

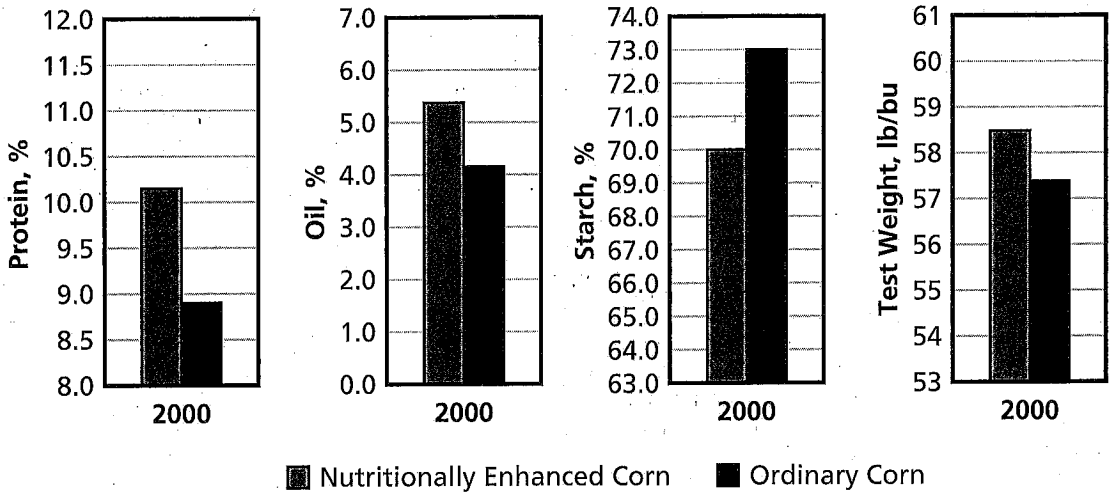
Organism	Genetic modification	Result
Bacteria, fungi	Human genes are added to bacteria and fungi to produce hormones or antibodies.	Bacteria and fungi synthesize hormones or antibodies.
Food plants	Genes from bacteria that are toxic to insects are added to plants.	Plants synthesize their own pesticides.
Food plants	Genes from cold water fish are added to plants.	Plants become resistant to freezing.
Bacteria, plants	Genes from other organisms that can break down environmental pollutants are added to bacteria or plants.	Bacteria or plants can break down oil spills and chemical pollutants.
Cows, sheep, goats	Genes for the production of hormones or drugs are inserted into the animal embryo.	Animals give milk that contains hormones or drugs.
Humans	Genes for the production of anticancer substances are added to cancerous cells.	Engineered cells multiply in the tumor, helping the body combat the cancer.

GENETICALLY MODIFIED FOODS

Table 1 shows several examples of genetic engineering. Earth's population is about 6.5 billion today and may increase to 8 billion by the year 2020. One of society's biggest challenges is finding ways to feed this huge number of people. The goals of most genetic engineering of food plants—especially corn, soybeans, wheat, and rice—is to increase both crop yields and the nutritional content of foods. Today, about 75% of the soybeans and 35% of the corn in the United States come from genetically engineered plants.

In one example of genetic modification, plants are given genes that make them resistant to herbicides, which are chemicals that kill plants. Then a field of these treated plants can be sprayed with a herbicide that kills all the competing plants (weeds), leaving only the desired crop. In another example, genes from certain bacteria can be inserted into plants, which then synthesize compounds that are toxic to insects: in effect, the plant makes its own pesticide.

FIGURE 2: COMPARISON OF NURITIONAL CONTENT BETWEEN GENETICALLY ENHANCED CORN AND ORDINARY CORN



Genetic engineering can improve the nutritional content of grains such as wheat, corn, and rice that are high in starch but low in protein. Most naturally occurring plant proteins do not contain all of the amino acids that humans need. Genes for the synthesis of additional protein containing amino acids missing from the plant can be added to these plants. The graph in **Figure 2** above compares the protein, oil, and starch content of ordinary corn with corn that has been nutritionally enhanced by genetic engineering. Note that the amounts of protein and oil (fat) in the engineered corn are increased and the starch content is decreased compared with the ordinary corn. Also, the density of the corn in pounds per bushel (lb/bu) is increased, which means that the engineered corn provides more nutrition per unit volume.

CONTROVERSIES OVER GENETIC ENGINEERING

However, there are drawbacks as well as benefits to genetically modified food crops. For example, insect pests could develop resistance to a toxin produced by a plant, and then that toxin would be ineffective against those pests in the future. Some people have raised the concern that added genes could be transferred to nongenetically modified crops. For example, the genes that make crops resistant to herbicides might be passed on to weeds.

Some people can have severe allergic reactions to some foods, such as peanuts. If genes from peanuts were used to genetically modify another plant, people might become allergic to that plant as well. Others fear the possibility that genetically engineered plants, bacteria, and fungi could displace the normal organisms in the ecosystem.

GENETIC ENGINEERING IN HUMANS

Genetic engineering could be used to cure human genetic diseases such as sickle-cell anemia, cystic fibrosis, and hemophilia. However, the use of genetic engineering to cure or prevent human diseases poses unique difficulties and challenges. For a disease not to develop in a person, genes that prevent the disease must be inserted into a very early embryo or a fertilized egg. As of now, no practical way exists to tell if a genetic disorder exists in early embryos. Many genetic disorders are discovered only after birth. Much research still needs to be done before genetic engineering can be effectively used to cure human genetic diseases. In addition, the potential to screen for some diseases prior to birth also raises a number of ethical questions.

Careers in Biological Chemistry

Genetic engineering is just one of the fast-growing fields within biological chemistry today. The possibilities for careers in this area are almost unlimited.

BIOCHEMIST

Biochemistry today is a vast, wide-open field. A degree in biochemistry can prepare one for an almost unlimited number of careers. In the laboratory, biochemists do basic research in a variety of areas, including genetic engineering, toxicology, medicine, and biotechnology. An advanced degree in biochemistry can also prepare one to teach and do research at a college or university.

PHARMACOLOGIST

Pharmacology is the study of how medicines interact with the human body. Some pharmacologists study the biochemistry of human life processes. Other pharmacologists work for pharmaceutical companies and attempt to design drug molecules that will interact in specific ways with the molecules of the body. In a hospital, a clinical pharmacologist is an expert on the action of drugs and combinations of drugs on patients. Pharmacologists in hospitals are often physicians as well. So, they work with patients by monitoring drug action and the side effects of drugs on patients.

PLANT GENETICIST

A plant geneticist can work to develop new plant varieties by altering the genetic makeup of plants: everything from flowers of different colors to tomatoes that taste better to wheat that is short and wind resistant. A plant geneticist may work in a research laboratory or outdoors, such as on an experimental farm. Some plant geneticists use the techniques of genetic engineering to isolate genes and transfer genes from one species to another. This field usually requires an advanced college degree.

Topic Questions

1. Describe briefly how modern genetic engineering is used to modify an organism.

2. Give two examples of the use of genetic engineering to aid human health.

3. What is the purpose of creating plants that are resistant to herbicides?

4. What problems may arise from planting genetically engineered crops that produce compounds that are toxic to insects?

5. Use the graphs in **Figure 2** to estimate the increase in percentage of protein and oil and the decrease in percentage of starch in the nutritionally enhanced corn.

6. Look at the difference in density between ordinary and nutritionally enhanced corn shown in **Figure 2.** What would be the difference in weight between 1,000 bushels of genetically enhanced corn and ordinary corn?

Name _____ Class _____ Date _____

Biological Chemistry Lab

Identifying Organic Compounds in Foods

Carbohydrates, proteins, and lipids are nutrients that are essential to all living things. Some foods, such as table sugar, contain only one of these nutrients. Most foods, however, contain mixtures of proteins, carbohydrates, and lipids. You can confirm this by reading the information in the "Nutrition Facts" box found on any food label.

In this investigation, you will use chemical substances, called indicators, to identify the presence of specific nutrients in an unknown solution. By comparing the color change an indicator produces in the unknown food sample with the change it produces in a sample of known composition, you can determine whether specific organic compounds are present in the unknown sample.

Benedict's solution is used to determine the presence of monosaccharides, such as glucose. A mixture of sodium hydroxide and copper sulfate determine the presence of some proteins (this procedure is called the biuret test). Sudan III is used to determine the presence of lipids.

OBJECTIVES

Determine whether specific nutrients are present in a solution of unknown composition.

Perform chemical tests using substances called *indicators*.

MATERIALS

- albumin solution
- Benedict's solution
- copper sulfate solution
- glucose solution
- labeling tape
- sodium hydroxide solution
- Sudan III solution
- unknown solution
- vegetable oil
- distilled water

EQUIPMENT

- 1 L beaker
- hot plate
- droppers (9)
- 10 mL graduated cylinder
- marker
- glass stirring rods (9)
- test tubes (9)
- test-tube rack
- tongs or test-tube holder

SAFETY 

- Put on a lab apron, safety goggles, and gloves.
- In this lab, you will be working with chemicals that can harm your skin and eyes or stain your skin and clothing. If you get a chemical on your skin or clothing, wash it off at the sink while calling to your teacher. If you get a chemical in your eyes, immediately flush it out at the eyewash station while calling to your teacher.
- Do not touch the hot plate. Do not touch the test tubes with your hands.
- Do not plug or unplug the hot plate with wet hands.
- Do not use Sudan III solution in the same room with an open flame.

Procedure

As you perform each test, record your data in your lab report, organized in a table like the one on the next page.

TEST 1

1. Make a water bath by filling a 1 L beaker half full with water. Then put the beaker on a hot plate and bring the water to a boil.
2. While you wait for the water to boil, label one test tube "1-glucose," label the second test tube "1-unknown," and label the third test tube "1-water." Using the graduated cylinder, measure 5 mL of Benedict's solution and add it to the "1-glucose" test tube. Repeat the procedure, adding 5 mL of Benedict's solution each to the "1-unknown" test tube and "1-water" test tube.
3. Using a dropper, add 10 drops of glucose solution to the "1-glucose" test tube. Using a second dropper, add 10 drops of the unknown solution to the "1-unknown" test tube. Using a third dropper, add 10 drops of distilled water to the "1-water" test tube. Mix the contents of each test tube with a clean stirring rod. (It is important not to contaminate test solutions by using the same dropper or stirring rod in more than one solution. Use a different dropper and stirring rod for each of the test solutions.)
4. When the water boils, use tongs to place the test tubes in the water bath. Boil the test tubes for 1 to 2 minutes.
5. Use tongs to remove the test tubes from the water bath and place them in the test-tube rack. As the test tubes cool, an orange or red precipitate will form if large amounts of glucose are present. If small amounts of glucose are present, a yellow or green precipitate will form. Record your results in your data table.

SAMPLE DATA TABLE: IDENTIFICATION OF SPECIFIC NUTRIENTS BY CHEMICAL INDICATORS

Test	Nutrient in test solution	Nutrient category (protein, lipid, etc.)	Result for known sample	Result for unknown sample	Result for distilled water
1	glucose	carbohydrate	red or orange precipitate	no change	no change
2	albumin	protein	pink-purple color	pink-purple color	no change
3	vegetable oil	lipid	pink color	no change	no change

TEST 2

6. Label one clean test tube "2-albumin," label a second test tube "2-unknown," and label a third test tube "2-water." Using a dropper, add 40 drops of albumin solution to the "2-albumin" test tube. Using a second dropper, add 40 drops of unknown solution to the "2-unknown" test tube. Using a third dropper, add 40 drops of water to the "2-water" test tube.
7. Add 40 drops of sodium hydroxide solution to each of the three test tubes. Mix the contents of each test tube with a clean stirring rod.
8. Add a few drops of copper sulfate solution, one drop at a time, to the "2-albumin" test tube. Stir the solution with a clean stirring rod after each drop. Note the number of drops required to cause the color of the solution in the test tube to change. Then add the same number of drops of copper sulfate solution to the "2-unknown" and "2-water" test tubes.
9. Record your results in your data table.

TEST 3

10. Label one clean test tube "3-vegetable oil," label a second test tube "3-unknown," and label a third test tube "3-water." Using a dropper, add 5 drops of vegetable oil to the "3-vegetable oil" test tube. Using a second dropper, add 5 drops of the unknown solution to the "3-unknown" test tube. Using a third dropper, add 5 drops of water to the "3-water" test tube.
11. Using a clean dropper, add 3 drops of Sudan III solution to each test tube. Mix the contents of each test tube with a clean stirring rod.
12. Record your results in your data table.
13. Clean up your materials and wash your hands before leaving the lab.

Analysis

1. **Analyzing Methods** What are the experimental controls in this investigation?

2. **Analyzing Methods** Explain how you were able to use the color changes of different indicators to determine the presence of specific nutrients in the unknown substance.

3. Analyzing Methods List four potential sources of error in this investigation.

Conclusions

1. **Drawing Conclusions** Based on the results you recorded in your data table, identify the nutrient or nutrients in the unknown solution.

Name _____ Class _____ Date _____

Biological Chemistry Lab

Measuring the Release of Energy from Sucrose

The carbohydrate *sucrose*, or table sugar, is made by plants to store energy. All living things must have energy to power their cells. That energy is obtained from organic molecules such as sucrose through the processes of *fermentation* and *cellular respiration*. Fermentation, which occurs in the absence of oxygen, releases a relatively small amount of energy. Cellular respiration, which occurs in the presence of oxygen, releases a great deal of energy. Because energy conversions are not 100 percent efficient, some of the energy released is in the form of heat. The addition of energy as heat to a system results in an increase in temperature.

Another product of both fermentation and cellular respiration is carbon dioxide. A solution called *limewater* can be used to indicate the presence of carbon dioxide. Limewater, which is normally clear, turns cloudy in the presence of carbon dioxide.

OBJECTIVES

Predict how the temperature of a solution will change as a chemical process occurs in the solution.

Relate a change in temperature to the release of energy from sucrose.

MATERIALS

- lukewarm water, 800 mL
- limewater, 100 mL
- sucrose, 150 g
- dried yeast package

EQUIPMENT

- safety goggles
- lab apron
- insulated bottles, 500 mL (2)
- beaker, 1000 mL
- flask, 250 mL
- pieces of rubber tubing, 40 cm (2)
- glass stirring rod
- wax pencil
- two-hole stoppers with a thermometer inserted in one hole and a 10 cm piece of glass inserted in the other hole (2)

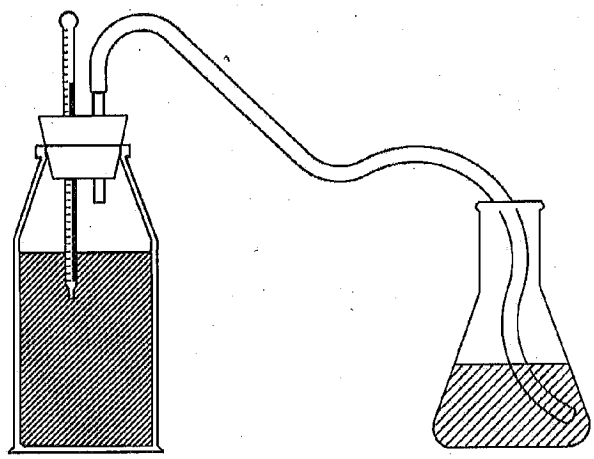
SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.

