PHYSICAL SCIENCE

ACTIVITIES MANUAL

Robert L. Hartshorn
Linda Barrett Phelps
William R. Cranford

The Center of Excellence for Science and Mathematics Education
The University of Tennessee at Martin
145 Gooch Hall
Martin, Tennessee 38238-5029

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INTRODUCTION

The primary reason for developing this *Physical Science Activities Manual* originated about three years ago. At that time the impending change in courses that would no longer meet science graduation needs, specifically, the high school general science course, concerned us here at the Center of Excellence for Science and Mathematics Education (CESME). The heir apparent to the general science course seemed to be the physical science course. On the surface it may seem that they are basically the same course, but on closer examination there is a considerable difference in content. An exclusive emphasis is placed on chemistry and physics in the physical science course at the expense of the earth science and life science topics that were contained in the old general science course. Considerably different backgrounds are also required for teachers of the physical science course. Therefore, the main purpose of this *Physical Science Activities Manual* is to provide background along with a variety of activities to enable new and veteran teachers to teach a genuine physical science course instead of a "warmed-over" general science course. A more recent stipulation from the State Board of Education stating that three years of science will be required for graduation by all students further increases the urgency for providing this type of material for teachers who will be instructing an anticipated influx of new physical science students.

Lets determine what this manual **is not**. First, it **is not** a lab manual. The pages in it are not designed to be copied and given to students. Although many times instructions are given for carrying out an activity, they are given for the teacher's information. Almost always they will have to be adapted to the local equipment and facilities. This manual is a teacher resource and should only be used that way. Furthermore, it **is not** a series of lesson plans. By all means, there is an order of presentation represented in each lesson, but good teachers always interpret and adapt any set of material to fit their needs. In no way are the suggestions meant to be carried out in a lock-step fashion as per the manual. To encourage your changes this manual has been provided on computer diskette so that you can go in and add, delete, or rearrange the activities to fit your own purposes. And finally, it **is not** all inclusive. There are many topics that belong in a physical science course that are not addressed in the pages that follow. In developing this manual many new activities (really, many of them were old activities but new to us) were unearthed for which there was not sufficient room for inclusion in this version of the manual. It is extremely possible that many of the activities that you use in your course are better or at least different from the ones we have included. By all means, continue to use them. We would appreciate receiving copies of your favorite activities appropriate to this type of physical science course. We will pass them on to other teachers participating in current and future projects of the CESME.

The philosophy embraced in this manual is student-centered rather than teacher-centered. Although there are directions for teacher-led demonstrations, the vast majority of the activities are to be carried out by students. This philosophy encourages student observation and collection of data so that students (along with teacher direction) invent answers to questions prompted by the opening activities of a lesson. In essence, students will learn to "do" science because they are trying to answer a question or find a solution to a disturbing disequilbrating phenomenon that you provide for them. Every teacher has asked the question, "How do I get them interested in doing what I want them to do?" The heart of this manual's philosophy is to get them to "do" science because **they** want to do it. That is why we have steered away from a host of verification experiments. Once they know what the law says, why should they actively engage in following a bunch of cookbook directions to "prove" what they already know? To this end, all lessons are written in the format of the Learning Cycle. Its basic premise is that a lesson should begin with some type of challenge or discrepant event. In this way, even before the student knows what you want them to find out, he/she will have an immediate purpose for becoming a part of the instruction that you have planned. The second phase involves "inventing" the concept that accounts for the outcomes of the exploration activities. Students, along with teacher encouragement and channeling, attempt to empirically explain previous observations. Finally, these concepts are extended to similar situations in an attempt to let students try out their newly invented concepts and thereby experience a more thorough understanding than would have come by accepting somebody else's version of how a phenomenon works.

The majority of science educators today have agreed on one over-riding principle that should guide us in what we choose to teach in our science course. (By the way it is not what is contained on the TCAP or other standardize tests.) **They have concluded that teaching less is better.** One of the factors that has contributed to declining interest in science among our students has been our encyclopedic coverage of topics in a course such as physical science. Because we feel that we have to "cover" the book or a syllabus addressing every know question that has ever been asked on the TCAP, we lightly address a host of ideas and do not provide the opportunity for our students to internalize more than a handful. Then we wonder why they are confused and don't seem to like science. What is even worse is that in doing this we have turned science into a glorified exercise in "vocabulary." Our students might be able to recognize Archimedes' principle on a multiple choice or matching test, but probably four out of five of them do not understand this principle at anything but knowledge level. They don't comprehend it and definitely can not apply it to situations other than the one presented in class. For this and other reasons the lessons in this manual go into much more detail, providing multiple situations concerning the same main idea, than your text book or lab manual traditionally addresses. Some of you may look at the *Physical Science Activities Manual* and conclude that it is too complex or detailed for your class. This may be true in some instances. But, it may simply be that you have not been accustomed to letting the students be participants in rather than recipients of science in your class. For many students spending time in a participatory way allows them to understand science for the first time. After learn to take the responsibility for doing science instead of just passively enduring another science class, the full range of these lessons will be more truly achievable by your students.

For those of you who agree to accept the challenge of participatory, activity-taught science this manual will be a valuable resource. For those students lucky enough to have been in your classes there will be an appreciation and understanding of physical phenomena to an extent that you have never before seen. Possibly the most important outcome will be for some students, who formerly hated science because they could never understand it, a realization that they actually can learn science. Some might even decide to sign up for more advanced science courses in the future. Now wouldn't that be something!!!

Untold numbers of people deserve thanks for their contribution to this manual. First and foremost are all those teachers around the state who have showed an interest in improving the level of science instruction in their schools and have asked that resources such as this *Physical Science Activities Manual* be created. Without your interest in the product of this project it would never have been completed. Second, we would like to thank all our own former teachers as well as present colleagues from who we have stolen many ideas. Some of the experiences from which we have drawn our ideas happened so long ago that we sometimes actually thought that our ideas were original. The chances of this are extremely remote. Suffice it to say that good science teachers routinely share with and steal ideas from anyone and everyone else who is concerned about providing quality science instruction. Our apologies to each of you for not giving you credit for stealing it before we did. We do want to thank Mary Thorpe for her help in designing the cover for this manual. And finally, we want to thank a variety of science educators from across the country who have stimulated us with activities, presentations, and "better" ways to teach something at the various professional meetings we have attended during the past ten or fifteen years. It is our hope that we may in some small way stimulate you to provide a richer and more exciting version of physical science instruction by utilizing the activities in this manual.

Robert L. Hartshorn
Linda Barrett Phelps
William R. Cranford

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THE LEARNING CYCLE MODEL

"Class, you'll notice that I've given each lab group a D-cell battery and battery holder, a flashlight bulb, and a piece of insulated wire," Mrs. Smith began. "Using these materials, I'd like you to light the bulb." As the students succeeded in lighting their bulbs, she asked them to explain how they had done it.

After students had shared ideas about their bulb systems, Mrs. Smith introduced the terms in their science textbook *current* and *open* and *closed circuit*. She had students read about these terms and then discussed the reading with them.

Finally the students applied their knowledge of electric circuits to a new situation. Each group connected a switch and two new pieces of wire to their bulb system and created a closed circuit. Mrs. Smith asked them to describe how the switch worked, and to try to explain how the light switches in the classroom turn the overhead light on and off.

The steps in Mrs. Smith's method may seem to be in reverse, but she was practicing a teaching strategy called the Learning Cycle to develop students' understanding of open and closed circuits. In the Learning Cycle, students first engage in hands-on activities to familiarize them with the concepts and relationships <u>before</u> being introduced to new terms, reading text material, graphing or otherwise analyzing their observational data. Next, concepts are developed based on experiences acquired from exploratory activities. It appears that students are more receptive to understanding a concept if they have first engaged directly in a concrete experience which has raised a question in their minds. It is this need for further understanding that urges them to enter in to the reevaluating old or building new concepts. The third part of the Learning Cycle features an application activity where the concept is used in a slightly different setting than was originally developed, thus giving them a chance to more fully understand the concept in terms of a wider frame of reference.

The Learning Cycle is anchored in a thorough understanding of learning theory. Although Robert Karplus is generally viewed as the "father" of this model of instruction, its roots go back to the developmental learning theories of Piaget. A slightly more theoretical discussion of the model is provided below in more psychological terms.

Piaget (1964) identified four major factors which he believes relevant to the development of cognitive reasoning abilities. These factors are

1 <u>Maturation</u> - students must be biologically mature and physically developed and therefore capable of operating physically in their environment.
2. <u>Experience</u> - students past concrete experience and the ability to recall these experiences are critical for further development. Piaget outlines two types of experience: <u>Physical Experience</u> (drawn directly from objects) and <u>Logical-Mathematical Experience</u> (drawn by actions which affect objects).
3. <u>Social Communication</u> - students must be capable of communicating information via written and oral language.
4. <u>Equilibration</u> - for cognitive growth, students must be supplied a situation of cognitive challenge where their existing mental operations are not adequate. The accommodative process (called equilibration) by which the student deals with this new information will result in cognitive growth.

A translation of this Piagetian theory into a workable model for designing learning experience should incorporate each of these factors (Campbell, 1977). When applied to adolescent students, factors one and three are probably not as important as factors two and four. Piaget himself stresses the interdependence of all four factors but suggests factor two and its proper relation to factor four are fundamental to learning and development.

The Learning Cycle Model, as originally conceived by Robert Karplus in the 1960s, can be divided into three major segments: **Exploration**, **Concept Invention**, and **Concept**

Extension. The following is an overview illustrating the important general characteristics of each phase.

<u>Exploration</u> - Following a brief statement of topic and direction, students are encouraged to learn through their own experience. Activities may be supplied by the instructor which will help the students recall (and share) past concrete experiences or assimilate new concrete experiences helpful for later invention and/or extension activities. During this activity the students receive only minimal guidance from their instruction and explore new ideas spontaneously.

1. This phase of the Learning Cycle provides students with reinforcement of previous concrete experience and/or introduces them to new concrete experience related to the intended outcome objectives.
2. The activity allows for "open-ended" considerations, encouraging students to allow concrete experiences to evoke non-concrete ideas as possible relevant factors.
3. During the exploration activity the instructor supplies encouragement and hits and/or suggestions to maintain an appropriate level of disequilibrium.
4. This activity provides the instructor information concerning the students ability to deal with the concepts and/or skills being introduced. In addition, the students will deal the reasoning skills which they may evoke in search for the solution to a problem.

<u>Concept Invention</u> - In this phase, the concrete experience provided in the exploration is used as the basis for generalizing a concept, for introducing a principle, or for providing an extension of students' skill or reasoning. Student and instructor roles in this activity may vary depending upon the nature of the content. Generally, students should be asked to "invent" part or all of the relationship for themselves with the instructor supplying encouragement and guidance when needed. this procedure allows for students to "self-regulate" and therefore move toward equilibrium with the concepts introduced.

1. During the invention activity students are encouraged to formulate relationships which generalize their ideas and concrete experiences.
2. The instructor acts as a mediator in assisting students to formulate these relationships so as to be consistent with the outcome objectives.

<u>Concept Extension</u> - the extension or application phase of the Learning Cycle allows each student an opportunity to directly apply the concept or skill learned during the invention activity. This activity allows additional time for accommodation required by students needing more time for equilibration. It also provides additional equilibrating experiences for students who have already accommodated the concepts introduced.

1. To begin the extension activity, students and instructors interact in planning an activity for apply the "invented" concept and/or skill in a situation relevant to the instructional objectives.
2. Finally, students are asked to complete the designed activity to the satisfaction of the instructor. While this extending activity allows students to directly apply the invented concept to a new situation, the broadening nature of the activity provides for further equilibration of new cognitive abilities.

Although the Learning Cycle allows each student the opportunity to think for himself, the instructor must be an ever present "overseer" of the activity, and by providing probing questions, hints, and encouragement keep the activity going. Yet the instructor must guard against over playing his role as director and planner. It is here that many of you who implement the Learning Cycle for the first time may have trouble. Traditionally, the teacher has been the "fount of knowledge" in both the classroom and laboratory settings. We have been the ones with all the answers and with the "best way" to get the results that we want our students to use. Our role changes when using the Learning Cycle. We are now facilitators. Yes, we can still be a source of knowledge, but it is not volunteered. Rather, we consultants and cheerleaders instead of authority figures that students follow in lockstep. It is oh so hard to stand by and watch the students figure out solutions when we could with a few well placed instructions save them time and allow them to get better results. But what we deprive them of is the pleasure of building their own knowledge. When they invent it, they have ownership. When they invent it, they remember it. And after they get over the shock of having this type of freedom (and responsibility) and experience the thrill of succeeding, some will even like science.

DEFINITION OF MATTER

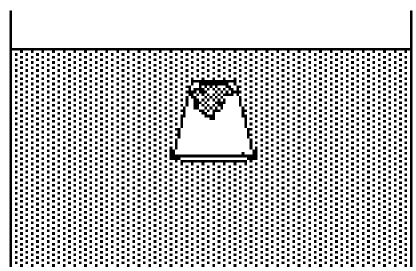
PROBLEM PRESENTATION / EXPLORATION

A. Station A Setup

1. Student stations will be identically equipped with the following materials: a meter stick, 3 pieces of string, 2 balloons, Scotch® tape, and a straight pin.
2. Inflate both balloons equally. Take a number of strips of the tape and affix them to one of the balloons so that a large portion of the external surface is covered. Using two pieces of string, tie one balloon to each end of the meter stick. Tie the third piece of string to the middle of the meter and hang it from some type of overhead support so that the meter stick is balanced and the balloons hang equally. Then burst the balloon with the tape by using the pin. Record all observations. [The balloon being burst loses air and that side goes up showing that the air really does have mass. The purpose of the tape is to keep the pieces of the balloon from flying all over the place when the balloon is burst. Although this demonstration does not take into consideration the buoyant effect of the balloon before it was burst, the demonstration should dramatically demonstrate the fact that air has mass.]

B. Station B Setup

1. Student stations will be identically equipped with the following materials: a piece of tissue, a paper or Styrofoam cup, water, and a beaker or similar container.
2. Fill the beaker or similar container half full of water. Crumple the tissue and place in the bottom of the cup so that it fits tightly. Next, turn the cup upside down and slowly lower in a line perpendicular to the table into the container of water until the whole cup is under water. Finally, remove the cup by lifting it straight up out of the water. Record all observations.



3. After punching a small hole in the bottom of the cup with a pen or pencil, repeat the procedure and explain the results. [Because the air can leave the cup through the hole as the cup is lowered into the water, the water can enter and wet the tissue. In the first instance the water could not enter because the air took up the space. As we have seen in other places, two types of matter can not be in the same place at the same time.]

CLASS RESPONSE / CONCEPT INVENTION

A. Matter Has Mass

1. Reconstruct the balancing balloons. Ask whether it would be possible to put air into one of the balloons thus making that side heavier which would really show that, indeed, air does have mass.
2. To help students figure out how to do this take another balloon, blow it up, tie it off, and put a piece of scotch tape on the outside surface of the balloon. Arrange another piece of tape so that it will make an X. Peel back the second piece of tape so that it is still affixed to the balloon but not crossing the first piece and making the X. (We will reform the X shortly.)
3. Have one student carefully insert a needle through the first piece of tape attached to the balloon. The tape will contract around the needle and seal it

off so that the balloon will not burst or leak (at least not for a while). Upon removal of the needle the second piece of tape can then be quickly pushed down over the hole left by the needle. If all goes as planned, the needle won't burst the balloon, and when the needle is removed and the second piece of tape pressed to the balloon no air will escape. [Do you really think this will work??? Try it, you'll be surprised.]

4. Taking it one step further, a syringe instead of the needle can be used to puncture one of the balloons balanced on the meter stick. Once the entry has been made the plunger of the syringe can be pushed in and introduce air into the balloon. As in #3 above, when the syringe is removed and the second piece of tape pressed down onto the balloon it should result in this balloon having more air that it started with and it should hang down indicating its greater mass.

B. Matter Occupies Space

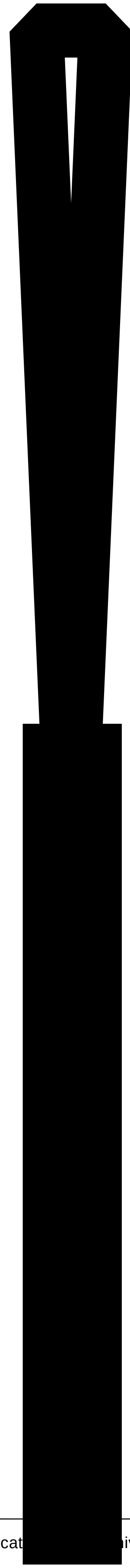
1. Have each group report its observations. Ask them, "Why didn't the tissue get wet in the first case?" Make sure that they understand that the water couldn't occupy the same space as the air. Even though they can't see the air, it is still made up of matter and takes up space.
2. What would happen if the cup with the tissue paper wasn't lowered straight down but tilted at angle? [Someone probably did this in the exploration phase and got their paper wet.] Here the air had a way to get out from under the edge of the cup when it was tilted thus allowing the water to get in.
3. To illustrate this repeat lowering the cup with tissue paper straight down under the water. At this point no water has entered and wetted the tissue. Now, submerge a squeeze bottle filled with colored water. At an angle aim the stream of water under the lip of the cup. In doing so the stream of water will force out some air and allow the water to enter.

C. After all observations have been recorded, try to get the class to come to a consensus on what two properties of air were exhibited in this experiment. [Air has mass and occupies volume.]