Procedure

1. Prepare a data table in which to record time and temperature values for the experimental bottle and the control bottle.
2. Put on safety goggles and a lab apron. Using a wax pencil, label two insulated bottles with the initials of your group's members. Label one of the bottles "Control" and the other "Experimental."
3. In a 1000 mL beaker, dissolve 150 g of sucrose in 800 mL of lukewarm water. Pour half of the sucrose solution into the insulated bottle marked "Control."
4. Add one package of fresh yeast to the sucrose solution remaining in the beaker, and stir. Pour the sucrose-yeast mixture into the bottle marked "Experimental."
5. Set up the two insulated bottles, two 250 mL flasks with limewater, and two 40 cm pieces of rubber tubing as shown in **Figure 1** below. Adjust the thermometers until they extend down into the solutions in the bottles and the liquid column can be seen above the stopper. *Note: Be sure that the glass tubing does not touch the solutions in the bottles.*

FIGURE 1



6. Record the time and the initial temperature of the solution in each bottle in your data table.

   What do you predict will happen in each bottle over the next 48 hours?

7. Clean up your work area and wash your hands before leaving the lab.
8. Continue to record the temperature in each bottle for 48 hours. Take turns with your lab partner during the school day to take temperature data between class periods. Record as many readings as possible during the next 48 hours.

   What happened in each flask of limewater?

9. Dispose of your materials according to the directions from your teacher.
10. Make a line graph of the data. Plot time on the x-axis (horizontal axis) and temperature on the y-axis (vertical axis). Use two different colors to graph the results from each bottle. Plot a point on the graph that corresponds to the temperature at each time. The curve of the experimental data points will show the yeast's energy production. Complete the graph by drawing curves through the plotted points.

Analysis

1. **Analyzing Results** What are some indications that a chemical reaction was taking place inside one of the insulated bottles?

2. **Analyzing Methods** What is the purpose of the glass tube and rubber tubing in this experiment?

Conclusions

1. **Drawing Conclusions** How would you explain the change in temperature observed during the experiment?

2. **Drawing Conclusions** How could you alter this experiment to show that the energy is released from sucrose?

3. **Drawing Conclusions** How would you explain what happens to the lime-water in the two setups?

4. **Inferring Conclusions** Which process, fermentation or cellular respiration, caused the changes observed in this experiment? How could you test your hypothesis?

Extension

1. **Further Inquiry** Soon after the yeast is placed in the sucrose solution, take one drop of the solution and place it on a slide. Observe the yeast with a microscope under high power, and estimate the number of cells seen. Repeat the above process on the second and third days. Relate your findings to the energy-releasing process.
2. **Research and Writing** Look up the meanings of the terms *exothermic*, *endothermic*, *exergonic*, and *endergonic*. Write a paragraph that describes the processes of fermentation and cellular respiration using the appropriate terms from the list above.

Name _____ Class _____ Date _____

Biological Chemistry Lab

Diffusion and Cell Membranes

Some chemicals can pass through the cell membrane, but others cannot. Not all chemicals can pass through a cell membrane with equal ease. The cell membrane determines which chemicals can diffuse into or out of a cell.

As chemicals pass into and out of a cell, they move from areas of high concentration to areas of low concentration. Cells in *hypertonic* solutions have solute concentrations lower than the solution that bathes them. This concentration difference causes water to move out of the cell into the solution. Cells in *hypotonic* solutions have solute concentrations greater than the solution that bathes them. This concentration difference causes water to move from the solution into the cell. The movement of water into and out of a cell through the cell membrane is called *osmosis*.

In this lab, you will use eggs with a dissolved shell as a model for a living cell. You will then predict the results of an experiment that involves the movement of water through a membrane.

OBJECTIVES

Explain changes that occur in a cell as a result of diffusion.

Distinguish between hypertonic and hypotonic solutions.

MATERIALS

- corn syrup, 1 bottle
- distilled water
- raw eggs (2)
- paper towels (2)
- vinegar (400 mL)

EQUIPMENT

- thermometer
- 250 mL beakers (6)
- 600 mL beakers (2)
- glass stirring rod
- tablespoon or tongs

SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing. Do not touch or taste any chemicals. Know the locations of the emergency shower and eyewash station and how to use them.
- If you get a chemical on your skin or clothing, wash it off at the sink while calling to the teacher. Notify the teacher of a spill. Spills should be cleaned up promptly, according to your teacher's directions.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.

Procedure

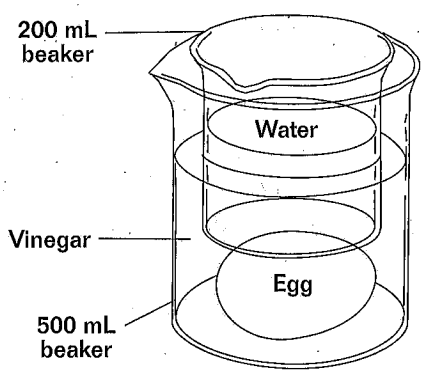
1. Label one 600 mL beaker "Egg 1: water" and the other 600 mL beaker "Egg 2: syrup." Also label the beakers with the initials of each member of your group. Measure the mass of each of two eggs to the nearest 0.1 g, and record your measurements in **Table 1** below. **CAUTION: When handling raw eggs, clean up any material from broken eggs immediately. Wash your hands with soap and water after handling the eggs.**
2. Put on safety goggles and a lab apron. Pour 200 mL of vinegar into each labeled beaker. Using a tablespoon or tongs, place an egg into each beaker. *Note: Always return each egg to the same beaker.*

TABLE 1: EGGS IN VINEGAR

Egg	Mass of fresh egg with shell	Observations after 24 h	Mass after 24 h in vinegar
1			
2			

3. Place a 250 mL beaker containing 100 mL of water on each egg to keep it submerged as shown in **Figure 1** below. Add more vinegar if the egg is not covered by the vinegar already in the beaker. If some vinegar spills over when the 250 mL beaker is placed on the egg, carry the 600 mL beaker carefully to a sink and pour vinegar some out. Store your beakers for 24 hours in the area specified by your teacher.
4. Clean up your work area and wash your hands before leaving the lab.

FIGURE 1



5. After 24 hours, observe the eggs. Record your observations in **Table 1.**
6. Put on safety goggles and a lab apron. Label two separate sheets of paper towel "Egg 1" and "Egg 2," respectively. Pour the vinegar from the beakers into a sink. Using a tablespoon or tongs, remove the eggs and rinse them with water. Place each egg on the appropriately labeled paper towel. Measure the mass of each egg, and record the measurement in **Table 1.**
7. Return Egg 1 to its beaker, and add water until the egg is covered. Return Egg 2 to its beaker, and add corn syrup until the egg is covered. Store the beakers and eggs in the same place as before for 24 hours. Clean up your work area, and wash your hands before leaving the lab.
8. Predict how the mass of each egg will change after 24 hours in each liquid. (HINT: An egg is surrounded by a membrane. Inside the membrane, the egg white consists mainly of water and dissolved protein. The yolk consists mainly of fat and water. Syrup is sugar dissolved in water. The protein, fat, and sugar are solutes.) Record your predictions in **Table 2** below.

   What will have occurred if your egg gains or loses mass?

   _____

9. Observe your eggs after 24 hours. Record your observations in **Table 2.** Measure and record the final masses of the two eggs.

TABLE 2: EGGS SOAKED IN TWO LIQUIDS

Egg	Liquid	Prediction of mass of fresh egg with shell	Observations after 24 h	Mass after 24 h in vinegar
1				
2				

10. Dispose of your materials according to the directions given by your teacher.
11. Clean up your work area, and wash your hands before leaving the lab.

Analysis

1. **Analyzing Results** What caused the change in appearance in Egg 1 after it was soaked in the water?

   _____

   _____

2. **Applying Concepts** Why did the mass of the egg increase after soaking in the vinegar solution?

_____

3. **Analyzing Results** How did your results in step 9 compare with the prediction you made in step 8?

_____

4. **Analyzing Results** What material seems to have moved through the membrane of Egg 2 after it was soaked in the syrup? In what direction did it move?

_____

Conclusions

1. **Drawing Conclusions** Which egg was in a hypertonic solution? Explain.

_____

_____

2. **Drawing Conclusions** Which egg was in a hypotonic solution? Explain.

_____

_____

Extension

1. **Further Inquiry** Design an experiment to see what results can be obtained by placing living yeast cells in hypertonic and hypotonic solutions.
2. **Further Inquiry** Look up the chemical compositions of egg shell and of vinegar. Use this information to write a chemical equation that explains how egg shell dissolves in vinegar.

Name _____ Class _____ Date _____

Biological Chemistry Lab

INQUIRY LAB

Observing Enzyme Detergents

Enzymes are substances that speed up chemical reactions. Each enzyme operates best at a particular pH and temperature. Substances on which enzymes act are called substrates. Many enzymes are named for their substrates. For example, a protease is an enzyme that helps break down proteins. In this lab, you will investigate the effectiveness of laundry detergents that contain enzymes.

OBJECTIVES

Recognize the function of enzymes in laundry detergents.

Relate temperature and pH to the activity of enzymes.

MATERIALS

- 1 g each of 5 brands of laundry detergent
- 18 g regular instant gelatin or 1.8 g sugar-free instant gelatin
- 0.7 g Na_2CO_3
- pH paper
- plastic wrap
- tape
- 50 mL boiling water
- 50 mL distilled water

EQUIPMENT

- balance
- 150 mL beaker
- 50 mL beakers (6)
- glass stirring rod
- 10 mL graduated cylinder
- metric ruler
- pipet with bulb
- test-tube rack
- 6 test tubes
- thermometer
- oven mitt or tongs
- wax pencil

SAFETY

- Always wear safety goggles and a lab apron to protect your eyes and clothing. Do not touch or taste any chemicals. Know the location of the emergency shower and eyewash station and how to use them.
- If you get a chemical on your skin or clothing, wash it off at the sink while calling to the teacher. Notify the teacher of a spill. Spills should be cleaned up promptly, according to your teacher's directions.
- Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so.

Pre-Lab Preparation

Based on the objectives for this lab, write a question you would like to explore about enzyme detergents.

Procedure

PART A: MAKE A PROTEIN SUBSTRATE

1. Put on safety goggles and a lab apron.
2. **CAUTION: Use an oven mitt or tongs to handle heated glassware.** Put 18 g of regular (1.8 g of sugar-free) instant gelatin in a 150 mL beaker. Slowly add 50 mL of boiling water to the beaker, and stir the mixture with a stirring rod. Test and record the pH of this solution.
3. Very slowly add 0.7 g of Na_2CO_3 to the hot gelatin while stirring. Note any reaction. Test and record the pH of this solution.
4. Place six test tubes in a test-tube rack. Pour 5 mL of the gelatin-Na_2CO_3 mixture into each tube. Use a pipet to remove any bubbles from the surface of the mixture in each tube. Cover the tubes tightly with plastic wrap and tape. Cool the tubes, and store them at room temperature until you begin Part C. Complete step 12.

PART B: DESIGN AN EXPERIMENT

5. Work with members of your lab group to explore the question you wrote in the Pre-Lab Preparation. To explore the question, design an experiment that uses the materials listed for this lab.

   As you design your experiment, decide the following:

   a. what question you will explore

   b. what hypothesis you will test

   c. what detergent samples you will test

   d. what your control will be

   e. how much of each solution to use for each test

   f. how to determine if protein is breaking down

   g. what data to record in your data table
6. Write a procedure for your experiment. Make a list of all the safety precautions you will take. Have your teacher approve your procedure and safety precautions before you begin the experiment.

PART C: CONDUCT YOUR EXPERIMENT

7. Put on safety goggles and a lab apron.
8. Make a 10% solution of each laundry detergent by dissolving 1 g of detergent in 9 mL of distilled water.
9. Set up your experiment. Repeat step 12.
10. Record your data after 24 hours.

PART D: CLEANUP AND DISPOSAL

11. Dispose of solutions, broken glass, and gelatin in the designated waste containers. Do not pour chemicals down the drain or put lab materials in the trash unless your teacher tells you to do so.
12. Clean up your work area and all lab equipment. Return lab equipment to its proper place. Wash your hands thoroughly before leaving the lab and after finishing all work.

Analysis

1. **Analyzing Methods** Suggest a reason for adding Na_2CO_3 to the gelatin solution.

_____

_____

2. **Analyzing Results** Make a bar graph of your data. Plot the amount of gelatin broken down (change in the depth of the gelatin) on the y-axis and detergent on the x-axis.

_____

Conclusions

1. **Drawing Conclusions** What conclusions did your group infer from the results? Explain.

_____

_____

Extension

1. **Further Inquiry** Write a new question about enzyme detergents that could be explored with another investigation.

_____

_____

Do research in the library or media center to answer these questions:

2. What other household products contain enzymes, and what types of enzymes do they contain?

_____

_____

3. What type of organic compound is broken down by each enzyme that you identified?

_____

_____

Name _____ Class _____ Date _____

Topic Introduction

An Introduction to Food Chemistry

When people eat food, they don't usually think about chemistry. They may begin to think of chemistry when they read a list of ingredients on a food package and see terms such as folic acid, BHT, or monosodium glutamate. People may react by saying that these are "chemicals" in the food. However, as you have learned in previous science classes, food is matter, and like all other matter, it is composed of chemical compounds.

The major food chemicals are proteins, fats, carbohydrates, water, mineral ions, and flavoring agents. **Food chemistry** *is the identification of the components of food and the study of the changes that take place when food is stored, prepared, and cooked.* Food chemists find out how processing and cooking change the taste, appearance, aroma, and nutrient content of food. Some food chemists study how substances used in processing affect the final food product. Another branch of food chemistry is *flavor chemistry,* in which chemists analyze the natural substances that give flavor and aroma to food and the ways that their molecular structures produce certain tastes and smells.

A Current Hot Topic: Flavor, Aroma, and Molecular Structure

Doesn't pizza smell good right out of the oven? Does the anticipation of its taste make your mouth water? How about a freshly baked muffin? It certainly smells and tastes a lot different from the raw batter. There is a lot of chemistry going on when you smell or taste foods.