CONCEPT EXTENSION

A. I Bet You Can't

1. Insert a long stem funnel into a one-hole rubber stopper and insert it into an Erlenmeyer flask, a Florence flask, or into any other bottle for which the stopper fits.
2. Make sure the stopper has been tightly pushed in.
3. Ask students to predict what will happen upon pouring water into the funnel. [Depending on how fast you pour the water into the funnel you may see slightly different things. If it is trickled in, some air will be able to escape up and out of the funnel allowing water to trickle in. If you pour it in quickly, air will not be able to leave. Some may drop in resulting in a slight burping sound. Only a small amount of water will enter the bottle.]



B. Describe what would happen when you blow air into the balloon above. Explain what you see happen. [They will now be able to inflate the balloon to any great degree since the space around the balloon is filled with matter that pushes pack. The air surrounding the balloon can be compressed a little but not much.]

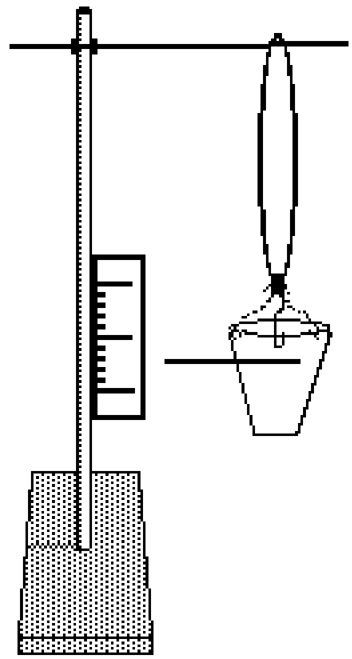
MEASUREMENT OF MASS

PROBLEM PRESENTATION:

A. The CHALLENGE in this activity is for students to build a spring balance to find the unknown mass of an object. A commercial spring balance should be available for them to examine. Also, a previously constructed spring balance like they will be building should be on display.

B. Station Setup

1. Five stations will be identically equipped with a 3 ounce paper cup, four paper clips, a large elastic rubber band, a metric ruler, a couple of metal washers, and a toothpick (Bag #1). These materials will be used to construct and calibrate a spring balance (see diagram).



2. Our unit of mass will be nontraditional; we will measure mass in "penny units." (Use pennies minted after 1982 because the composition of pennies, and therefore their weight, changed in 1982.)
3. The students should be instructed to build a spring balance from the materials found in bag #1 so that they can determine the unknown mass of the object provided, in "penny units." This can be done by determining the stretch for zero pennies, 5 pennies, 10 pennies, etc. By plotting # pennies on the x axis and the "stretch", on the y axis a simple calibration curve can be made. The stretch can be indicated by the graduations on the ruler for zero pennies, 5 pennies, etc.
4. Each of the groups should attempt to find the mass of the same object. Because all rubber bands will not stretch the same, the calibration curves may look different for different groups. But the value determined from each calibration curve should result in the same mass for the common object being considered.

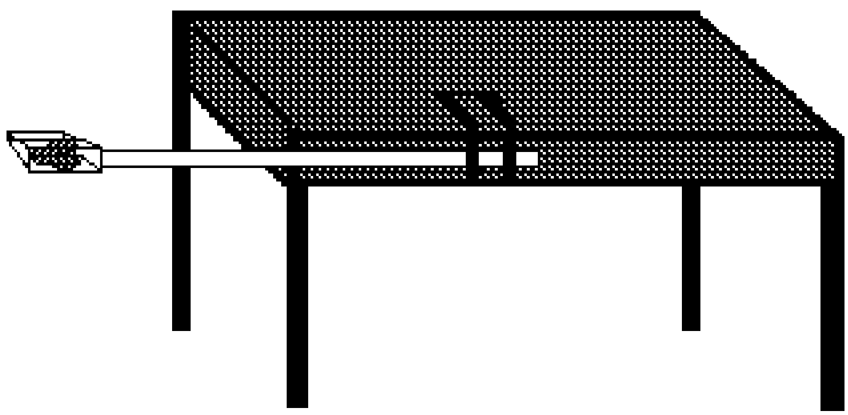
Mass (pennies)	0	5	10	15	20	25
Stretch (cm)	43	53	65	75	88	9

5. Instruct the students that once they know the stretch of the unknown object they should locate this position on the Y axis (for example, 85 cm). Then, starting at this position and moving right in a line parallel to the X axis they will reach the calibration line. Now, if they go down from here parallel to the Y axis until the line crosses the X axis, they will instantly have determined the mass of the unknown object (19 pennies).

CLASS RESPONSE / CONCEPT INVENTION

A. After a reasonable mass of the unknown object has been determined, ask whether this process would work to find out the mass inside the NASA's shuttle while in space. Point out that since there is no gravity in the shuttle, the spring balance would register **0 penny units** when the unknown mass was attached to the spring balance. To solve this problem we need to construct an inertia balance.

1. How could they determine the mass of the object in space by using the materials in bag #2? Indicate that as in the previous determination, a calibration curve will have to be constructed.
2. Bag #2 should contain a hacksaw blade, a clamp, an empty paper clip box. The box should be secured to the hacksaw blade with tape. By then clamping the blade to the table it should be free to swing back and forth. (As in the case of the spring balance, an inertia balance should be constructed ahead of time and put on display to help guide the students in their construction of their inertia balance. See diagram below.)



3. The inertial mass can be determine by the effect of the object on the oscillation of the blade. Perhaps the easiest way to do this is to determine the period of oscillation (the time that it takes for the blade to oscillate back and forth once.) To get a good period of oscillation, count the number of oscillations in a given number of seconds (say, 10 seconds), and then divide the number of seconds by the number of oscillations. Remember one oscillation is one swing left to right and back to left, and the period is the time per oscillation.

Pennies Added	Number of Oscillations	Time for 10 Oscillations (seconds)	Period (sec/oscillation)
0	10		
10	10		
20	10		
30	10		
40	10		
50	10		
Unknown Mass 1st Trial	10		

Unknown Mass 2nd Trial	10		

Now plot on the y axis your experimentally determined period and on the x axis the mass in "penny units." This is now a calibration curve for determining the inertial mass of an object. It should be a straight line. It can be used to find the mass of an unknown by putting the unknown mass in the box, finding its period, and reading its mass off the calibration curve.

B. Would you expect the inertial mass and gravitational mass to be the same for a given object? Are they? What is the ratio of the inertial mass to the gravitational mass? How do we explain this? What would the gravitational mass be on the moon? (The gravity on the moon is 1/6 that of gravity on the earth.) What would be the gravitational mass on Jupiter? (The gravity on Jupiter is 2.37 times that of gravity on the earth.) What would be the ratio of inertial mass to gravitational mass on the moon? on Jupiter?

CONCEPT EXTENSION

A. In answering the questions in part B. under CLASS RESPONSE / CONCEPT INVENTION we assumed that inertial mass stayed constant while gravitational mass changed depending on location.

1. Are these assumptions true?
2. We know that Astronauts train in airplanes where there is zero gravity before they go into space. Without going into space, can we simulate a change in our gravitational mass? For example, what happens to apparent gravitational mass when we descend in an elevator? What happens to our inertial mass when descending in the same elevator?
3. Ask students to reason out how common bathroom scales work. If someone has an old set of scales, take it apart so that they students can see that there is a spring inside that responds to different amounts of mass placed on it. In other words, it can be thought of as acting somewhat like the spring balance that they build in class. What effect would the downward movement of the elevator have on the apparent mass registered on the scales? [It should simulate less gravity such as would be found on the moon, however, not to the same extent.]
4. Have students go to a building that has an elevator (the speedier the elevator, the better.) Have them place a working set of bathroom scales (one with digital readout would be best) on the floor of the elevator and have one student stand on it while the elevator is motionless. Have another student record the gravitational mass. As the elevator starts to move have the student recorder call out the gravitational mass until the elevator comes to rest. Did the gravitational mass change? [Yes]
5. Transport the spring balance and the inertial balance to the elevator and determine whether the gravitational mass and the inertial mass can be detected to change as the elevator descends. These determinations should only be attempted after the students are relatively accomplished in using their spring and inertial balances. [The gravitational mass will change but not the inertial mass.]
6. Because everyone may not have access to an elevator, see if you can get a student to ride along with the experimenters and videotape the events so that the rest of the class can experience the extension of the relationship of gravitational mass and inertial mass.

POP GOES THE POPCORN

PROBLEM PRESENTATION / EXPLORATION

A. How many of you have plans to take chemistry? How many of you have ever "used" chemistry? Does anyone "use" chemistry every day? Well, guess what? You each use chemistry every single day of your lives! If you have ever used a household cleaner, or cooked your favorite food, or **eaten your favorite food**, then you have used chemistry. Food is made of carbohydrates, fats, proteins, and other organic material, which are all studied in a branch of chemistry that we call organic chemistry.

B. Popcorn, for example, is made up of protein and fat, which you need in your diet. Have you ever thought about what happens when you pop popcorn? How do those small kernels become fluffy and soft? Have you ever noticed that almost always all of the kernels do not pop? Have you ever wondered why?

C. The CHALLENGE in this experiment will be to determine if all popcorn pops the same way.

D. The materials needed for this experiment are 125 mL of popcorn, a cookie sheet, an oven, and a popcorn popper, or large pot. (If a microwave oven is more accessible, this might serve as a good alternative -- Use the loose microwave popcorn that comes in a bottle if you will be using a microwave oven.)

E. This activity can be completed as a homework assignment or students may be divided into five equal groups for work in the lab.

F. "Measure out 50 mL of popcorn kernels and count them. Count a second group of kernels equal in number to the first. Preheat the oven to 200°F (93°C). Spread group #2 of the kernels onto the cookie sheet and place them in the oven for 90 minutes. Next, pop the group #1 kernels. Do not use any oil. After popping, count the number of unpopped kernels and record. Then choose ten of the popped kernels and measure the length of each in mm, recording all measurements. Add the 10 measurements and divide by 10 in order to obtain an average. Record the average. After 90 minutes, remove group #2 from the oven and allow to cool. Then pop in exactly the same way as group #1. Again, count the number of unpopped kernels and record. Measure ten of the popped kernels in mm and record each measurement. Again, add the 10 measurements and divide by 10 in order to obtain an average. Record the results. Eat one kernel from each group and compare. Is there any difference in taste?"

# of Unpopped Kernels	
Group #1	Group #2

Kernel #	Group #1 Length (mm)	Group #2 Length (mm)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

CLASS RESPONSE / CONCEPT INVENTION

A. Have each group report their results to the class. Record on the chalkboard or on an overhead transparency. If students worked individually at home, allow each student to report his or her results. What happened? Why was there a difference between the two batches of popcorn? HINT: What was the only variable that you altered in your experiment? (Students should realize at this point that the kernel contains moisture, and that the moisture is what makes the corn pop. If the moisture is heated very quickly, it vaporizes into steam and expands rapidly, causing the kernel to explode.) If the kernels are heated slowly, some of the moisture escapes and then when heated rapidly not enough water will be left to explode and make all of the kernels pop.

B. Determine the % of water in popcorn.
   1. Do all kernels of popcorn have the same amount of water in them? The easiest way is to pop them one at a time and find out.
   2. Have each group in the class pop two individual kernels in the following manner.
   3. Weigh each kernel before it has popped and record its mass.
   4. Place a single kernel in a 500 mL Erlenmeyer flask with a cork loosely in the mouth. Attach a clamp to the flask and to a ring stand.
   5. In your hand hold a Bunsen burner and aim it at the flask. Move the flame over the bottom of the flask evenly. Soon the kernel will pop into a flower of popcorn.
   6. Immediately upon popping remove the clamp from the ring stand and agitate the flask so that the flower of popcorn will not stick to the bottom of the flask.
   7. Remove the flower of popcorn and weigh it. Make sure that it has cooled to room temperature before weighing.
   8. Note what is deposited on the inside of the flask [Water]

C. Fill in the information in the following table

Kernel #	1	2	3	4	5	6	7	8	9	10
Mass Before										
Mass After										
Diff in Mass										
% Mass Lost										

What is the average % mass lost (H_2O lost) of these ten kernels?

CONCEPT EXTENSION

A. What would happen if stale popcorn were allowed to soak in water overnight? Design your own experiment to see what might happen.

B. What do you think is the difference between microwave popcorn and regular popcorn? Can you use regular popcorn in a microwave oven? Can you use microwave popcorn in oil and a regular corn popper? What do you think the percentage of water in popcorn has to do with these questions. [Microwave popcorn has a larger % of water than regular popcorn.]

CONSERVATION OF MASS

PROBLEM PRESENTATION / EXPLORATION:

A. Each group will be given 4-5 minutes per station to observe the outcome of the specified activity and make as many measurements as they can think of. Tell the students that after they have been to all of the lab stations that they will be asked to figure out what each activity had in common, or what happened in each case that was the same.

B. Station Setup

1. Station #1
   a) Materials: balance, a metric rule, a magnifying glass, a thermometer, a beaker of warm water, an English walnut, a hammer
   b) Directions: *"Without opening the Ziploc® bag, crack open the walnut by hitting with the hammer."*
2. Station #2
   a) Materials: balance, a metric rule, a magnifying glass, a thermometer, a beaker of warm water, paper towels, a sealed Ziploc® bag containing an ice cube
   b) Directions: *"Melt the ice cube by putting the Ziploc® bag containing the ice cube into the beaker of warm water."*
3. Station #3
   a) Materials: balance, a metric rule, a magnifying glass, a thermometer, a beaker of warm water, a sealed Ziploc® bag with two sealed test tubes of liquid inside. [In one test tube is lead nitrate solution and in the other test tube is sodium iodide. When mixed together, these two solutions will produce a bright yellow solid.]
   b) Directions: *"Without unzipping the bag, uncork the tops of the two test tubes and allow their contents to pour out into the bag. DO NOT UNZIP THE BAG."*
4. Station #4
   a) Materials: balance, a metric rule, a magnifying glass, a thermometer, a beaker of warm water, a sealed Ziploc® bag containing 25 mL of water and a sealed bottle with 5 grams of NH_4NO_3 in it.
   b) Directions: *"Without unzipping the bag, unstopper the bottle and allow the solid to come in contact with the liquid in the bag. Shake the bag. DO NOT UNZIP THE BAG"*
5. Station #5
   a) Materials: balance, a metric rule, a magnifying glass, a thermometer, a beaker of warm water, a hot plate, a filter flask fitted with a rubber stopper, two kernels of pop corn , a rubber balloon
   b) Directions: *"Place the pop corn in the filter flask. Place the rubber stopper back into the flask. Attach the balloon to the side arm of the filter flask. Place the apparatus on the hot plate and leave it there until the kernels pop."*

CLASS RESPONSE / CONCEPT INVENTION

A. Have each group report its findings on an observation sheet. If possible have one member of the group transfer the group's findings to an appropriate table on the board or a transparency so that the whole class can see the outcomes of the other groups.

B. After all groups have reported their observations, try to get the class to come to consensus about all the things that the five activities had in common. Possibly they will try to draw conclusions on the basis of physical and chemical reactions. This is a good way to reinforce the lesson on properties, but all five stations did not have just chemical, or just physical reactions. If they can't agree on the common event, ask them what one thing remained the same, before and after each transformation, for the materials at each lab station. If no one mentions the use of the balance, see if you can get them to concentrate on the mass of each system.

C. Assuming that there might be some measurement error that might make the conclusion harder to visualize, work with the class to see if they can come up with the idea that the mass remained constant in both the physical changes as well as in the chemical changes. Common errors might be weighing the system when it is either colder or hotter than before the transformation. Some students might not carefully dry the Ziploc® bags after they have been in the water. Reading the balance wrong will probably take care of itself since more than one student in a group will probably be involved in the massing process. Also, all groups will be carrying out the activities and the repetition of data can serve to point out erroneous measurements. The observation that the mass remains constant throughout a chemical or physical reaction is generally known as The Law of Conservation of Mass. Another way of looking at this law is that no matter is destroyed during a chemical or physical reaction.

D Because some of the exploration activities carried out by the groups may not have utilized the balance to its fullest benefit, a few more activities where the Law of Conservation of Mass can be experienced may be needed to reinforce the concept.

1. Examine a new flash bulb and one that has been flashed. Which one looks like it has a greater mass? (Most students would say the used one because it has additional products of oxidation visible.) Put a new bulb on the balance and record its mass. Flash the bulb, let it cool, and put it back on the balance. The mass should remain constant.
2. A similar demonstration would be to put two or three kitchen matches into a 500 mL Erlenmeyer flask and tightly stopper it with a rubber stopper. Put on a balance and determine the mass and record it. Remove the flask from the balance and carefully bring a Bunsen burner close to the flask so that the heat will come in contact with the matches in the flask and ignite.

   CAUTION: Heat only for a short time. Extreme caution should be used when ever a closed container is heated.

   After cooling back to room temperature return the flask to the balance and record its mass. Have students predict what the mass will be. [Once again, the mass should be the same. The flask must cool before determining its mass.]
3. Next demonstrate three situations where by mixing two substances together it may appear that mass is disappearing.
   a.) Place 25 g of rock salt in a 100 mL graduated cylinder. Carefully fill the cylinder to the 100.0 mL mark with water, put a rubber stopper in the mouth of the cylinder, and place it on a balance. Record its mass. Take the cylinder off the balance, shake it vigorously until all the rock salt has dissolved. Observe the level of solution now in the cylinder. Where has the missing liquid gone? What should the students predict will be the mass when it is now put back on the balance? [The mass should remain constant. As the salt dissolved, the ions mixed between the spaces of the water particles and the volume decreased slightly.]
   b.) Into one 100 mL graduate cylinder place 50 mL of water. Into another 100 mL graduate cylinder place 50 mL of alcohol (ethyl alcohol works best). Place both graduated cylinders on a balance and record the mass. Now, slowly pour the contents of cylinder #2 into cylinder #1. Place both graduated cylinders back on the balance. Notice the combined volume and the total mass. Once again the mass is conserved but the volume shrinks.
   c.) You will need three identical balances and three balls of Play-Doh®. Each of the balls of Play-Doh® must have the same mass. While the students are watching flatten one of the balls out into a pan cake.