THE DIFFERENCE BETWEEN "TASTE" AND "FLAVOR"

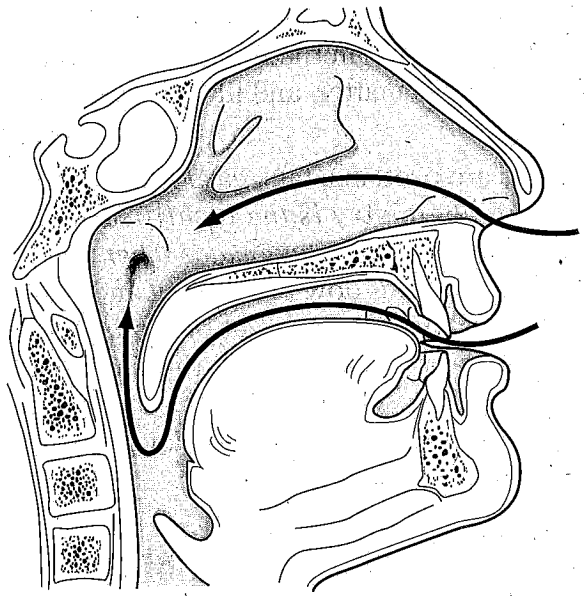
Food chemists use the words *aroma* and *flavor* instead of "smell" and "taste" because they understand each of these four words in different ways. You may have learned that humans recognize four fundamental tastes—sweet, sour, salty, and bitter. Some scientists would add a fifth fundamental taste called *umami,* a Japanese word for the taste of meat broth. This taste is associated with the presence of the amino acid glutamic acid. Monosodium glutamate, MSG for short, has the umami taste. Other research has pointed to the existence of even a sixth fundamental taste: the taste of polyunsaturated fatty acids, which are fatty acids that have more than one double bond between carbon atoms in the chain.

The term *flavor* involves much more than the fundamental tastes. Flavor refers to the total experience you have when you taste food, which is a combination of taste, aroma, and chemical irritation.

Aroma is our perception of the volatile substances that reach the *olfactory,* or smell, receptors in the nasal cavities. Some scientists estimate that 90% of what we call flavor is really the aroma of food. Many of the volatile compounds that contribute to flavor enter the nasal cavities from the mouth, not through the nostrils, as shown in **Figure 1** on the next page. So, the sensations of aroma and flavor are not easily separated.

FIGURE 1: THE NASOPHARYNGEAL PASSAGE

Food chemicals enter the nasopharyngeal passage, which links the mouth and nose, and are detected by olfactory (smell) receptors. Smells contribute much to the overall "flavor" experience of a food.



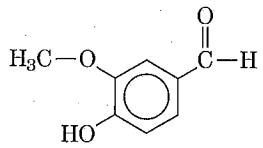
FLAVOR INCLUDES CHEMICAL IRRITATION

In addition to taste and aroma, foods such as black pepper, hot chiles, ginger, and cinnamon have a "hot" flavor because they contain chemically irritating compounds. These compounds irritate the taste and smell receptors, causing a burning sensation. The "heat" of a food depends on which substances are present and how concentrated the substances are. Scientists have suggested that people enjoy hot food because the body releases endorphins in reaction to the "heat." Endorphins produce a sensation of pleasure. However, at some concentrations, these compounds can cause physical pain and can be toxic.

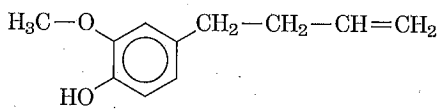
WHY ARE FLAVORS ADDED?

A lot of food chemists work in the food industry developing appealing flavors for processed food. These "flavorists" learn what substances are likely to produce certain flavors and aromas and how mixtures of substances can duplicate natural flavors. If you are wondering why it is necessary to add flavor to foods, think of all of the precooked, prepared foods you see in a supermarket—frozen foods you can heat and eat, food that has been processed to remove fat, instant coffee and tea, and foods such as soft drinks that don't even exist in a natural form. People want these sorts of products but expect them to taste good too. When foods are processed, many of their flavor and aroma components are lost or changed. So, flavor chemists analyze the components of the natural food and attempt to duplicate those flavors in the processed product. Sometimes chemists add flavors that don't even exist in the food's natural form.

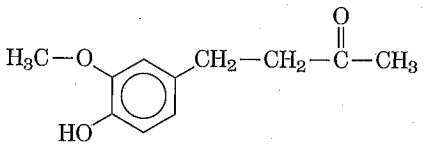
FIGURE 2: A COMPARISON OF FOUR VANILLOID COMPOUNDS



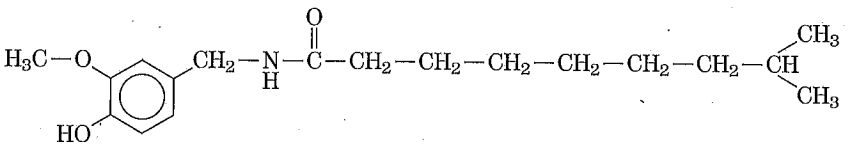
Vanillin



Eugenol



Zingerone



Capsaicin

FLAVOR AND MOLECULAR STRUCTURE

Scientists think that the flavor and aroma produced by a given molecule relates to the way the molecule interacts with a protein in a receptor connected to a nerve. However, chemists now know that flavor and aroma depend a lot on the shapes and sizes of molecules. Scientists continue to do research to pinpoint all of the features of molecules that contribute to flavor and aroma. Sometimes, small differences in molecular structure make a great difference in flavor. Look at the structural formulas of the four compounds shown in **Figure 2** above. These molecules are classified as *vanilloid* compounds because they have the same parent structure as vanillin. They all have distinctive odors, but each one smells very different from the others because of the differences in the "side chains" attached to the vanilloid parent structure.

FLAVORS OF THE VANILLOID FAMILY

Characteristics and sources of the vanilloid compounds shown in **Figure 2** are summarized in **Table 1** on the next page. Vanillin itself has the pleasant, sweet smell of vanilla. Eugenol, on the other hand, has a much stronger, spicy scent. In high concentrations, eugenol can actually numb pain, which is why oil of clove (which contains eugenol) has sometimes been used on toothaches. The strength

TABLE 1: A COMPARISON OF FOUR VANILLOID COMPOUNDS

Name	Flavor	Natural Sources
Vanillin	vanilla	vanilla bean, wood
Eugenol	clove	bay leaves, cloves, allspice
Zingerone	hot ginger	ginger root, mustard
Capsaicin	hot, burning taste	hot chile peppers (not black pepper)

of flavor sensation overwhelms the perception of the toothache pain. Zingerone is the main flavor in ginger. If you've ever taken a bite of raw ginger root, you know that zingerone has a pungent, hot flavor. Zingerone does not seem as strong as eugenol, however, because it is not as volatile or not as much reaches your smell receptors in gaseous form. Finally, capsaicin is the hot compound found in hot chile or cayenne peppers. Its distinguishing chemical characteristic is its long hydrocarbon side chain.

WHY IS CAPSAICIN HOT?

The hydrocarbon chain in a capsaicin molecule causes it to bind to the oily lipid molecules that make up the cell membrane, which keeps the inside of a cell separate from its environment. When a capsaicin molecule binds in this way, calcium ions flood into the cell. This action is one of the things that happens when cells are exposed to high temperatures. The result is that you perceive a sensation that is just like the experience of heat, which is why we call spicy food "hot."

The effect of capsaicin on cells is the reason that capsaicin is one of the components of pepper spray. Capsaicin produces a hot taste on the tongue, but capsaicin in the eyes and nasal passages can be extremely painful. Capsaicin is also useful in *counterirritant* lotions and creams. Counterirritants can relieve the sensation of pain by causing pain themselves when they are applied to the skin. Typically, they are applied to areas of the body with strains, sprains, and arthritic pain. Scientists are still trying to determine the exact mechanism by which counterirritants work. One theory is that substances such as capsaicin irritate the skin, causing pain that masks the muscle or joint pain. In addition, the skin irritation causes increased blood flow to the whole area, and this can help heal muscle or joint injury.

Food scientists are using both genetic engineering and classical breeding techniques to create new types of chiles to suit a variety of preferences.

Careers in Food Chemistry

Food chemists have opportunities to work in a wide variety of interesting careers. A few of these careers are described below.

FLAVORIST/PERFUMER

As you read above, flavor and aroma are almost inseparable. The main difference between flavorists and perfumers is that flavorists work with food and perfumers work with all kinds of scents, not just the ones used in perfumes. Flavorists participate in the development of food products and study the molecular changes that occur when food is cooked. Some flavorists do research to determine what substances contribute to the natural flavors of food and try to find ways to re-create those flavors.

Many perfumers work to find scents that will make consumer products, even ones unrelated to food, more attractive to customers. Think of the many household cleaning products and their huge variety of smells. Perfumers contribute to the scent of everything from soap to new cars. Today, most professional flavorists and perfumers hold college degrees, often in chemistry.

DIETICIAN

Dieticians must understand the chemistry of food and the reactions used to digest nutrients. Becoming a professional dietician requires a college degree, internship, and state licensing in most cases. Dieticians do more than just plan meals for schools and hospitals. Some dieticians work with professional, college, or Olympic sports teams as well as fitness and health clubs. Some dieticians are in private practice, where they prescribe diets for patients to ensure good nutrition while meeting some special need, such as gaining or losing weight, managing an allergy, or alleviating some diseases involving the digestive system.

FOOD TECHNOLOGIST

Food technologists deal with the composition and changes in food from agricultural production to processing, storage, and distribution. Students who want to be food technologists study chemistry and biology in college and also take specific courses in food technology. Some food technologists work in research to find ways to maintain acceptable tastes and textures in food as it is processed. Other food technologists work with engineers to develop processing, packaging, and shipping techniques that will ensure the quality of food products while meeting government regulations.

Topic Questions

1. Why are flavoring substances added to processed foods?

2. Explain the difference between "taste" and "flavor."

3. What structural feature of the vanilloid compounds is responsible for their very different flavors?

4. Explain why chemical compounds such as eugenol and capsaicin can be used as anesthetics.

5. Draw the part of the chemical structure that is common to all four vanilloid compounds discussed.

Name _____ Class _____ Date _____

Food Chemistry Lab

PROBEWARE LAB

Energy Content of Foods

You are a lab technician working for NASA. Recently you were given the job of deciding what type of foods should be included in the next space mission. Four food types have been selected as possible snacks for the astronauts. You need to determine which of these four food choices has the highest *energy content*, while adding the least amount of mass to the mission.

Your team will test two of the food types using a method known as calorimetry. During this process, you will burn a food sample positioned below a can containing a given amount of cold water. The water temperature will be monitored during the experiment using a temperature probe. By calculating the temperature change of the water, you will determine how much energy was released when the food sample burned.

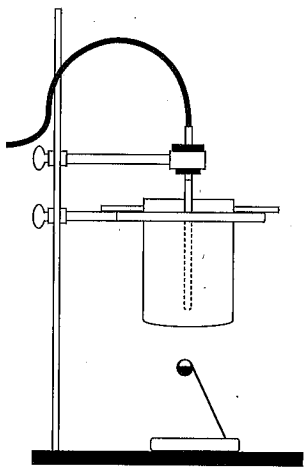


FIGURE 1

OBJECTIVES

Measure temperature changes.

Calculate energy changes using specific heat.

Infer the energy content of food.

Relate energy content to types of food.

Evaluate whether the nutrition labels are accurate.

MATERIALS

- can, small
- food sample (2)
- matches
- water, cold
- wooden splint

EQUIPMENT

- food holder (see **Figure 1**)
- graduated cylinder, 100 mL
- LabPro or CBL2 interface
- stirring rod (2)
- ring stand with a 4-in. ring
- slit stopper
- TI graphing calculator
- utility clamp
- Vernier temperature probe

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- Secure loose clothing, and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- In order to avoid burns, wear heat-resistant gloves whenever instructed to do so.
- If you are unsure of whether an object is hot, do not touch it.
- Avoid wearing hair spray or hair gel on lab days.
- Whenever possible, use an electric hot plate as a heat source instead of an open flame.
- Never return unused chemicals to the original container; follow instructions for proper disposal.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Plug the temperature probe into Channel 1 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
3. Turn on the calculator, and start the DATAMATE program. Press CLEAR to reset the program.
4. Set up the calculator and interface for the temperature probe.
   a. Select SETUP from the main screen.
   b. If the calculator displays a temperature probe in CH 1, proceed directly to Step 5. If it does not, continue with this step to set up your sensor manually.
   c. Press ENTER to select CH 1.
   d. Select TEMPERATURE from the SELECT SENSOR menu.
   e. Select the temperature probe you are using (in degrees Celsius) from the TEMPERATURE menu.

5. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select TIME GRAPH from the SELECT MODE menu.
   c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.
   d. Enter "6" as the time between samples in seconds.
   e. Enter "100" as the number of samples. The length of the data collection will be 10 minutes.
   f. Select OK to return to the setup screen.
   g. Select OK again to return to the main screen.
6. Obtain a piece of one of the two foods assigned to you and a food holder like the one shown in **Figure 1.** Find and record the initial mass of the food sample and food holder. **CAUTION:** *Do not eat or drink in the laboratory.*
7. Determine and record the mass of an empty can. Obtain cold water from your teacher, and add 50 mL of it to the can. Determine and record the mass of the can and water.
8. Set up the apparatus as shown in **Figure 1.** Use a ring and stirring rod to suspend the can about 2.5 cm (1 in.) above the food sample. Use a utility clamp to suspend the temperature probe in the water. The probe should not touch the bottom of the can. Remember that the temperature probe must be in the water for at least 30 seconds before you complete Step 9.

DATA TABLE 1

Food sample 1:			
initial mass of food sample and holder:			
mass of empty can:		mass of can and water:	
Food sample 2:			
initial mass of food sample and holder:			
mass of empty can:		mass of can and water:	

DATA COLLECTION

9. Select START to begin collecting data. Record the initial temperature of the water, T_1, in Data Table 2 (round to the nearest 0.1°C). **Note:** You can monitor temperature in the upper-right corner of the real-time graph displayed on the calculator screen. Remove the food sample from under the can, and use a wooden splint to light it. Quickly place the burning food sample directly under the center of the can. Allow the water to be heated until the food sample stops burning.
10. Continue stirring the water until the temperature stops rising. Record this maximum temperature, T_2. Data collection will stop after 10 minutes (or press the [STO▶] key to stop *before* 10 minutes have elapsed).
11. Determine and record the final mass of the food sample and food holder.

12. To confirm the initial (T_1) and final (T_2) values you recorded earlier, examine the data points along the curve on the displayed graph. As you move the cursor right or left, the time (X) and temperature (Y) values of each data point are displayed below the graph.
13. Press ENTER to return to the main screen. Select START to repeat the data collection for the second food sample. Use a new 50 mL portion of cold water. Repeat Steps 6–12.
14. When you are done, place burned food, used matches, and partially burned wooden splints in the container provided by the teacher.

DATA TABLE 2

Food sample 1:					
T_1:		T_2:		final mass of sample and holder:	
Food sample 2:					
T_1:		T_2:		final mass of sample and holder:	

Analysis

1. **Organizing Data** Find the mass of water heated for each sample. _____

2. **Organizing Data** Find the change in temperature of the water, ΔT, for each sample. _____

3. **Organizing Data** Find the mass (in grams) of each food sample burned. _____

4. **Analyzing Results** Calculate the heat absorbed by the water, q, using the equation

$$q = C_p m \Delta T$$

where q is heat, C_p is the specific heat, m is the mass of water, and ΔT is the change in temperature. For water, C_p is 4.18 J/g°C. Convert your final answer to units of kJ. _____

5. Analyzing Results Use the results of the previous two steps to calculate the energy content (in kJ/g) of each food sample. _____

_____

_____

DATA TABLE 3

Food sample 1:			
mass of water heated:	g	temperature change, ΔT:	°C
mass of food burned:	g	heat, q:	kJ
energy content of food sample:			kJ/g
Food sample 2:			
mass of water heated:	g	temperature change, ΔT:	°C
mass of food burned:	g	heat, q:	kJ
energy content of food sample:			kJ/g

Conclusions

1. Evaluating Results Record your results and the results of other groups in the Class Results Table below. Which food had the highest energy content? Which had the lowest energy content? _____

_____

CLASS RESULTS TABLE

Marshmallows	Peanuts	Cashews	Popcorn
kJ/g	kJ/g	kJ/g	kJ/g
kJ/g	kJ/g	kJ/g	kJ/g
kJ/g	kJ/g	kJ/g	kJ/g
kJ/g	kJ/g	kJ/g	kJ/g
kJ/g	kJ/g	kJ/g	kJ/g

Average for each food type:

kJ/g	kJ/g	kJ/g	kJ/g

2. Evaluating Results Food energy is often expressed in a unit called a Calorie (or dietary calorie). There are 4.18 kJ in one Calorie. Based on the class average for peanuts, calculate the number of Calories in a 50.0 g package of peanuts. _____

_____

3. **Evaluating Results** Two of the foods in the experiment have a high fat content (peanuts and cashews), and two have a high carbohydrate content (marshmallows and popcorn). From your results, what generalization can you make about the relative energy content of fats and carbohydrates? _____

4. **Evaluating Results** Based on the data you and your classmates collected, which of the four foods tested would you suggest to send on the NASA space mission?

Extensions

1. **Applying Results** If you were packing for a mountain hike, what kind of snacks would you bring along? Why? _____

2. **Critiquing Methods** Was all of the energy as heat that was given off by the burning food sample transferred to the water in the can? How could this experiment be improved to account for all of the energy given off when the food sample was burned? _____

3. **Applying Results** Listed on the following page are possible nutrition labels for each of the food samples that you tested. Based on the data you and your classmates obtained in this lab, determine which of these labels are accurate and which are not. If you find a label to be incorrect, explain your reasoning.

Energy Content of Foods *continued*

MARSHMALLOWS

Nutrition Facts	
Serving Size 1 ounce	
Servings Per Container 6	
Amount per serving	
Calories 260	Calories from Fat 160
	% Daily Value
Total Fat 18g	**13%**
Saturated Fat 5g	**27%**
Cholesterol 0mg	**0%**
Sodium 260mg	**11%**
Total Carbohydrate 23g	**8%**
Dietary Fiber 1g	**11%**
Sugars 18g	
Protein 1g	

PEANUTS

Nutrition Facts	
Serving Size 1 ounce	
Servings Per Container 16	
Amount per serving	
Calories 165	Calories from Fat 125
	% Daily Value
Total Fat 14g	**20%**
Saturated Fat 1.9g	**10%**
Cholesterol 0mg	**0%**
Sodium 122mg	**5%**
Total Carbohydrate 5g	**2%**
Dietary Fiber 1g	**4%**
Sugars 2g	
Protein 8g	

CASHEWS

Nutrition Facts	
Serving Size 1 ounce	
Servings Per Container 16	
Amount per serving	
Calories 80	Calories from Fat 26
	% Daily Value
Total Fat 3g	**4%**
Saturated Fat 0.5g	**3%**
Cholesterol 0mg	**0%**
Sodium 177mg	**7%**
Total Carbohydrate 8g	**3%**
Dietary Fiber 2g	**8%**
Sugars 2g	
Protein 5g	

POPCORN

Nutrition Facts	
Serving Size 1 cup	
Servings Per Container 8	
Amount per serving	
Calories 30	Calories from Fat 0
	% Daily Value
Total Fat 0.3g	***%**
Saturated Fat 0g	***%**
Cholesterol 0mg	**0%**
Sodium 0mg	***%**
Total Carbohydrate 6g	**2%**
Dietary Fiber 1g	**4%**
Sugars 2g	
Protein 0g	
***Less than 1% of US RDA**	

Name _____ Class _____ Date _____

Food Chemistry Lab

PROBEWARE LAB

Buffer Capacity in Commercial Beverages

Quickslurp Beverages, Inc., has just produced a new lemonade drink mix. As a food scientist working in the quality control department, your job is to ensure that the product tastes the same no matter what type of water is used to prepare it. The difference in pH of varying water samples can affect the overall taste of the drink. To prevent any change in taste, a citric acid–sodium citrate buffer has been added to the mix. You are responsible for ensuring that this buffer system properly resists small changes in pH that may result when water is added.

Household tap water can vary in pH from 6.5 to 8.5. That means that some water sources are slightly acidic, whereas others are slightly basic. The buffer added to the drink mix can resist changes in pH upon the addition of small amounts of H^+ or OH^- ions, preventing any change in the drink's taste. Combining a weak acid with a salt of the weak acid can form one type of buffer. Citric acid and sodium citrate have been added to the drink mix and are an example of this kind of buffer pair.

You will make a direct comparison of buffer capacity between the lemonade drink mix and an unbuffered 0.010 M citric acid solution. The pH of the drink mix will be monitored with a pH sensor as a solution of 0.10 M NaOH is titrated into the solution. A second titration will be performed using the citric acid solution in place of the drink mix. A comparison between the two titrations will reveal the buffering capacity of the lemonade drink mix.

OBJECTIVES

Measure pH changes.

Graph pH-volume data pairs.

Compare pH change in buffered and unbuffered solutions.

Calculate buffer capacity of a lemonade drink.

MATERIALS

- citric acid solution, 0.01 M
- lemonade drink
- NaOH solution, 0.10 M
- rinse bottle with distilled water
- water, distilled

EQUIPMENT

- beaker, 250 mL
- graduated cylinder, 50 mL or 100 mL
- LabPro or CBL2 interface
- magnetic stirrer with stirring bar (if available)
- ring stand
- TI graphing calculator
- utility clamp (2)
- Vernier pH sensor

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- If any substance gets in your eyes, notify your instructor immediately and flush your eyes with running water for at least 15 minutes.
- If a chemical is spilled on the floor or lab bench, alert your instructor, but do not clean it up yourself unless your teacher says it is OK to do so.
- Secure loose clothing and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Use a graduated cylinder to measure out 40 mL of the lemonade drink and 60 mL of distilled water into a 250 mL beaker. **CAUTION:** *Do not eat or drink in the laboratory.*
3. Place the beaker on a magnetic stirrer and add a stirring bar. If no magnetic stirrer is available, you will need to stir the beaker with a stirring rod during the titration.
4. Plug the pH sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.

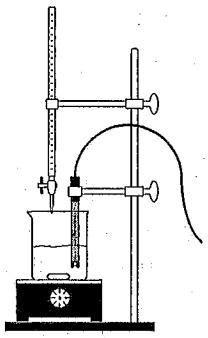


FIGURE 1

5. Use a utility clamp to suspend a pH sensor on a ring stand as shown in **Figure 1.** Position the pH sensor in the lemonade mixture, and adjust its position so that it is not struck by the stirring bar.
6. Obtain a 50 mL buret, and rinse it with a few mL of the 0.10 M NaOH solution. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.* Dispose of the rinse solution as directed by your teacher. Use a utility clamp to attach the buret to the ring stand as shown in **Figure 1.** Fill the buret a little above the 0.00 mL level with 0.10 M NaOH solution. Drain a small amount of NaOH solution so that it fills the buret tip *and* leaves the NaOH at the 0.00 mL level of the buret. Record the precise concentration of the NaOH solution in your data table.

DATA COLLECTION

7. Turn on the calculator, and start the DATAMATE program. Press [CLEAR] to reset the program.
8. Set up the calculator and interface for the pH sensor.
   a. Select SETUP from the main screen.
   b. If CH 1 displays PH, proceed directly to Step 9. If it does not, continue with this step to set up your sensor manually.
   c. Press [ENTER] to select CH 1.
   d. Select PH from the SELECT SENSOR menu.
9. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select EVENTS WITH ENTRY from the SELECT MODE menu.
   c. Select OK to return to the main screen.
10. You are now ready to perform the titration. This process goes faster if one person adjusts and reads the buret while another person operates the calculator and enters volume data.
    a. Select START to begin data collection.
    b. Before you have added any NaOH solution, press [ENTER] and type in "0" as the buret volume in mL. Press [ENTER] to save the first data pair for this experiment.

c. Add 2.0 mL of NaOH titrant. When the pH stabilizes, press ENTER and enter the current buret reading. You have now saved the second data pair for the experiment.

d. Continue to add 2.0 mL at a time, entering the buret level after each one. When the pH has leveled off between 10.5 and 11, press STO▶ to end data collection.

11. Examine the data on the displayed graph. As you move the cursor right or left on the graph, the volume (X) and pH (Y) values of each data point are displayed below the graph. Go to the region of the graph with the largest increase in pH. Find the NaOH volume just *before* this jump. Record this value in the data table. Then record the NaOH volume *after* the 2 mL addition producing the largest pH increase.

12. Store the data from the first run so that it can be used later:

a. Press ENTER to return to the main screen, and then select TOOLS.

b. Select STORE LATEST RUN from the TOOLS menu.

13. Use a graduated cylinder to measure out 40 mL of 0.010 M citric acid solution and 60 mL of distilled water into a 250 mL beaker. Position the pH sensor, beaker, and stirring bar as you did in Step 5. Refill the buret to the 0.00 mL level of the buret with 0.10 M NaOH solution. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*

14. Repeat Steps 6 and 10–11 of the procedure. **Important:** Add the same total volume of NaOH that you did in the first trial using the same number of 2 mL additions. Both lists of data must have the same number of points and the same volumes to be compatible for graphing in Step 16.

15. When you are finished, dispose of the beaker contents as directed by your teacher. Rinse the pH sensor, and return it to the pH storage solution.

16. A good way to compare the two curves is to view both sets of data on one graph:

a. Press ENTER to return to the main screen.

b. Select GRAPH from the main screen, then press ENTER.

c. Select MORE, then select L2 AND L3 VS L1 from the MORE OPTIONS menu.

d. Both pH runs should now be displayed on the same graph. Each point of the first run (lemonade drink) is plotted with a box, and each point of the second run (unbuffered citric acid solution) is plotted with a dot.

17. Print a graph of pH versus volume (with two curves displayed). Label each curve as "buffered lemonade" or "unbuffered citric acid."

DATA TABLE

	Lemonade	Citric acid solution
Concentration of NaOH	M	M
Volume of NaOH added *before* largest pH change	mL	mL
Volume of NaOH added *after* largest pH change	mL	mL
Volume of NaOH added at equivalence point	mL	mL
Mole NaOH	mol	mol

Analysis

1. **Examining Data** Use your graph and data table to locate the equivalence point. The equivalence point is characterized as the region of greatest pH change. Add the two NaOH values determined in Step 11, and divide by two. Record the result in your data table as the volume of NaOH added at the equivalence point.
2. **Organizing Data** Using the volume of NaOH titrant added, calculate the number of moles of NaOH used in each titration. Record the results in your data table.

Conclusions

1. **Interpreting Information** Which of the two solutions required more NaOH to reach the equivalence point? _____

2. **Analyzing Graphs** Compare the graph of each titration. How does the titration curve of the buffered lemonade drink mix compare with that of the unbuffered citric acid solution? _____

3. **Applying Conclusions** Based on the results of this experiment, do you believe the buffer system of the prepared lemonade drink is sufficient to handle more extreme pH changes? _____

_____

_____

Extensions

1. **Designing Experiments** Prepare three equal volume samples of lemonade drink using water samples with a pH of 6, 7, and 8. Test the resulting pH of the lemonade drink by using the pH sensor.

Name _____ Class _____ Date _____

Topic Introduction

An Introduction to Chemical Engineering

An engineer is a person who finds ways to put scientific knowledge to practical use. **Chemical engineers** *are people who study processes that involve matter and find ways to monitor and control those processes, often on an industrial scale.* These processes can be anything from the transport of solids, liquids, or gases, to carrying out series of chemical reactions on an industrial scale. For example, a chemical engineer may use a knowledge of chemistry to design ways of producing chemical products including pharmaceuticals, paint, petroleum products, plastics and other polymers, paper, fertilizers, and even the materials used to make microchips.

Chemical engineers work in many other areas. Some chemical engineers work in environmental fields to find ways to control and eliminate pollution. Other chemical engineers work in medicine and biotechnology, where they may design devices that control the flow of gases and liquids, improve kidney dialysis machines, or find new materials that can be used for medical devices within the body. Think of all the complex devices you might find in the operating rooms and patient care facilities of a large hospital. Someone had to design all of these items, and a chemical engineer was probably involved.

A Current Hot Topic: Biomedical Engineering

Biomedical engineering *is one of the newest branches of engineering and combines chemical engineering, biology, medicine, and computer science to devise new ways to improve health care.* It is such a growing field in today's society that chemical engineering departments at many universities have changed their names to include biomedical engineering.

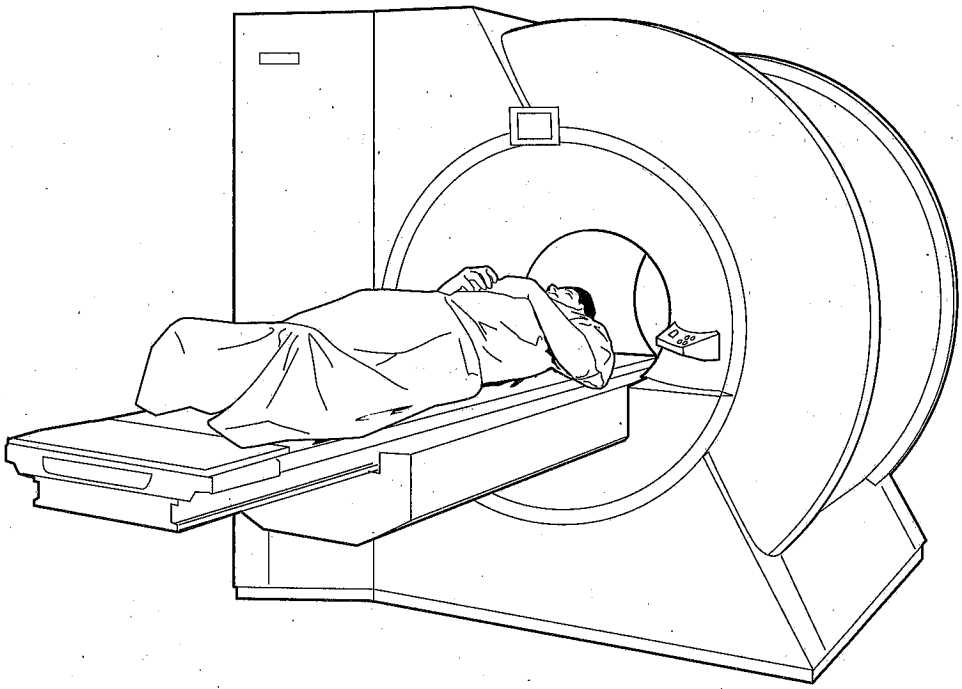
Biomedical engineers work with physicians, surgeons, dentists, nurses, technicians, and researchers in a wide range of tasks. For example, biomedical engineers may develop new processes for diagnosis and treatment, research new types of materials that can take the place of human tissues or speed up healing, or design improved prosthetic devices that can move in response to nerve impulses.