Roll the other one out lengthwise and join one end to the other end to make a doughnut. Now, have the students predict which one has the greatest mass. Even though Piaget says that students in your class should have developed to the point that they can conserve mass, it might be interesting to see if some still think that the altering of the shape has altered the mass.

4. Finally, demonstrate an example of where mixing two substances together appears to create mass.
   a.) Into one 100 mL graduate cylinder place 50 mL of carbon disulfide. [A word or caution: carbon disulfide smells terrible. If you have a fume hood, use it. If you don't, do it outside or next to an open window.] Into another 100 mL graduate cylinder place 50 mL of ethyl acetate (fingernail polish remover). Place both graduated cylinders on a balance and record the mass. Now, slowly pour the contents of cylinder #2 into cylinder #1. Place both graduated cylinders back on the balance. Notice the combined volume and the total mass. Once again the mass is conserved but the volume increases.

CONCEPT EXTENSION

A. The Law of Conservation of Mass can be used to determine the mass of a reactant or product in a chemical reaction. For example, how could you determine the mass of carbon dioxide that is generated when two Alka-Seltzer tables are dissolved in 100 mL of water at room temperature?
   1. Place on a balance an Erlenmeyer flask containing 100 mL of water.
   2. Break in half two Alka-Seltzer® tables and wrap them in a Kleenex tissue.
   3. Lodge the (Kleenex® + tablets) in the neck of the flask Place the flask + Kleenex® + tablets on a balance and record the total weight
   4. With a pencil gently push the Kleenex®+ Alka-Seltzer® tablets down into the water and watch the mass of the system indicated on the balance.
   5. As the reaction takes place the carbon dioxide should form and leave through the top of the flask.
   6. The difference in the mass is the mass of the carbon dioxide formed.
   7. Repeat the experiment with the following change. Don't put the broken Alka-Seltzer® tablets in a Kleenex®, rather put them into a balloon. Carefully, without allowing the tablets to spill out of the balloon, attach the balloon to the mouth of the flask. With the whole system resting on the balance, adjust the balloon so that the tablets will now fall into the water.
   8. What difference would you expect to see this time. [Depending on how sensitive your balance is, you will probably see no change in mass since the carbon dioxide is being trapped in the balloon. However, if the balance is sensitive, there will be a slight decrease in what registers on the balance. This is due to the buoyant effect of the trapped gas which actually causes the weight to appear lighter.]

B Another important chemical principle is the Law of Definite proportions which says that chemical compounds of the same substance will always have the same proportion by mass without regard to where and how the compound originated. That means that water has the same proportion of oxygen and hydrogen in Russia, in Canada, in Africa, and in Tennessee. Furthermore, different brands of the same chemical substance should have the same proportion no matter where they were produced.
   1. Epson Salts is the common name for magnesium sulfate heptahydrate. If some Epson Salts is heated, it gives off water. Now, if all brands of Epson Salts have the same proportion of water, we should be able to experimentally verify this using the Law of Conservation of Mass.
   2. Purchase three different brands of Epson salts. Most drug store chains have their own generic brand. Measure out different amounts of the three brands and assign them to the different groups.

3. You need some type of heat source to drive off the water. Bunsen burners would work, if you have them. The Epson Salts could be placed into a large test tube and heated slowly but thoroughly for about 10-15 minutes to drive off the water.
4. The Epson Salts could also be put into an oven and heated for a couple of hours at about 350°F (176°C).
5. Regardless of the way you drive off the water you must insure that it all has been driven off. If the Bunsen burner is used, the tube should be weighed after the initial heating and then heated again until two weighings are within 0.2 g. Remember, you must allow the tube to cool down to room temperature before you can weigh it on the balance. If the oven is used, a second heating of about thirty minutes is needed to insure that all the water has been driven off.
6. Individual groups could carry out the determinations on different brands of Epson salts and determine the percentage of water in each. (See the experiment on the Law of Definite Proportions for further information.)

DETERMINATION OF VOLUME

PROBLEM PRESENTATION / EXPLORATION

A. Students are to rank (from smallest to largest) a series of objects (see B below) in terms of the objects' volume. The series will contain both regularly and irregularly shaped objects.

B. Station Setup

1. Five stations will identically be equipped with a metric ruler, a 100 mL graduated cylinder, a large beaker, a small beaker (this should fit inside the large beaker).
   - a.) a paperback book
   - b.) a new piece of chalk
   - c.) a piece of rope
   - d.) 5 marbles
   - e.) a lead sinker
   - f.) a small container of olive or mineral oil
2. Students will then be instructed to predict the volume of each of the objects.
3. Next, the volume of each object should be measured using the materials at their lab stations.
4. The objects should then be ranked, from lowest to largest volume.

CLASS RESPONSE / CONCEPT INVENTION

A. Have each group record its findings on a transparency or on the chalkboard.

B. Also have each group give a brief report on the methods used in calculating the volume for each object. Examine the idea that two objects can't be at the same place at the same time. Therefore, when the lead sinker was put into the graduate cylinder of water, it displaced a volume of water equal to the volume of the sinker. This made the combined volume greater by a volume equal to that of the sinker.

C. Assuming that there will be some error in the measurements, have the class discuss possible sources of error.

CONCEPT EXTENSION

A. A classroom CHALLENGE could be to design a way to measure the volume of a human being, preferably, one of the class members. This design should actually be carried out so that a numerical value for the student's volume will be obtained. A photograph of any equipment or "contraptions" used should be provided.

B. Explain to students that the volume of all objects cannot be measured directly. Sometimes indirect methods must be employed to find the volume of a single object.

1. Set up 5 identical stations, each containing a birthday candle, a ream of paper, 50 pennies, a spoonful of sugar, a graduated cylinder, a metric ruler, a bottle of rubbing alcohol, and water.
2. Ask students to determine the volume of the birthday candle, 1 piece of paper, 1 penny, and the sugar, using the materials at their station. [The birthday candle will float in water, but sink in the alcohol, therefore, its volume can be found by displacement of alcohol instead of displacement of water. The sugar will dissolve in water making it difficult to find its volume by water displacement, but it will not dissolve in alcohol; once again substituting alcohol makes this a logical extension of the volumes that have been found by indirect means. Students will need to measure the volume of all 50 pennies and then divide by 50. Likewise, the volume of a single piece of paper comes from finding the volume of the ream of paper and dividing by 500.]

DENSITY

PROBLEM PRESENTATION / EXPLORATION

A. At each station students will find a number of objects that have been tightly wrapped in aluminum foil. They are told that a number of these objects are made out of the same substance, even though at first glance it might not appear so since the packages have different shapes. The CHALLENGE is to find out which ones are made out of the same substance *"without opening, removing, or tearing off the aluminum foil "* by using the equipment provided at the station.

1. At each station there should be about 8 to 10 aluminum foil wrapped packages of substances, a balance, a large graduated cylinder, and a supply of water. Each package should be labeled as A, B, C, etc.
2. Packages of the same substance should vary in mass. Don't put out more than three different substances at a station. Make sure that every package's volume can be found using the size graduated cylinder that you have provided. (If you have overflow cans, objects can be larger.) To cut down on measurement errors, your smallest samples should displace at least 15 mL of water.
3. Suggested substances:
   - a.) nails of different sizes (make sure that they are made out of the same material)
   - b.) marbles or ball bearings of different sizes
   - c.) rubber stoppers of different sizes
   - d.) pieces of limestone, sandstone, or other rocks broken into pieces of various sizes
   - e) different amounts of clay or Silly Putty®, not Play Doh®
   - f.) different sized lead sinkers
   - g.) different amounts of sand
   - h.) different amounts of popcorn kernels
   - i.) different numbers of pennies (You must use all pennies before 1982, or all pennies after 1982. The composition of a penny changed in 1982. There is about a 20% difference in weight for the same size coin)
4. Since kids will be kids, some will try to solve this problem by feeling the samples instead of finding the density as is intended. Therefore, try to package the samples to discourage this. A little of this doesn't hurt, but still, the objective is for them to identify the substance by focusing on the mass and volume of each object and realizing that there is a constant mass/volume relationship for any substance made out of the same material. Even though they may not discover this fully, it is important that they have this time to explore and gain information.
5. Provide a table in which they can record their masses and volumes or place a master chart on the blackboard.

CLASS RESPONSE / CONCEPT INVENTION

A. Each group should report back to the class on how they decided on which packages contained the same substances. Since the packages in each group are labeled the same (A, B, C, etc.), it makes it easier for the groups to follow along with each other as they report their results. After each of the four or five groups have reported, there should be consensus about which packages belong in which groups.