BIOINSTRUMENTATION

In the area of **bioinstrumentation,** *a biomedical engineer works to find ways to control electronic devices used in diagnosis, treatment, and patient monitoring with computers or to record and analyze the data that the devices gather.* A bioinstrumentation engineer may devise or improve ways to have computers analyze the information from imaging techniques such as magnetic resonance imaging (MRI) scans. An MRI device is shown in **Figure 1** on the next page.

FIGURE 1: MAGNETIC RESONANCE IMAGING

Inside an MRI chamber, an extremely strong magnetic field is applied to the body. Hydrogen atoms in the body's molecules resonate in response and emit radio signals. These signals are analyzed by a computer program that constructs an image of a cross section of the body.



BIOMECHANICS

All engineers study mechanics, the science of forces and motion. Biomedical engineers use *biomechanics* to analyze motion within the body, including the interaction of muscles, tendons, ligaments, and bone. Also, biomechanical engineers study the motion of bodily fluids, such as blood in the circulatory and respiratory systems. Advances in biomechanics have increased understanding of how the heart, lungs, blood vessels, and capillaries work. Knowledge of biomechanics has led to the development and improvement of devices such as replacement joints, artificial hearts and heart valves, and artificial kidneys.

ORTHOPEDIC AND REHABILITATION BIOENGINEERING

Orthopedic and rehabilitation bioengineering is closely related to biomechanics. Engineers in this field may develop new materials to use in replacement joints so that the joints behave like natural joints. Research is underway to find materials that can take the place of tendons, ligaments, and cartilage. Some bioengineers work in the field of sports medicine, devising ways in which athletes can use their energy most efficiently and designing methods and devices to treat sports injuries.

Engineers are also working on devices to overcome sensory loss. An example is an artificial retina to enable people with failed retinas to see. In one approach, a tiny video camera is mounted on eyeglasses. The video signal is sent to a microchip on the retina where it stimulates some of the remaining undamaged retinal cells. The image produced is not very clear, but it enables the person to distinguish faces and many objects. Other engineers are developing an artificial retina that can send signals to the optic nerve or directly to the brain and can form more-detailed images.

BIOMATERIALS ENGINEERING

Biomaterials engineers develop materials that can safely be used in the human body. Materials to be used in the body must be unreactive, nontoxic, and sturdy, whether they are to be left in the body permanently or are in the body briefly, during surgery. One of these materials you may be familiar with is *cyanoacrylate* (super glue), which is often used to close wounds and surgical incisions. When glue is used, no stitches need to be removed later.

One focus of research in biomaterials is to develop "scaffold" materials that can act as support for the regrowth of tissue such as new skin for burn patients or new bone for patients with severe injuries or that have had bones removed because of cancer. These scaffolds can be made of ceramics, plastics, or other biological materials. Natural coral is sometimes used as a support for the regrowth of bone tissue.

A goal of engineers in biomaterials is to find a way to allow the body to regrow neurons. Such a discovery could help people who are paralyzed as a result of spinal cord injuries. Other research in biomaterials is directed at finding ways to regrow missing body parts. Before that can happen, scientists must learn more about the genetic factors that cause tissue to form certain structures such as bones, muscles, connective tissue, and skin.

Careers in Chemical Engineering

MEDICAL IMAGING TECHNOLOGIST

Medical imaging involves many techniques that have been developed to produce images of the internal structure of the body. You probably already know about X ray imaging, in which high-energy electromagnetic radiation passes through the body but is partially or completely blocked by internal structures. As the rays exit the body, they expose a piece of photographic film. When the film is developed, a "shadowgram" of the internal organs is revealed.

Ultrasound imaging is another technique in which high-frequency sound waves reflect from internal structures and the echoes are used to produce an image. Other techniques include positron emission tomography (PET), in which a small amount of a radioactive isotope is injected into the body. The radiation from the isotope is analyzed by a computer and an image is created. A medical imaging technician may prepare a patient, explain the imaging procedure, operate the imaging equipment, and make sure that the resulting images clearly show what the doctor wishes to see.

PILOT PLANT ENGINEER/TECHNICIAN

When a company decides to produce a new product, engineers often try out the manufacturing process on a smaller scale, using what is called a *pilot plant.* Chemical engineers are usually involved when the process involves combinations of matter or chemical reactions to produce new substances such as drugs. A pilot plant technician works with the engineers to find a way to obtain a good quality product as economically as possible. If the process involves chemical reactions, engineers use the pilot plant to determine the temperatures, pressures, flow rates, concentrations, and catalysts that give the best reaction rates and product yields. The technician may measure chemicals, record pilot plant data, control the process, use computers to analyze process data, and report results to the engineering staff.

ADVANCED MATERIALS ENGINEER

Materials engineers are always on the lookout for new materials with better properties. Advanced materials engineers develop new materials to meet specific needs. For example, engineers in the automobile and aerospace industries are always interested in making their vehicles lighter without sacrificing strength. Engineers may want a metal alloy (a mixture of two or more metals) that is light yet extremely strong. Some of the newest materials are those used in nanotechnology, which deals with the development of complex machines so small that they can be seen only with electron microscopes.

Topic Questions

1. What does a chemical engineer do?

2. Name at least three other kinds of professionals with which a biomedical engineer might work.

3. Describe a method that has been developed in biomedical engineering that enables visually impaired people to see.

4. What is the function of scaffold materials in biomedical engineering?

5. How might a chemical engineer contribute to the development of an airplane that is lighter yet stronger than airplanes used today?

Name _____ Class _____ Date _____

Chemical Engineering Lab

PROBEWARE LAB

Micro-Voltaic Cells

Your small plane has just crashed on a remote island in the South Pacific. After recovering from the crash, you inventory the plane's contents. The only useful item still working in the plane is the radio, but the plane's battery has been completely destroyed, and you have no other means of powering the radio. Wandering around the island, you discover a small building that appears to be an abandoned research facility. Inside you discover a working gasoline generator and a laboratory filled with chemicals and various items of lab equipment, but no batteries. Upon careful consideration, you decide that there is no way to get the generator to the radio or the radio to the lab. You decide that your best bet is to construct a new battery.

In one of the cabinets, you discover a collection of metal strips and solutions. The writing is in a foreign language with which you are unfamiliar. It is apparent from the writing that certain metals correspond to certain solutions. Remembering a little about electrochemistry from your high school chemistry class, you decide that you can use the metal strips and solutions to build an electrochemical cell. You realize that before you can begin, you need to establish a table of reduction potentials in order to choose the proper metals for the anode and cathode of the cell. After further searching, you discover a working voltmeter and all the materials necessary to create a series of micro-voltaic cells using the unknown metals and solutions.

In this experiment, you will be using a calculator-interfaced voltage probe in place of a voltmeter. The (+) lead makes contact with one metal and the (–) lead with another. If a positive voltage appears on the calculator screen, the cell has been connected correctly. If the voltage reading is negative, switch the positions of the leads. The metal attached to the (+) lead is the cathode (where reduction takes place) and thus has a higher, more positive reduction potential. The metal attached to the (–) lead is the anode (where oxidation takes place) and has the lower, more negative reduction potential.

OBJECTIVES

Measure potential differences between various pairs of half-cells.

Predict potentials of half-cell combinations.

Compare measured cell potentials with predicted cell potentials.

Calculate percentage error for measured potentials.

Establish the reduction potentials for five unknown metals.

MATERIALS

- filter paper, 11.0 cm diameter
- metals M_1, M_2, M_3, M_4, and M_5, 1 cm × 1 cm each
- $NaNO_3$, 1 M
- sandpaper
- solutions of M_1^{2+}, M_2^{2+}, . . . , and M_5^{2+}, 1 M each

EQUIPMENT

- forceps
- glass plate, 15 cm × 15 cm, or Petri dish, 11.5 cm diameter
- LabPro or CBL2 interface
- TI graphing calculator
- voltage probe

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices.
- If any substance gets in your eyes, notify your instructor immediately and flush your eyes with running water for at least 15 minutes.
- If a chemical is spilled on the floor or lab bench, alert your instructor, but do not clean it up unless your instructor says it is OK to do so.
- Secure loose clothing, and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Plug the voltage probe into Channel 1 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
3. Turn on the calculator, and start the DATAMATE program. Press CLEAR to reset the program.

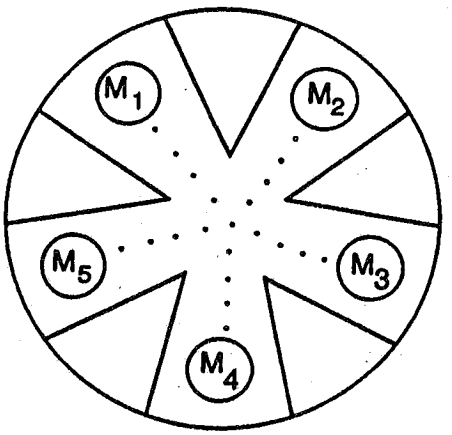


FIGURE 1

4. Set up the calculator and interface for the voltage probe.

a. If the calculator displays VOLTAGE (V) in CH 1, proceed directly to Step 5. If it does not, continue with this step to set up your sensor manually.

b. Select SETUP from the main screen.

c. Press ENTER to select CH 1.

d. Select the voltage probe you are using from the SELECT SENSOR menu.

e. Select OK to return to the main screen.

5. Obtain a piece of filter paper, and draw five small circles with connecting lines, as shown in **Figure 1.** Using a pair of scissors, cut wedges between the circles as shown. Label the circles "M_1," "M_2," "M_3," "M_4," and "M_5." Place the filter paper on top of the glass plate.

6. Obtain five pieces of metal, M_1, M_2, M_3, M_4, and M_5. Sand each piece of metal on both sides. Place each metal near the circle with the same number.

7. Place three drops of each solution on its circle (M_1^{2+} on M_1, etc.). Then place the piece of metal on the wet spot with its respective cation. The top side of the metal should be kept dry. Then add several drops of 1 M $NaNO_3$ to the dotted lines drawn between each circle and the center of the filter paper. Be sure there is a continuous trail of $NaNO_3$ between each circle and the center. You may have to periodically dampen the filter paper with $NaNO_3$ during the experiment.
CAUTION: *Handle these solutions with care. Some are poisonous, and some cause hard-to-remove stains. If a spill occurs, ask your teacher how to clean it up safely.*

DATA COLLECTION

8. Use metal M_1 (the one that is obviously copper) as the reference metal. Determine the potential of four cells by connecting M_1 to M_2, M_1 to M_3, M_1 to M_4, and M_1 to M_5. This is done by bringing the (+) lead in contact with one metal and the (–) lead in contact with the other. If the voltage displayed on the main screen of the calculator is (–), then reverse the leads. Wait about five seconds to take a voltage reading, and record the (+) value appearing on the calculator screen in Table 1 (round to the nearest 0.01 V). Also record which metal is the (+) terminal and which is (–), when the voltage value is positive. Use the same procedure and measure the potential of the other three cells, continuing to use M_1 as the reference electrode.

DATA TABLE 1

Voltaic cell (metals used)	Measured potential (V)	Metal number of (+) lead	Metal number of (–) lead
M_1/M_2			
M_1/M_3			
M_1/M_4			
M_1/M_5			

9. Go to Step 1 of Processing the Data. Use the method described in Step 1 to rank the five metals from the lowest (–) reduction potential to the highest (+) reduction potential. Then *predict* the potentials for the remaining six cell combinations.

10. Now return to your work station and *measure* the potential of the six remaining half-cell combinations. If the $NaNO_3$ salt bridge solution has dried, you may have to re-moisten it. Record each measured potential in Table 2.

DATA TABLE 2

	Predicted potential (V)	Measured potential (V)	Percentage error (%)
M_2/M_3			
M_2/M_4			
M_2/M_5			
M_3/M_4			
M_3/M_5			
M_4/M_5			

11. When you are finished, select QUIT and exit the DATAMATE program.

12. When you have finished, use forceps to remove each of the pieces of metal from the filter paper. Rinse each piece of metal with tap water. Dry it, and return it to the correct container. Remove the filter paper from the glass plate using the forceps, and discard it as directed by your teacher. Rinse the glass plate with tap water, making sure that your hands do not come in contact with wet spots on the glass.

PROCESSING THE DATA

1. After finishing Step 8 in the procedure, arrange the five metals (including M_1) in Data Table 2 from the lowest reduction potential at the top (most negative) to the highest reduction potential at the bottom (most positive). Metal M_1, the standard reference, will be given an arbitrary value of 0.00 V. If the other metal was correctly connected to the *negative* terminal, it will be placed *above* M_1 in the chart (with a negative E° value). If it was connected to the positive terminal, it will be placed below M_1 in the chart (with a positive E° value). The numerical value of the potential relative to M_1 will simply be the value that you measured. Record your results in Table 3.

DATA TABLE 3

Metal (M_x)	Lowest (–) reduction potential, E° (V)
	Highest (+) reduction potential, E° (V)

Then calculate the *predicted* potential of each of the remaining cell combinations shown in Table 2, using the reduction potentials you just determined (in Table 3). Record the predicted cell potentials in Table 2. Return to Step 10 in the procedure, and finish the experiment.

2. Calculate the percentage error for each of the potentials you measured in Step 10 of the procedure. Do this by comparing the measured cell potentials with the predicted cell potentials in Table 2.

Analysis

1. Examining Data Which metal had the highest reduction potential? Which had the lowest reduction potential?

_____

_____

2. Examining Data Which combination of metals had the largest measured cell potential? _____

_____

_____

3. Analyzing Results In Step 8, the metal M_1 was arbitrarily given a reduction potential of 0.00 V and used as the reference metal in determining the potential of each voltaic cell. The metal M_1 can be positively identified as being copper. According to the Table of Standard Reduction Potentials, Cu has a reduction potential of +0.34 V. Adjust all of the reduction potentials in Table 3 by adding +0.34 V. Use the Table of Standard Reduction Potentials found in your textbook to properly identify each of the unknown metals in Table 3.

Conclusions

1. Drawing Conclusions If metal M_4 were actually gold, would your measured cell potential have been higher or lower? Explain why. _____

_____

_____

_____

_____

2. Drawing Conclusions If the battery back in the plane requires a 6 V power source, how can you arrange the electrochemical cell to yield the necessary voltage? _____

_____

_____

_____

_____

Name _____ Class _____ Date _____

Chemical Engineering Lab

PROBEWARE LAB

Air Pressure and Piston Design

Recently, your design firm has been contracted to design the piston and cylinder for an air compressor. As the staff mechanical engineer, you are responsible for this task. You have been issued a list of specifications for the compressor. The cylinder must have a total volume of 2 L and a compressed volume of 500 mL. Before you can determine the best material to use for the cylinder and piston, you must calculate how much pressure the walls of the cylinder must withstand.

To better understand the relationship between pressure and volume of a confined gas, you will need to investigate Boyle's Law. In 1662, Robert Boyle established that there was a mathematical relationship between the pressure of a confined gas and its volume when the temperature and amount of gas remained constant.

In this experiment, your team will determine the relationship between the pressure and volume of a confined gas. The gas you use will be air, and it will be confined in a syringe connected to a pressure sensor. As you move the piston of the syringe, the volume and pressure of the gas contained within will change. The pressure change will be monitored using a pressure sensor. It is assumed that the temperature and amount of gas will remain constant throughout the experiment. Pressure and volume data pairs will be collected and analyzed in this experiment. Using your collected data, you will determine the mathematical relationship between the pressure and volume of the confined gas. Then, you will be able to apply what you have learned to the piston design problem.

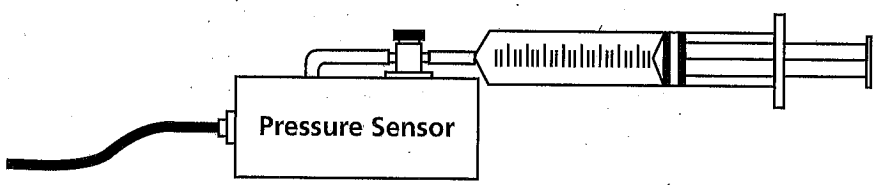


FIGURE 1

OBJECTIVES

Measure pressure changes.

Graph pressure-volume data pairs.

Calculate pressure and volume relationship.

Relate Boyle's law to real-world applications.

EQUIPMENT

- LabPro or CBL2 interface
- syringe, plastic, 20 mL
- TI graphing calculator
- Vernier gas pressure sensor or Vernier pressure sensor

SAFETY

Although the equipment and procedures used in this experiment are not particularly hazardous, always exercise caution when in labs, because there may be other hazards present in the lab room.

Procedure

EQUIPMENT PREPARATION

1. Prepare the pressure sensor and an air sample for data collection.
   a. Plug the pressure sensor into Channel 1 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
   b. With the 20 mL syringe disconnected from the pressure sensor, move the piston of the syringe until the front edge of the inside black ring is positioned at the 10.0 mL mark.
   c. Attach the 20 mL syringe to the valve of the pressure sensor.
   - Newer Vernier gas pressure sensors have a white stem protruding from the end of the sensor box—attach the syringe directly to the white stem with a gentle half turn.
   - Older Vernier pressure sensors have a 3-way valve at the end of a plastic tube leading from the sensor box. Before attaching the 20 mL syringe, align the blue handle with the stem of the 3-way valve that will *not* have the syringe connected to it, as shown in **Figure 2** at the right—this will close this stem. Then attach the syringe directly to the remaining open stem of the 3-way valve.

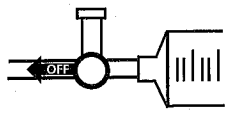


FIGURE 2

2. Turn on the calculator, and start the DATAMATE program. Press CLEAR to reset the program.
3. Set up the calculator and interface for a gas pressure sensor or pressure sensor.
   a. Select SETUP from the main screen.
   b. If the calculator displays a pressure sensor set to kPa in CH 1, proceed directly to Step 4. If it does not, continue with this step to set up your sensor manually.
   c. Press ENTER to select CH 1.
   d. Select PRESSURE from the SELECT SENSOR menu.
   e. Select the correct pressure sensor (GAS PRESSURE SENSOR or PRESSURE SENSOR) from the PRESSURE menu.
   f. Select the calibration listing for units of KPA.

4. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select EVENTS WITH ENTRY from the SELECT MODE menu.
   c. Select OK to return to the main screen.

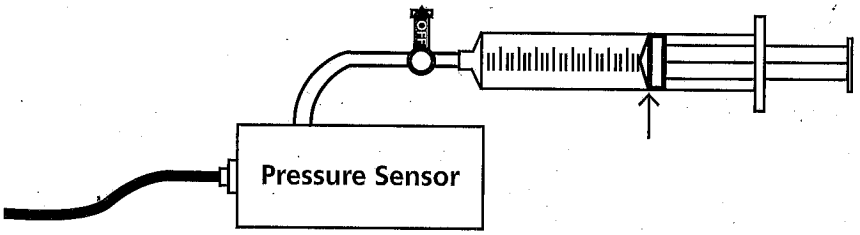


FIGURE 3

DATA COLLECTION

5. You are now ready to collect pressure and volume data. It is best for one person to take care of the gas syringe and for another to operate the calculator.
   a. Select START to begin data collection.
   b. Move the piston so the front edge of the inside black ring (see **Figure 3**) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the calculator screen stabilizes.
   c. Press [ENTER], and type in "5," the gas volume (in mL), on the calculator. Press [ENTER] to store this pressure-volume data pair.
   d. To collect another data pair, move the syringe to 7.5 mL. When the pressure reading stabilizes, press [ENTER] and enter "7.5" as the volume.
   e. Continue with this procedure using volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
   f. Press [STO▶] when you have finished collecting data.
6. Examine the data pairs on the displayed graph. As you move the cursor right or left, the volume (X) and pressure (Y) values of each data point are displayed below the graph. Record the pressure (round to the nearest 0.1 kPa) and volume data values in your data table.

Volume (mL)	Pressure (kPa)	Constant, k (P/V or $P \cdot V$)

7. Based on the graph of pressure versus volume, decide what kind of mathematical relationship exists between these two variables. Is it a direct relationship (greater pressures lead to greater volumes) or an inverse relationship (greater pressures lead to smaller volumes)? You can use the graphing calculator to see if you made the right choice:

a. Press [ENTER], then select ANALYZE from the main screen.

b. Select CURVE FIT from the ANALYZE OPTIONS menu.

c. Select POWER (CH 1 VS ENTRY) from the CURVE FIT menu. The graphing calculator can determine what line or curve fits a graph of your data best (this is called a *regression analysis*). For the statistics shown, a and b are the values for the equation shown.

$$y = ax^b$$

or

$$(\text{pressure}) = a(\text{volume})^b$$

If the relationship is direct, b will have a positive value. If the relationship is inverse, b will have a negative value.

d. To display the regression curve that best fits your graph of pressure versus volume, press [ENTER]. If you have correctly determined the mathematical relationship, the curve should very nearly fit the points on the graph (that is, pass through or near the plotted points).

8. (optional) Print a graph of pressure versus volume, with a regression line displayed.

Analysis

1. Examining Data When the syringe volume is moved from 5.0 mL to 10.0 mL, how did your pressure values change? Show the pressure values in your answer.

_____

_____

_____

2. Identifying/Recognizing Patterns Based on your data, if you take 1.0 L of air and place it in a 2.0 L cylinder, how would the pressure change? _____

_____

_____

3. **Identifying/Recognizing Patterns** How would the pressure change if 1.0 L of air was placed in a 3.0 L cylinder? _____

4. **Examining Data** When the syringe volume is moved from 20.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer. _____

5. **Identifying/Recognizing Patterns** How would the pressure change if 1.0 L of air was compressed in a cylinder to 500 mL? _____

6. **Describing Events** What experimental factors are assumed to be constant in this experiment? _____

Conclusions

1. **Drawing Conclusions** From your previous answers and the shape of the curve in the graph of pressure versus volume, is the relationship between the pressure and volume of a confined gas direct or inverse? Explain your answer.

2. **Applying Conclusions** Calculating the proportionality constant, k, is one way to determine if a relationship is inverse or direct. If this relationship is direct, $k = P/V$. If it is inverse, $k = PV$. Based on your answer to Conclusions question 1, choose one of these formulas and calculate k for the seven ordered pairs in your data table (divide or multiply the P and V values). Show the answers in the third column of the Data Collection table.

3. **Evaluating Data** How *constant* were the values for k you obtained in Conclusions question 2? Minor variation can be expected, but the values for k should be relatively constant. _____

4. **Interpreting Information** Write an equation for Boyle's law using P, V, and k. Write a definition explaining Boyle's law. _____

5. **Applying Conclusions** Calculate the gas pressure exerted on the cylinder walls when compressed at each of the following volumes. Assume that the initial atmospheric pressure is 100.0 kPa.

Compressed volume (L)	Gas volume (L)	Pressure (kPa)
1.00	1.0	100.0
0.50	1.0	
0.25	1.0	
2.00	1.0	

Extensions

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure versus *reciprocal of volume* (1/volume or volume^{-1}) may also be plotted. To do this using your calculator:
   - **a.** Press [ENTER], then return to the main screen.
   - **b.** Select QUIT to quit DATAMATE program. (Then press [ENTER] on a TI-83 Plus or TI-73).
   - **c.** Create a new data list, reciprocal of volume, based on your original volume data, following the steps shown below for your type of calculator.

TI-73 Calculators

- **d.** To view the data lists, press [LIST].
- **e.** Move the cursor up and to the right until the L3 heading is highlighted.
- **f.** Create a list of *1/volume* values in L3. First press [2nd] [STAT], and select L1. Then press [2nd] [x^{-1}] [ENTER].

TI-83 and TI-83 Plus Calculators

d. To view the data lists, press [STAT] to display the EDIT menu, and select Edit.

e. Move the cursor up and to the right until the L3 heading is highlighted.

f. Create a list of *1/volume* values in L3 by pressing [2nd] [L1] [x^{-1}] [ENTER].

TI-86 Calculators

d. To view the data lists, press [2nd] [STAT] and select EDIT.

e. Move the cursor up and to the right until the L3 heading is highlighted.

f. Create a list of *1/volume* values in L3 by pressing [NAMES] [L1] [2nd] [x^{-1}] [ENTER].

g. Press [2nd] [QUIT] when you are finished with this step.

TI-89, TI-92, and TI-92 Plus Calculators

d. Press [APPS], then select Home.

e. On a TI-89 calculator, create a list of *1/volume* values in L3 by pressing [CLEAR] [1] [÷] [ALPHA] [L] [1] [STO▸] [ALPHA] [L] [3] [ENTER]. On a TI-92 or TI-92 Plus, press [CLEAR] [1] [÷] [L] [1] [STO▸] [L] [3] [ENTER].

2. Follow this procedure to determine what curve best fits your graph of pressure versus 1/volume:

a. Restart the DATAMATE program.

b. Select ANALYZE from the main screen.

c. Select CURVE FIT from the ANALYZE OPTIONS menu.

d. Select LINEAR (CH1 VS CH2). Note that CH1 is pressure and CH2 is 1/volume. The linear-regression statistics for these two lists are displayed for the equation in the form

$$y = ax + b$$

where x is 1/volume, y is pressure, a is a proportionality constant, and b is the y-intercept.

e. To display the linear-regression curve on the graph of pressure versus 1/volume, press [ENTER]. If the relationship between P and V is an inverse relationship, the plot of P versus $1/V$ should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

3. (optional) Print a copy of the graph of pressure versus 1/volume, with the linear regression curve displayed.

Name _____ Class _____ Date _____

Chemical Engineering Lab

PROBEWARE LAB

Evaporation and Ink Solvents

You are an organic chemist working for a company that manufactures various types of ink. You have been asked to create a calligrapher's ink that dries quickly at room temperature. The company feels that such a product would be a big hit because faster-drying ink would cause less distortion to the paper on which it is used. Ink consists of two components: a pigment, or coloring agent, and a solvent. The pigment is what gives the ink its color. The solvent is the chemical in which the pigment is dissolved. Your job is to select a solvent that will evaporate quickly.

To determine the best solvent to use, you will test two types of organic compounds—alkanes and alcohols. To establish how and why these substances evaporate, you will test four alcohols and two alkanes. From your results, you will be able to predict how other alcohols and alkanes will evaporate.

The two alkanes you will test are pentane, C_5H_{12}, and hexane, C_6H_{14}. Alkanes contain only carbon and hydrogen atoms, whereas alcohols also contain the –OH functional group. In this experiment, two of the alcohols you will test are methanol, CH_3OH, and ethanol, C_2H_5OH. To better understand why these substances evaporate, you will examine the molecular structure of each for the presence and relative strength of hydrogen bonding and London dispersion forces.

The process of evaporation requires energy to overcome the intermolecular forces of attraction. For example, when you perspire on a hot day, the water molecules in your perspiration absorb heat from your body and evaporate. The result is a lowering of your skin temperature known as evaporative cooling.

In this experiment, temperature probes will be placed into small containers of your test substances. When the probes are removed, the liquid on the temperature probes will evaporate. The temperature probes will monitor the temperature change. Using your data, you will determine the temperature change, ΔT, for each substance and relate that information to the substance's molecular structure and presence of intermolecular forces.

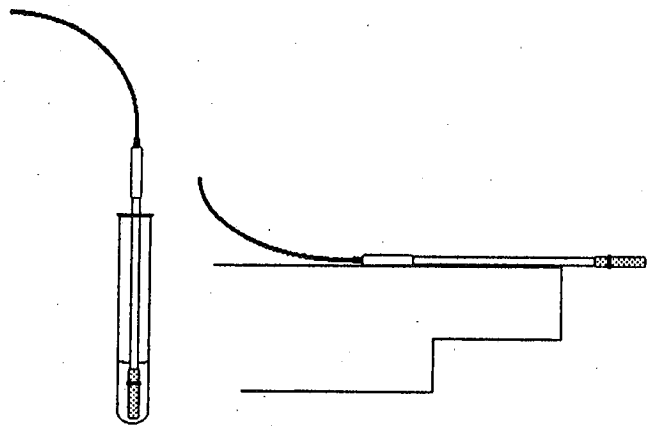


FIGURE 1

Evaporation and Ink Solvents *continued*

OBJECTIVES

Measure temperature changes.

Calculate changes in temperature.

Relate temperature changes to molecular bonding.

Predict temperature changes for various liquids.

MATERIALS

- 1-butanol
- 1-propanol
- ethanol (ethyl alcohol)
- filter paper pieces, 2.5 cm × 2.5 cm (6 pieces)
- masking tape
- methanol (methyl alcohol)
- *n*-hexane
- *n*-pentane
- rubber bands, small (2)

EQUIPMENT

- LabPro or CBL2 interface
- TI graphing calculator
- Vernier temperature probes (2)

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- If any substance gets in your eyes, notify your instructor immediately and flush your eyes with running water for at least 15 minutes.
- Use flammable liquids only in small amounts.
- When working with flammable liquids, be sure that no one else in the lab is using a lit Bunsen burner or plans to use one. Make sure there are no other heat sources present.
- Secure loose clothing, and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Pre-Lab Procedure

Before doing the experiment, complete the pre-lab table below. The name and formula are given for each compound. Draw a structural formula for a molecule of each compound. Then determine the molecular weight of each of the molecules. Dispersion forces exist between any two molecules and generally increase as the molecular weight of the molecule increases. Next, examine each molecule for the presence of hydrogen bonding. Before hydrogen bonding can occur, a hydrogen atom must be bonded directly to an N, O, or F atom within the molecule. Record whether each molecule has hydrogen-bonding capability.