1. While the groups are carrying out their explorations, visit each group and try to determine which one is getting the best values for the density of their substances. Have this group record their mass, volume, and mass/volume results on a transparency and project it so that the whole class can see that for the packages classified into the same group there is a constant mass/volume relationship.
2. As each group reports, question, with mock disbelief, how they can put two

objects that obviously have different masses in the same category. Use the same questioning tactic about packages having large differences in volume. Try to get them to convince you that it is neither mass nor volume that is important, but it is the mass/volume relationship that is characteristic of a substance's identity.

3. You might finally act as though you understand this relationship but want to be sure by doing one more experiment. Ask the class if what they have been trying to convince you of means that if we would separate a long paper clip chain into a short piece and a long piece that the short piece would have the same mass/volume relationship as the long piece?. (Make a paper clip chain of at least 500 paper clips; to get the short piece disconnect about 100 paper clips from the long chain.) Carefully carry out, in front of the whole class, the mass determination and the volume determination of both the short and long pieces of the chain. Then compute the m/v ratios for both pieces. Emphasize that the m/v relationship is an identifying property of matter.
4. Only after this hands-on opportunity to see this relationship has been provided should you name this relationship as DENSITY.

B. Indicate to the class that the only type of matter for which they have found the density is a solid. Ask them how they would find the density of a liquid?

1. Have each group return to their station and determine the density of 50 mL of water. [Remind them that if they weigh the clean and dry graduated cylinder empty and then pour the liquid in up to the 50 mL mark and place the graduated cylinder plus liquid on the balance, the first mass can be subtracted from the second mass and will result in the most accurate value for the mass of the liquid.]
2. Next, have them determine the density for 50 mL of another liquid that you provide for them. (Suggested liquids: Kayro® syrup, cooking oil, rubbing alcohol, lighter fluid, Coke®, and vinegar.) Make a table showing the mass of 50 mL of the various substances. Take this time to point out that for the same volume different substances will have a different mass, in other words, they have different densities.

C. While it was relatively easy to determine the density of Coke by finding the mass of a measured volume, finding the density of soda in cans presents a slightly different problem.

1. Prepare a container of water, a bucket, a sink, or an aquarium that is at least ten inches deep.
2. Place on the table a variety of cans of soda (one regular Coke®, one Diet Coke®, one Pepsi®, one Diet Pepsi®, one RC Cola®, one Diet Rite Cola®, one 7-UP®, one Diet 7-UP®, one Sprite®, and one Diet Sprite®, or other regular and diet brands)
3. Have students place the cans into the water and make observations about the behavior of the cans.
4. Question the students about what they observed. Probably they will deduce that the regular sodas sink in water and the diet sodas float. Prod them to offer an explanation.
5. Challenge them to devise an experiment to test their explanation. Some that might be offered would be that the diet sodas don't have as much liquid inside, or that diet sodas have more gas (carbonation) than the regular sodas, or that either the regular or diet cans had been shaken before being put into the water, or that the ingredients weighed differently, or that maybe one kind had been frozen while the other kind had not been frozen, or even that the empty diet cans weigh less than the empty regular cans.
6. The beauty of this exercise is that not only do you have an opportunity to teach about density but you have a vehicle to challenge the students to design and carry out an experiment to test a hypothesis.
7. Don't give in and tell them the answer; make them prove their point and convince the rest of the class. This is a great opportunity to practice the

process skills while at the same time providing the type of event to exercise the higher level reasoning skills of analyzing, synthesizing, and evaluating.

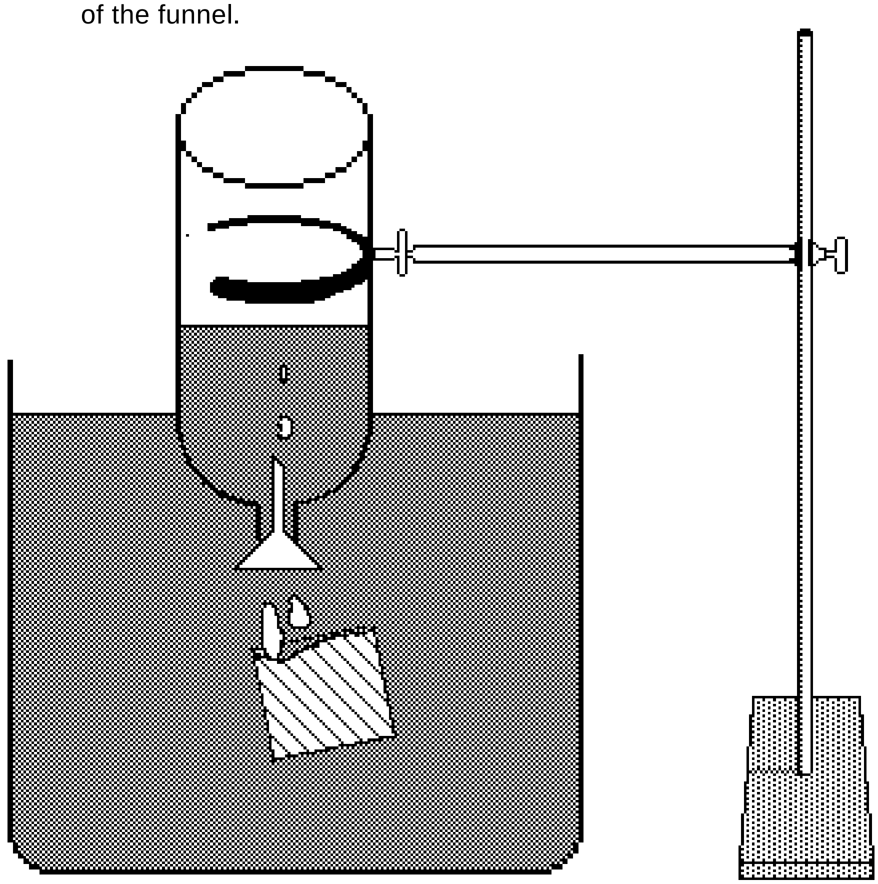
D. After the liquid densities have been determined, bring up the following problem. The density of a solid or liquid is easy to find because measuring both mass and volume can be done easily. However, how can we measure the mass and volume of a gas?

1. Demonstrate the following for the class. Start by taking an empty Ziploc® bag and putting it over the gas jet and filling up the bag with propane. If you don't have gas jets in your lab, you can exhale into the bag. Show the class that zipping the bag shut will allow us to trap a volume of gas. Point out that accurately finding the volume of the bag would be difficult, but that there **is** a neat way of doing this.

a.) In a large sink, bucket, washtub, or aquarium filled with water, submerge and completely fill a 2-Liter Coke® bottle with water. Arrange it so that the bottle is upside down.

b.) Submerge a large funnel in the water and allow it to rest on the bottom of the bucket, etc. Put the water-filled Coke bottle on top of the funnel so that the funnel's stem is protruding into the bottle.

c.) Now, submerge the bag of gas and position it underneath the mouth of the funnel.

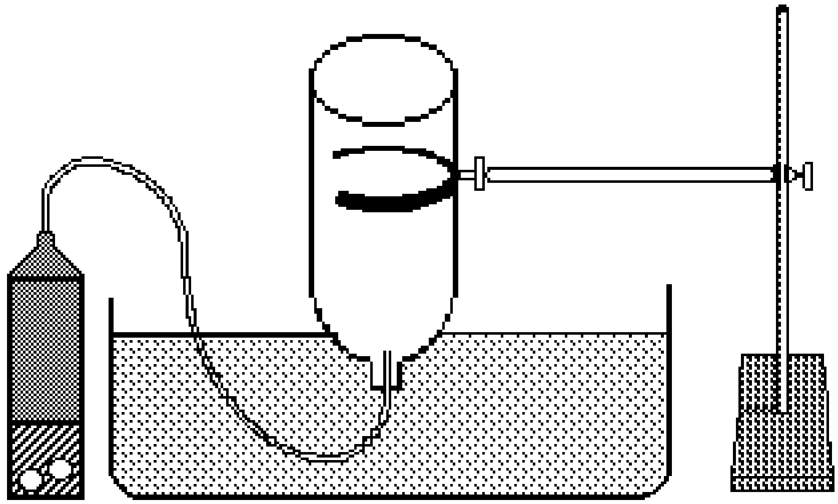


d.) Carefully unzip the bag about one cm allowing the gas to escape. The bubbles of gas will go up the funnel into the bottle and push out water. **REMEMBER TWO KINDS OF MATTER CAN'T BE IN THE SAME PLACE AT THE SAME TIME.** Gently squeeze out all of the gas from the bag.

e.) While the bottle is still underneath the water, screw on the bottle cap and then remove the bottle from the bucket.

f.) Ask the class how the volume of the gas trapped in the bottle can be found. If there are no responses, say that we are interested in knowing what the gas's volume is but the amount of space doesn't have to be filled with gas. Could we find out how much water would fill that same space? Point out again that we want to know the volume and that it will be the same whether it is filled with propane, air, water, or milk. Surely someone will suggest that we simply measure how much water we would need to pour into the bottle to fill it back up and that this would be the volume of the gas. Indicate that we are simply doing the opposite of what we did when we collected the gas. Once again, since **TWO KINDS OF MATTER CAN'T BE IN THE SAME PLACE AT THE SAME TIME,** pouring in the water will force the gas to escape. This is all right, since we are only trying to get the volume that the gas had occupied **before** it escaped.