Substance	Formula	Structural formulas	Molecular weight	Hydrogen bond (yes or no)
Ethanol	C_2H_5OH			
1-propanol	C_3H_7OH			
1-butanol	C_4H_9OH			
n-pentane	C_5H_{12}			
Methanol	CH_3OH			
n-hexane	C_6H_{14}			

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles! **CAUTION:** *The compounds used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid their contact with your skin or clothing. Be sure there are no open flames in the lab during this experiment. Notify your teacher immediately if an accident occurs.*
2. Plug temperature probe 1 into Channel 1 and temperature probe 2 into Channel 2 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
3. Turn on the calculator, and start the DATAMATE program. Press [CLEAR] to reset the program.
4. Set up the calculator and interface for two temperature probes.
   a. Select SETUP from the main screen.
   b. If the calculator displays two temperature probes, one in CH 1 and another in CH 2, proceed directly to Step 5. If it does not, continue with this step to set up your sensor manually.
   c. Press [ENTER] to select CH 1.
   d. Select TEMPERATURE from the SELECT SENSOR menu.
   e. Select the temperature probe you are using (in degrees Celsius) from the TEMPERATURE menu.

f. Press ▼ once, then press ENTER to select CH2.

g. Select TEMPERATURE from the SELECT SENSOR menu.

h. Select the temperature probe you are using (in degrees Celsius) from the TEMPERATURE menu.

5. Set up the data-collection mode.

a. To select MODE, use ▲ to move the cursor to MODE and press ENTER.

b. Select TIME GRAPH from the SELECT MODE menu.

c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.

d. Enter "3" as the time between samples in seconds.

e. Enter "80" as the number of samples. (The length of the data collection will be four minutes.)

f. Select OK to return to the setup screen.

g. Select OK again to return to the main screen.

6. Wrap probe 1 and probe 2 with square pieces of filter paper secured by small rubber bands as shown in **Figure 1.** Roll the filter paper around the probe tip in the shape of a cylinder. Hint: First slip the rubber band up on the probe, wrap the paper around the probe, and then finally slip the rubber band over the wrapped paper. The paper should be even with the probe end.

7. Stand probe 1 in the ethanol container and probe 2 in the 1-propanol container. Make sure the containers do not tip over.

8. Prepare two pieces of masking tape, each about 10 cm long, to be used to tape the probes in position during Step 9.

DATA COLLECTION

9. After the probes have been in the liquids for at least 30 seconds, select START to begin collecting temperature data. A live graph of temperature versus time for both probe 1 and probe 2 is being plotted on the calculator screen. The live readings are displayed in the upper-right corner of the graph, the reading for probe 1 first, the reading for probe 2 below it. Monitor the temperature for 15 seconds to establish the initial temperature of each liquid. Then simultaneously remove the probes from the liquids, and tape them so that the probe tips extend 5 cm over the edge of the table top as shown in **Figure 1.**

10. Data collection will stop after four minutes (or press the STO key to stop *before* four minutes have elapsed). On the displayed graph of temperature versus time, each point for probe 1 is plotted with a dot and each point for probe 2 with a box. As you move the cursor right or left, the time (X) and temperature (Y) values of each probe 1 data point are displayed below the graph. Based on your data, determine the maximum temperature, T_1, and minimum temperature, T_2. Record T_1 and T_2 for probe 1.

Press ▼ to switch the cursor to the curve of temperature versus time for probe 2. Examine the data points along the curve. Record T_1 and T_2 for probe 2.

11. For each liquid, subtract the minimum temperature from the maximum temperature to determine ΔT, the temperature change during evaporation.

12. Roll the rubber band up the probe shaft, and dispose of the filter paper as directed by your instructor.

13. Based on the ΔT values you obtained for these two substances, plus information in the pre-lab exercise, *predict* the ΔT value for 1-butanol. Compare its hydrogen-bonding capability and molecular weight with those of ethanol and 1-propanol. Record your predicted ΔT, and then explain how you arrived at this answer in the space provided. Do the same for *n*-pentane. It is not important that you predict the exact ΔT value; simply estimate a logical value that is higher, lower, or between the previous ΔT values.

14. Press ENTER to return to the main screen. Test your prediction in Step 13 by repeating Steps 6–12 using 1-butanol with probe 1 and *n*-pentane with probe 2.

15. Based on the ΔT values you have obtained for all four substances, plus information in the pre-lab exercise, predict the ΔT values for methanol and *n*-hexane. Compare the hydrogen-bonding capability and molecular weight of methanol and *n*-hexane with those of the previous four liquids. Record your predicted ΔT, and then explain how you arrived at this answer in the space provided.

16. Press ENTER to return to the main screen. Test your prediction in Step 15 by repeating Steps 6–12, using methanol with probe 1 and *n*-hexane with probe 2.

DATA TABLE

Substance	T_1 (°C)	T_2 (°C)	ΔT ($T_1 - T_2$) (°C)	Predicted ΔT(°C)	Explanation
Ethanol					
1-propanol					
1-butanol					
n-pentane					
Methanol					
n-hexane					

Analysis

1. **Analyzing Data** Which of the tested alcohols evaporated the fastest? Which alcohol had the largest ΔT value? What was the alcohol's molecular weight?

2. **Analyzing Data** Which of the alcohols tested evaporated the slowest? Which alcohol had the smallest ΔT value and molecular weight? _____

3. **Analyzing Results** The alcohol 1-butanol and alkane *n*-pentane have similar molecular weights, but their tests resulted in very different ΔT values. Based on the information in your pre-lab data table, explain the difference in the ΔT values of these substances. _____

4. **Analyzing Information** What types of intermolecular forces are evident in this experiment? _____

5. **Analyzing Data** Make a graph of your data with the molecular weight of each substance on the x-axis and ΔT on the y-axis.

Conclusions

1. **Evaluating Results** Alcohols with more than one –OH group are known as glycols. The substance ethylene glycol, CH_2OHCH_2OH, has a molecular weight of 62. Based on your data, would you expect it to have a larger or smaller ΔT than 1-propanol? Explain your answer using the results of this experiment.

2. **Inferring Conclusions** Of the substances tested in this experiment, which would work best as the solvent for the ink your company is developing?

Extensions

1. **Applying Results** Using methanol and ethanol as solvent choices, test different types of mediums. Use the different medium choices in place of the filter paper to determine if the medium has any effect on the rate of evaporation.

Name _____ Class _____ Date _____

Chemical Engineering Lab

PROBEWARE LAB

A Leaky Reaction

A recent test of discharge water at the Hassenfrass paper mill indicates that the water has become contaminated with sodium hydroxide. It is believed that a buried pipe carrying a solution of sodium hydroxide has sprung a leak and the solution is leaking into the discharge water. Unfortunately, there are many pipes running near the discharge channels and it is difficult to easily identify which pipe is leaking. The leak could be anywhere along a 200 m section of the discharge channel. The pH of the discharge water has been measured to determine the molarity and volume of solution escaping into the discharge water.

The environmental analysis firm you work for has been called out to locate the leak. Field technicians have put together a plan, which would involve replacing the discharge water with an aqueous solution of the indicator crystal violet. As the crystal violet solution flows through the discharge channel, it will react with the sodium hydroxide. This reaction results in a change in the color of the crystal violet solution from dark violet to colorless. The field technicians have contacted you because they need to know specifics concerning the crystal violet reaction. Your job is to determine the reaction rate and half-life when crystal violet and sodium hydroxide react. The field technicians believe that they can use colorimetric analysis to determine how long the crystal violet exiting the channel has reacted with the sodium hydroxide. This information, along with the flow rate of the channel, can be used to calculate how far up the channel the leak is occurring.

During the reaction, the solution will change from a violet color to colorless. Using a colorimeter set to the green (565 nm) wavelength, you will monitor the absorbance of the crystal violet solution over time. It is assumed that the measured absorbance is proportional to the concentration of crystal violet.

OBJECTIVES

Measure absorbance values of a crystal violet solution.

Gather absorbance vs. time data.

Graph absorbance-time data pairs.

Estimate the half-life of a reaction.

Calculate reaction time.

MATERIALS

- crystal violet solution, 2.5×10^{-5} M
- NaOH, 0.10 M
- water, distilled

EQUIPMENT

- beaker, 100 mL
- cuvette, plastic
- LabPro or CBL2 interface
- stirring rod
- TI graphing calculator
- Vernier colorimeter

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- If any substance gets in your eyes, notify your instructor immediately, and flush your eyes with running water for at least 15 minutes.
- Secure loose clothing, and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Use a 10 mL graduated cylinder to obtain 10.0 mL of 0.10 M NaOH solution. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.* Use another 10 mL graduated cylinder to obtain 10.0 mL of 2.5×10^{-5} M crystal violet solution. **CAUTION:** *Crystal violet is a biological stain. Avoid spilling it on your skin or clothing.*
3. Plug the colorimeter into Channel 1 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
4. Prepare a *blank* by filling an empty cuvette three-fourths full with distilled water. Seal the cuvette with a lid. To correctly use a colorimeter cuvette, remember the following:
   - All cuvettes should be wiped clean and dry on the outside with a tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - All solutions should be free of bubbles.
   - Always position the cuvette with its reference mark facing toward the white reference mark at the right of the cuvette slot on the colorimeter.

5. Turn on the calculator, and start the DATAMATE program. Press CLEAR to reset the program.
6. Set up the calculator and interface for the colorimeter.
   a. Place the blank in the cuvette slot of the colorimeter, and close the lid.
   b. Select SETUP from the main screen.
   c. If the calculator displays COLORIMETER in CH 1, set the wavelength on the colorimeter to 565 nm. Then calibrate by pressing the AUTO CAL button on the colorimeter, and proceed directly to Step 7. If the calculator does not display COLORIMETER in CH 1, continue with this step to set up your sensor manually.
   d. Press ENTER to select CH 1.
   e. Select COLORIMETER from the SELECT SENSOR menu.
   f. Select CALIBRATE from the SETUP menu.
   g. Select CALIBRATE NOW from the CALIBRATION menu.

First Calibration Point

   h. Turn the wavelength knob of the colorimeter to the 0% T position. When the voltage reading stabilizes, press ENTER. Enter "0" as the percent transmittance.

Second Calibration Point

   i. Turn the wavelength knob of the colorimeter to the green LED position (565 nm). When the voltage reading stabilizes, press ENTER. Enter "100" as the percent transmittance.
   j. Select OK to return to the setup screen.
7. Set up the data-collection mode.
   a. To select MODE, press ▲ once and press ENTER.
   b. Select TIME GRAPH from the SELECT MODE menu.
   c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.
   d. Enter "3" as the time between samples in seconds.
   e. Enter "60" as the number of samples. The length of the data collection will be three minutes.
   f. Select OK to return to the setup screen.
   g. Select OK again to return to the main screen.

DATA COLLECTION

8. You are now ready to begin monitoring data.
   a. To initiate the reaction, simultaneously pour the 10 mL portions of crystal violet and sodium hydroxide into a 100 mL beaker, and stir the reaction mixture with a stirring rod.

b. Empty the water from the cuvette. Rinse the cuvette with about 1 mL of the reaction mixture, and then fill it three-fourths full.

c. Place the cuvette in the cuvette slot of the colorimeter, and close the lid.

d. Monitor the absorbance reading on the main screen of the calculator for about 10 seconds (the absorbance reading should be gradually decreasing), then select START to begin data collection.

e. During the three-minute data collection, observe the solution in the beaker as it continues to react.

f. Data collection will end after three minutes.

g. Discard the contents of the beaker and cuvette as directed by your teacher.

DATA TABLE

	Trial 1	Trial 2
Initial absorbance		
Time at $\frac{1}{2}$ initial absorbance		
Half-life of reaction		
Time at $\frac{1}{4}$ initial absorbance		
Half-life of reaction		

CLASS DATA

Lab Team	Half-life	Lab Team	Half-life
1		7	
2		8	
3		9	
4		10	
5		11	
6		12	

Analysis

1. **Organizing Data** A graph of absorbance versus time will be displayed. Use the ▶ or ◀ keys to examine the data points along the displayed curve of absorbance versus time. As you move the cursor right or left, the time (X) and absorbance (Y) values of each data point are displayed below the graph. Determine the initial absorbance of the crystal violet solution. Write the initial absorbance in your data table.

2. **Examining Data** Using the displayed graph, estimate the half-life of the reaction; move the cursor to a data point that is about half of the initial absorbance value. The *time* it takes the absorbance (or concentration) to be halved is known as the *half-life* for the reaction. Depending on your initial absorbance value, determine a second half-life for the reaction by moving the cursor to the data point that corresponds to a quarter of the initial absorbance value. Record the half-lives in your data table.
3. **Analyzing Results** Record the half-life of the crystal violet reaction found by each lab team in the class in the data table on the previous page. Using the class data, calculate the average half-life. _____
4. **Analyzing Results** The field technicians filled the discharge channel with a 2.5×10^{-5} M solution of crystal violet. The initial absorbance of the solution was 0.488. The absorbance of the solution upon exiting the channel was 0.122. Using the average half-life calculated in Analysis question 3, calculate the length of time the crystal violet was reacting with the leaking sodium hydroxide.

_____

5. **Analyzing Results** It was determined that the solution flowed through the discharge channel at 2.0 m/s. Calculate the distance the reacting crystal violet traveled. _____

_____

Conclusions

1. **Evaluating Methods** How might you increase the accuracy of the results obtained in this lab exercise? Identify possible sources of error. _____

_____

_____

_____

Extensions

Designing Experiments Determine the reaction order with respect to crystal violet.

1. Analyze the data graphically to decide whether the reaction is zero, first, or second order with respect to crystal violet:
   - Zero order: If the current graph of absorbance versus time is linear, the reaction is *zero order.*

- First order: To see if the reaction is first order, it is necessary to plot a graph of the natural logarithm (ln) of absorbance versus time. If this plot is linear, the reaction is *first order.*
- Second order: To see if the reaction is second order, plot a graph of the reciprocal of absorbance versus time. If this plot is linear, the reaction is *second order.*

2. Follow these directions to create the natural log (ln) absorbance list in L3 and the 1/absorbance list in L4. To do this using your calculator, create a new data list based on your original volume data. Press [ENTER] to return to the main screen, and quit the DataMate program.

TI-73, TI-83, and TI-83 Plus Calculators

a. To view the lists, press [STAT] to display the EDIT menu and then select Edit.

b. To create a list of natural log (ln) of absorbance values in L3, move the cursor up and to the right until the L3 heading is highlighted, then press [LN] [2nd] [L2] [ENTER].

c. To create a list of reciprocal of absorbance values in L4, move the cursor up and to the right until the L4 heading is highlighted, then press [2nd] [L2] [x^{-1}] [ENTER].

d. Proceed to Step 3.

TI-86 Calculators

a. To view the lists, press [2nd] [STAT] and select EDIT.

b. To create a list of natural log (ln) of absorbance values in L3, move the cursor up and to the right until the L3 heading is highlighted, select NAMES, then press [L1] [2nd] [x^{-1}] [ENTER].

c. To create a list of reciprocal of absorbance values in L4, move the cursor up and to the right until the L4 heading is highlighted, then select L2, then press [2nd] [x^{-1}] [ENTER].

d. Press [2nd] [QUIT] when you are finished with this step, and then proceed to Step 3.

TI-89 Calculators

a. Press [APPS], then select Home.

b. To create a list of natural log (ln) of absorbance values in L3, press [CLEAR] [2nd] [LN] [ALPHA] [L] [2] [)] [STO▶] [ALPHA] [L] [3] [ENTER].

c. To create a list of reciprocal of absorbance values in L4, press [CLEAR] [1] [÷] [ALPHA] [L] [2] [STO▶] [ALPHA] [L] [4] [ENTER]. Proceed to Step 3.

TI-92 and TI-92 Plus Calculators

a. Press [APPS], then select Home.

b. To create a list of natural log (ln) of absorbance values in L3, press [CLEAR] [LN] [L] [2] [ST▸] [L] [3] [ENTER].

c. To create a list of reciprocal of absorbance values in L4, press [CLEAR] [1] [÷] [L] [2] [ST▸] [L] [4] [ENTER]. Proceed to Step 3.

3. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of absorbance, ln absorbance, or reciprocal of absorbance versus time:

a. Restart the DATAMATE program.

b. Select ANALYZE from the main screen.

c. Select CURVE FIT from the ANALYZE OPTIONS menu.

d. Select LINEAR (CH 1 VS ENTRY), LINEAR (CH 2 VS ENTRY), or LINEAR (CH 3 VS ENTRY) from the CURVE FIT menu. Note that CH1 is absorbance, CH2 is natural log (ln) absorbance, and CH3 is reciprocal of absorbance. The linear-regression statistics for these two lists you select are displayed for the equation in the form

$$y = ax + b$$

where x is time; y is absorbance, ln absorbance, or reciprocal absorbance; a is the slope; and b is the y-intercept.

e. To display the linear-regression curve on the graph, press [ENTER]. Examine your graph to see if the relationship is linear.

f. (optional) Print a copy of the graph.

g. To view a graph of the two other lists, press [ENTER] to return to the ANALYZE OPTIONS menu, and repeat Steps 3c–3f.

Name _____ Class _____ Date _____

Chemical Engineering Lab

PROBEWARE LAB

Solubility and Chemical Fertilizers

You have been hired as a chemist for a fertilizer manufacturer. The manufacturer is building a facility to manufacture a new brand of fertilizer. One of the chief components of this new fertilizer is potassium nitrate (KNO_3). Large pipes carrying the potassium nitrate solution feed into enormous vats where all the ingredients are mixed together. Your job is to create a solubility table so that engineers will know at what temperature the solution must be kept. If the solution's temperature dips too low, potassium nitrate crystals may form and clog the pipes. Such an incident could stop production, costing the company a lot of money.

Solubility is the maximum amount of a solute that can dissolve in a solvent. When additional solute is added past a solution's solubility, the additional solute will not dissolve. Temperature can have a great effect on solubility. Consequently, solubility values always include a temperature. For example, the solubility of sodium nitrate at 20°C is 88.0 g per 100 g of H_2O. If the temperature of the solvent is raised to 50°C, the solubility increases to 114.0 g per 100 g of H_2O. The solubility of most solid solutes increases with temperature. Solubility tables are a very useful tool in the preparation of concentrated solutions.

In this experiment, you will completely dissolve different quantities of potassium nitrate, KNO_3, in the same volume of water at a high temperature. As each solution cools, you will monitor temperature using a temperature probe and observe the precise instant that solid crystals start to form. At this moment, the solution is saturated and contains the maximum amount of solute at that temperature. Thus, each data pair consists of a *solubility* value (g of solute per 100 g H_2O) and a corresponding *temperature*. A graph of the temperature-solubility data, known as a solubility curve, will be plotted using the TI calculator.

OBJECTIVES

Measure temperature values of salt solutions.

Gather temperature-solubility data.

Create a solubility curve using temperature-solubility data.

Predict solubilities at different temperatures using a solubility curve.

Evaluate the effect of temperature on solubility.

MATERIALS

- potassium nitrate, KNO_3, 20 g

EQUIPMENT

- beaker, 250 mL
- beaker, 400 mL
- graduated cylinder, 10 mL
- hot plate
- LabPro or CBL2 interface
- ring stand
- stirring rod
- test-tube rack
- test tube, 20 mm × 150 mm (4)
- TI graphing calculator
- utility clamp (2)
- Vernier temperature probe (2)

SAFETY

- Wear safety goggles when working around chemicals, acids, bases, flames, or heating devices. Contents under pressure may become projectiles and cause serious injury.
- If any substance gets in your eyes, notify your instructor immediately and flush your eyes with running water for at least 15 minutes.
- Secure loose clothing, and remove dangling jewelry. Do not wear open-toed shoes or sandals in the lab.
- Wear an apron or lab coat to protect your clothing when working with chemicals.
- Never return unused chemicals to the original container; follow instructions for proper disposal.
- Always use caution when working with chemicals.
- Never mix chemicals unless specifically directed to do so.
- Never taste, touch, or smell chemicals unless specifically directed to do so.

Procedure

EQUIPMENT PREPARATION

1. Obtain and wear goggles.
2. Label four test tubes 1–4. Measure out the amounts of solid shown in the second column below (amount per 5 mL) into each of these test tubes. **Note:** The third column (amount per 100 g of H_2O) is *proportional* to your measured quantity and is the amount you will enter for your graph in Step 10.

Test tube number	Amount of KNO_3 used per 5.0 mL H_2O (weigh in Step 2)	Amount of KNO_3 used per 10^2 g H_2O (use in Step 10)
1	2.0	4.0×10^2
2	4.0	8.0×10^2
3	6.0	1.2×10^3
4	8.0	1.6×10^3

3. Add precisely 5.0 mL of distilled water to each test tube (assume 1.0 g/mL for water).
4. Plug the temperature probe into Channel 1 of the LabPro or CBL2 interface. Use the link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.
5. Turn on the calculator, and start the DATAMATE program. Press [CLEAR] to reset the program.
6. Set up the calculator and interface for the temperature probe.
   a. Select SETUP from the main screen.
   b. If the calculator displays a temperature probe in CH 1, proceed directly to Step 7. If it does not, continue with this step to set up your sensor manually.
   c. Press [ENTER] to select CH 1.
   d. Select TEMPERATURE from the SELECT SENSOR menu.
   e. Select the temperature probe you are using (in degrees Celsius) from the TEMPERATURE menu.
7. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select EVENTS WITH ENTRY from the SELECT MODE menu.
   c. Select OK to return to the main screen.
8. Fill a 400 mL beaker three-fourths full of tap water. Place it on a hot plate situated on (or next to) the base of a ring stand. Heat the water bath to about 90°C, and adjust the heat to maintain the water at this temperature. Place the temperature probe in the water bath to monitor the temperature and to warm the probe. **CAUTION:** *To keep from damaging the temperature probe wire, hang it over another utility clamp pointing away from the hot plate, as shown in* ***Figure 1.***

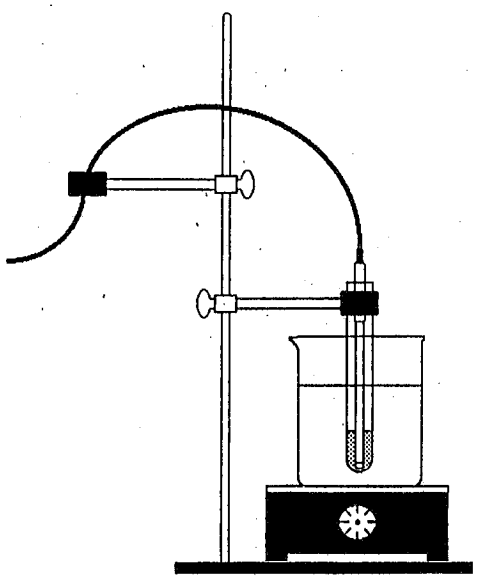


FIGURE 1

9. Use a utility clamp to fasten one of the test tubes to the ring stand. Lower the test tube into the water as shown in **Figure 1. Note:** To dissolve all of the KNO_3, you must heat test tubes 3 and 4 to a higher temperature than test tubes 1 and 2. Use your stirring rod to stir the mixture until the KNO_3 is *completely* dissolved. Do not leave the test tube in the water bath any longer than is necessary to dissolve the solid.

DATA COLLECTION

10. You are now ready to collect temperature-solubility data.

a. When the KNO_3 is completely dissolved, select START from the main screen.

b. Remove the temperature probe from the water bath, wipe it dry, and place it into the solution in the test tube.

c. Unfasten the utility clamp and test tube from the ring stand. Use the clamp to hold the test tube up to the light to look for the first sign of crystal formation. At the same time, stir the solution with a slight up and down motion of the temperature probe.

d. At the moment crystallization starts to occur, press [ENTER]. Enter the mass (g) in the TI calculator (mass [g] is the solubility value in column 3 of Step 2, *g per 100 g H_2O*).

e. After you have saved the temperature-mass data pair, return the test tube to the test tube rack and place the temperature probe in the water bath for the next trial.

11. Repeat Steps 9 and 10 for each of the other three test tubes. Here are some suggestions to save time.

- One lab partner can be stirring the next KNO_3/water mixture until it dissolves while the other partner watches for crystallization and enters data pairs using the TI calculator.
- Test tubes 1 and 2 may be cooled to lower temperatures using cool tap water in the 250 mL beaker. This drops the temperature much faster than air. If the crystals form too quickly, *briefly* warm the test tube in the hot-water bath and redissolve the solid. Then repeat the cooling and collect the data pair.

12. When you have collected the fourth and last data pair, press [STO▶] to stop data collection. Discard the four solutions as directed by your instructor.

13. Examine the data points along the curve on the displayed graph. As you move the cursor right or left, the solubility (X) and temperature (Y) values of each data point are displayed below the graph. Record the temperature values in your data table (round to the nearest 0.1°C).

14. Prepare a graph of solubility versus temperature. Before you the print the graph, set up the graph style and the scaling of the x- and y-axes:

a. Press [ENTER] to return to the main screen.

b. Select QUIT to exit the DATAMATE program.

TI-83 and TI-83 Plus Calculators

c. To plot a graph with solubility on the vertical axis and temperature on the horizontal axis, press [2nd] [STAT PLOT] and then select Plot1. Use the arrow keys to position the cursor on each of the following Plot1 settings. Press [ENTER] to select any of the settings you change: Plot1 = On, Type = ⌊⋰, Xlist = L2, Ylist = L1, and Mark = ■.

d. To scale the axes and set increments, press [WINDOW]. Scale the temperature from 0 to 100°C with increments of 10°C. Scale the solubility from 0 to 200 g with increments of 10 g.

e. Press [GRAPH] to view the graph of solubility versus temperature.

f. Print a copy of the graph of solubility versus temperature.

TI-73 Calculators

c. To plot a graph with solubility on the vertical axis and temperature on the horizontal axis, press [2nd] [PLOT] and then select Plot1. Use the arrow keys to position the cursor on each of the following Plot1 settings. Press [ENTER] to select any of the settings you change: Plot1 = On, Type = ⌊⋰, Xlist = L2 (press [2nd] [STAT] and select L2), Ylist = L1 (press [2nd] [STAT] and select L1), and Mark = ■.

d. To scale the axes and set increments, press [WINDOW]. Scale the temperature from 0°C to 100°C with increments of 10°C. Scale the solubility from 0 to 200 g with increments of 10 g.

e. Press [GRAPH] to view the graph of solubility versus temperature.

f. Print a copy of the graph of solubility versus temperature.

TI-86 Calculators

c. To plot a graph with solubility on the vertical axis and temperature on the horizontal axis, press [2nd] [STAT] and select PLOT. Select PLOT1. Press [▼] to move to a new setting, and press [ENTER] or the menu keys to change a setting. Use the following settings: Plot1 = On, Type = ⌊⋰ (select SCAT), Xlist Name = L2, Ylist Name = L1, and Mark = ■.

d. To rescale the *x*- and *y*-axes, press [GRAPH] and then select WIND. Rescale the temperature by entering a value of 0 for xMin, 100 for xMax, and 10 for xScl. Rescale the solubility by entering a value of 0 for yMin, 200 for yMax, and 10 for yScl.

e. Select GRAPH to view the graph of solubility versus temperature.

f. Print a copy of the graph of solubility versus temperature.

TI-89, TI-92, and TI-92 Plus Calculators

c. To view the data matrix, press [APPS], select Data/Matrix Editor, and then select Current. Press [F2] to select the Plot Setup menu. Highlight Plot 1, and press [F1] to select it. Choose Scatter for the Plot Type and then Box for the Mark. Press [C] [2] to enter the x-axis and [C] [1] to enter the y-axis. Press [ENTER] twice. **Note:** Use [ALPHA] [L] instead of [L] on a TI-89 calculator.

d. Press [♦] [WINDOW]. Scale the temperature from 0°C to 100°C with increments of 10°C. Scale the solubility from 0 to 200 g with increments of 10 g.

e. Press [♦] [GRAPH] to view the graph of solubility versus temperature.

f. Print a copy of the graph of solubility versus temperature.

DATA TABLE

Trial	Solubility (g/100 g H_2O)	Temp (°C)
1	4.0×10^2	
2	8.0×10^2	
3	1.2×10^3	
4	1.6×10^3	

ANALYSIS

1. **Analyzing Data** Using your calculator, apply a best-fit curve to the solubility graph created in Step 14. Print your graph with the best-fit curve. Label both axes, and show correct units. Label tick marks with the numerical values they represent.

2. **Analyzing Data** During fertilizer production, the concentration of potassium nitrate in the vats has been raised to 135 g per 100 g of H_2O. Based on your results, at what minimum temperature would you recommend the vats be kept to avoid crystal formation? _____

3. **Analyzing Data** According to your data, how is the solubility of KNO_3 affected when the temperature of the solvent is increased? _____

4. **Analyzing Results** Using your printed graph, tell if each of these solutions would be safe to run through the factory pipes:

   a. 55 g of KNO_3 in 100 g of water at 40°C _____

   b. 100 g of KNO_3 in 100 g of water at 50°C _____

   c. 150 g of KNO_3 in 100 g of water at 80°C _____

   d. 80 g of KNO_3 in 200 g of water at 90°C _____

5. **Analyzing Information** According to your graph, at what temperature would 45 g of KNO_3 completely dissolve in 100 g of water? _____

Conclusions

1. **Evaluating Results** Research the solubility of potassium nitrate using the Internet. Compare your solubility table data to established solubility values.

   How does your data compare? Explain if it is different. _____