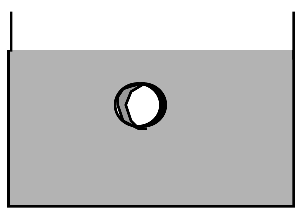
2. The next problem is how to find the mass of a gas. Don't entertain the suggestions from the class that we simply weigh a bag of gas on the balance. The reason that we don't want to do this is that the buoyancy of the air will give a false mass (too light). Instead, tell them that you know of another sneaky way that can be used to measure the mass of a gas.
   a.) Tell them to think about how the Highway Department finds out how much cargo a truck is carrying when it stops at the weighing stations on our state and federal highways. Do they take out all the cargo and put it on the scales? No! Painted on the side of the truck is its EMPTY MASS. Then by driving the truck onto the scales and finding its TOTAL MASS and subtracting its EMPTY MASS they can find the mass of the cargo.
   b.) Tell them that we are going to do the same kind of thing for finding the mass of the gas that comes out of two Alka-Seltzer® tablets when they are put into water. Tell them to attach a rubber hose to the nozzle of a plastic squeezable catsup bottle. After adding 50 mL of water they are to weigh the apparatus (bottle + rubber hose + water). Also they are to separately weigh two Alka-Seltzer® tablets. By adding these two masses together we will get the TOTAL MASS of our system. Next, the rubber hose should be inserted into the submerged 2 L bottle. The Alka-Seltzer® tables should be dropped into the catsup bottle and the lid quickly snapped on. The gas can now can be collected in the 2 L bottle by displacing a volume of water equal to the volume of gas generated. After all the gas has been collected, the mass of catsup bottle + rubber hose + 50 mL of water + what is left over from the Alka-Seltzer® tablets should be determined and will be called the EMPTY MASS.



c.) Now by subtracting the EMPTY MASS from the TOTAL MASS we will obtain the mass of the gas generated. The density of the gas in Alka-Seltzer® can now be determined by dividing mass by volume. [*The density should be greater than 1.5 g/L using this technique*.]

CONCEPT EXTENSION

A. We have seen that equal volumes of different liquids have different masses. We have learned to say that this means that different substances have different densities. Have the students imagine a bucket of water where a 50 mL hole has been carved out of the middle of the water.



What would happen if we put the 50 mL of the various substances that we have been working with into this hole? Would this 50 mL sink or rise? Predict what would happen in the table below.

Substance (50 mL)	Sink	Rise
Kayro Syrup	√	
Cooking Oil		√
Sand	√	
Alcohol		√
Lighter Fluid		√
Pennies	√	

Notice the densities of the substances that sank. Notice the densities of the substances that rose. (Refer back to Concept Invention, section B2.) What relationship is there between the density of an object placed in a fluid and the density of that fluid and whether the object will sink or float? [*Substances that have densities greater than the density of the liquid in which they are placed sink. Substances that have densities less than the density of the liquid in which they are placed rise upward to the top of the liquid. If an object had the same density as the liquid that made up* *the hole it would remain suspended between the top and bottom of the liquid in which it was placed.*]

B. Imagine a bucket of air instead of water. Once again imagine carving out a 50 mL hole. What would you suspect would happened if we filled the hole with other gases? [Reemphasize: *Substances that have densities greater than the density of the liquid in which they are placed sink. Substances that have densities less than the density of the liquid in which they are placed float.*] What would have to be true if the gas would float upward? What would have to be true if the gas sank downward? Instead of carving out a hole, what if we had a weightless balloon full of different gases and we suspended them in a room full of air? Which would rise? Which would fall? The density of air is about 1.29 g/L, therefore, if the mass of 1.0 L of our experimental gas is heavier than 1.29 g, it will fall. If it is less than 1.29 g it will float upward. Have students predict the outcomes in the following chart based upon the gas's density. The densities of many of these gases can be looked up in various references. The best one is the *Chemical Rubber Corporation Handbook of Chemistry and Physics*. There is one at the public library in case you don't have one in your school library.

Substance (1.0 L)	Mass (g)		Rise	Fall	Density (g/L)
	> 1.29 g	< 1.29 g			
Air					1.29
Butane**	√			√	2.59
Carbon Dioxide	√			√	1.97
Exhaled Air	√			√	
Helium		√	√		0.179
Hydrogen		√	√		0.089
Methane***		√	√		0.714
Oxygen	√			√	1.43
Propane****	√			√	1.97

C. Even though there is no such thing as a weightless balloon, we can approximate this by filling soap bubbles with the various gases and checking the predictions.

1. Obtain some gas in a balloon. Prepare the Bubble Blower by attaching a funnel to one end of a piece of rubber hose Attach the other end to the balloon. If the funnel is dipped in a soap solution* and then the gas in the balloon is forced out, gas will flow through the funnel and form bubbles containing the various gases instead of air. Observation will then confirm whether the density is >1.29 g/L or < 1.29 g/L.
2. If you have difficulty getting the gas into a balloon, a large syringe may be used instead. First, collect the gas by water displacement into any glass container. Prepare the syringe by closing the plunger, removing the needle, and replacing the needle with a length of rubber tubing. With the bottle of gas still submerged in the water, stick the rubber tubing into the bottle of gas and slowly pull up the plunger to fill the syringe with gas. Now fill the soap bubbles with gas by attaching the funnel dipped in soap solution to the rubber tubing and slowly pushing the plunger back in. (If you can't find a syringe, a bicycle pump might be used.)
3. (*) A recommended soap solution can be made by mixing 300 mL water, 85 mL Joy liquid detergent, and 15 mL glycerin (also known as glycerol and can be purchased at a drugstore). This produces a "tougher" bubble that is more conducive for study.
4. (**) A very easy way to collect a bottle of butane is to take a Bic® lighter and submerge it in water. When you "flick the Bic®" a bubble of butane will begin to rise. Capture this bubble by placing a glass bottle filled with water over it.

The butane will displace the water. Because this may be slow there is a faster way that you might get some butane. Into a Ziploc® bag spray some aerosol product that is propelled with butane or isobutane. The bag will get very cold and after a few seconds liquid butane will collect in the bag. Upon gently warming the liquid, butane will vaporize and start to fill up the bag. Butane-filled bubbles can then be collected.

5. (***) Methane gas can be produced mixing equal amounts of **solid** anhydrous sodium acetate and sodium hydroxide and placing them in a large DRY test tube.. Fit the top of the test tube with a stopper and a gas delivery tube. Carefully heat the test tube and collect the methane by water displacement. Care should be taken with open flames in the vicinity of methane since it is flammable.
6. (****) LP cylinders can be cheaply purchased at places like Wal-Mart or K-Mart.

D. As a final challenge have students propose ways in which they could "accurately" determine the density of an ice cube.

1. On the surface this looks like the straightforward problem encountered in Problem Presentation phase of this lesson. However, when the ice cube is placed on the balance, some of it will have melted and an accurate weight will not be obtained. Furthermore, trying to "accurately" find the volume of the ice cube presents another problem. If it is placed in water, its entire volume is not displaced. If put in something like alcohol, where it does sink, it melts appreciably giving an erroneous volume.
2. It should be interesting to see what ingenious ways students will think up to overcome these problems. The key lies in the idea presented in part A of the Concept Extension. *If an object had the same density as the liquid that made up the hole it would remain suspended between the top and bottom of the liquid in which it was placed.*
3. Someone may stumble across a very clever way to obtain this density while observing that ice cubes really do sink in alcohol. If the ice cube is placed in a relatively small amount of rubbing alcohol, it will sink. If left there, it can be seen that it indeed does melt. Depending on the size of the ice cube and the quantity of alcohol, after awhile the ice cube will start to float upward!! Upon agitation it will probably sink again, but soon will rise again. The obvious question to pose is WHY?
4. This phenomenon can be viewed without having to wait for it to happen by itself. If we carefully add water to the alcohol/ice cube mixture we will cause the density of the resulting solution to fall somewhere between the density of pure water and pure rubbing alcohol. At the point that the ice cube is suspended equally between the top and bottom of the glass the density of the liquid mixture must be the density of the ice cube! Now all that must be done is to pour out some of the liquid mixture and determine the mass of say 50 mL of it. This mass divided by 50 mL will give the density of the ice cube in g/mL.

PHYSICAL AND CHEMICAL PROPERTIES

PROBLEM PRESENTATION / EXPLORATION

A. Have each student pick out a peanut from a bag of peanuts.
   1. Examine your peanut carefully for 30 seconds. Make a list of all its characteristics. Give your peanut a name.
   2. Now, have all students at a table or a group of desks place their personal peanuts into a common pile and mix them up.
   3. Instruct each student to retrieve their personal peanut from the pile.

B. The identification or classification of an object is based on a specific set of properties that the object possesses. The characteristics that you used to identify you peanut were a set of properties.

C. Station Setup
   1. Each of five stations should be identically equipped with three glass bottles with stoppers. One bottle should contain sand or other similar solid; one should contain water; and the third should contain only air. Students should be asked to make and record observations of each bottle. If necessary, propose questions such as, "What is contained in each bottle? How would you classify each material? Are there similarities among the three materials? What are the differences?"
   2. Next, each of five stations should be identically equipped with a metric rule, a balance, a 100 mL graduated cylinder, three crayons of various colors from which the wrappers have been removed, and water. "Carefully observe each of the objects at your lab station. Using the equipment that has been provided and your own knowledge, make a list of the properties of the objects that would allow you to retrieve them from a container of similar objects."

CLASS RESPONSE / CONCEPT INVENTION

A. Each group should report back to the class about their observations of those materials in the three jars. (Hopefully, they will have discovered the three states of matter at this point. Some may indicate that there was nothing in the jar containing air. If so, ask them to recall what they learned about the properties of matter.)

B. Each group should then report their findings concerning the crayons. Record these findings on a transparency or on the chalkboard. "Which properties were the most helpful in identifying your objects?" [Characteristic properties will probably be: color, length, diameter, mass, floats or sinks in water.]

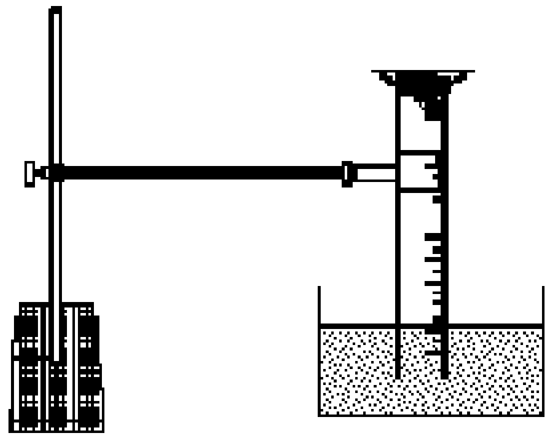
C. These properties along with melting point of solids, boiling point of liquids, coefficient of expansion, hardness, density, shape, odor, and taste are examples of **physical properties**. Notice that each of these properties can be investigated without changing the composition of the substance. If a large piece of paper is torn, there are smaller pieces but each of these pieces has the same makeup as the original large piece. After the melting point of a solid is determined it cools back down to give the same substance as before the heating. Measuring the density of an object does not change the composition of that object.

D. At this point, students will report to one of five stations and record all observations after completing the activities at that station. Each group should be given 5-10 minutes at each station. Instructions should be provided on cards at each station.
   1. Station #1
      a.) Materials should include a piece of paper, a match, forceps or tweezers, and a watch glass or glass dish.
      b.) "Record any properties of the paper that you observe."
      c.) "Tear the paper into two pieces and again record your observations."
      d.) "Hold one of the pieces of paper over the watch glass or dish, light the match, and burn the paper. Record all observations and any changes that have taken place. Which of these are physical changes?"

2. Station #2
   a.) Materials should include 1.0M copper (II) nitrate solution and 1.5M sodium hydroxide solution, a test tube, and a stirring rod.
   b.) "Mix 3 mL of each of the two solutions in the test tube, stir, and record all observations." (The copper (II) nitrate solution can be made by mixing 18.8 g of solute with enough water to make 100 mL solution. The sodium hydroxide solution can be made by mixing 6.00 g of the solute with enough water to make 100 mL of solution). Be careful when making the sodium hydroxide solution. **If you get any on you, wash it off with large amounts of water.**
3. Station #3
   a.) Materials should include 2 sugar cubes, 2 packages of granulated sugar, 2 paper towels, a 100 mL graduated cylinder, 4 paper cups, a microscope slide, 2 medicine droppers, a heat lamp or other similar heat source, and a microscope or magnifier.
   b.) "Place both a sugar cube and the granulated sugar from one of the packages on separate areas of a clean paper towel. Observe both types of sugar, then taste, and record all observations." (You might point out that normally nothing should be tasted in lab; however, today will be an exception.)
   c.) "Place each sample into a separate paper cup containing 25 mL of water and observe. Record any changes that take place.
   d.) "Crush a second sugar cube into crystals and place on a second paper towel. Place the contents of a second package of granulated sugar on a separate area of the towel. Note any differences in observations."
   e.) "Again, place each sample into a separate paper cup containing 25 mL of water and observe. Record any changes that take place."
   f.) "Place 3 or 4 drops of each of the samples that you just prepared onto separate areas of a microscope slide and place under a heat lamp to dry. Examine under a microscope or with a magnifier and record your observations."
4. Station #4
   a.) Materials should include a 1.00 g sample of ammonium nitrate in a tightly capped bottle, a Ziploc® bag, and 25 mL of water.
   b.) "Record observations of properties of ammonium nitrate and of water before beginning your experimentation."
   c.) "Place the sealed bottle of ammonium nitrate in the Ziploc® bag and add the sample of water. Seal the bag tightly. Next, remove the cap from the bottle containing the ammonium nitrate without opening the bag. Record all observations."
5. Station #5
   a.) Materials should include a small piece of chalk, 100 mL of 1.0 M hydrochloric acid, a test tube or flask, a one hole rubber stopper, a small dish or second test tube, rubber or glass tubing, and 100 mL of lime water (11.0 g calcium hydroxide / L of water).
   b.) "Record the properties of the chalk and the hydrochloric acid that you observe before beginning the experiment."
   c.) Carefully insert a flexible plastic straw into a one holed stopper. Add the piece of chalk to the test tube. Then add enough hydrochloric acid to completely cover the chalk. Quickly stopper the tube and place the end of the straw into another container filled with lime water. Record all observations." (The change of the lime water to a cloudy appearance is an indication of the presence of carbon dioxide.)
6. Station #6
   a.) Materials should include a clean piece of steel wool, a 100 mL graduated cylinder, a beaker, a ring stand or other support, a clamp, a medicine dropper, and water.

b.) "Before beginning this experiment, record all observable properties of the steel wool."

c.) "Push a small wad of the steel wool to the bottom of a 100 mL graduated cylinder. Place a few drops of water in the cylinder and shake to moisten the steel wool. Invert the cylinder and place it in a beaker of water, supporting the cylinder with a ring stand and clamp. Adjust the cylinder so that the level of water inside and outside the cylinder are at the same height. Let stand overnight. The next day, record and changes that are observed."



7. Station 7

a.) Cut off a piece of Scotch® tape about 15 cm long. Cut off a piece of masking tape about 15 cm long. Tape the two sticky sides together so that you have one 15 cm long piece of "double tape".

b.) Grasp the "double tape" with a spring loaded clothespin and place it over the flame of an alcohol lamp or a cigarette lighter for a few seconds. Record what happens.

c.) After the tape cools, turn it over so that the other side of the "double tape" is above flame and watch what happens now. What physical property of the tape could account for this behavior? [Each of these two types of tape expands at a different rate. One side of the tape is expanding faster that the other side. That is why one time the "double tape" bends upward from the flame but when turned over bends downward toward the flame. This is the principle of the bimetalic strip in many thermostats. The name of the physical property responsible for this phenomenon is the coefficient of linear expansion.]

E. After all experimentation has been completed and observations recorded, have each group report back to the class their findings. Record these observations on a transparency or the chalkboard. As a class divide the properties into two groups based on whether the material under consideration was the same material both before and after your experimentation or if it was different after the experimentation. Those properties where no permanent changes were made to the substance are physical properties. Those properties that seemed hidden until some external agent came in contact with them and allowed the property to be seen are called chemical properties. For example: not until oxygen came into contact with the paper and with enough heat supplied did combustion or oxidation take place. The property of oxidation is therefore a chemical property. The hidden property of the copper (II) nitrate and sodium hydroxide to come together and form a precipitate is a chemical property. As you would suspect, along with chemical changes come physical changes. The new substances formed have different physical properties from the substances before the chemical change took place.

Physical	Chemical
Color	Combustibility
Size	Form a Precipitate
Texture	Produce a Gas
Liquid/Solid/Gas	
Solubility	
Endothermic or Exothermic Heat of Solution	

CONCEPT EXTENSION

A. Station Setup

1. Cut a potato in half. Add a few drops of iodine solution to the freshly cut surface of the potato. The blue/black stain that forms is a positive test for starch in the potato. This is a chemical property of starch.
2. "Observe carefully a piece of toast. Record your observations. Break the toast in half, exposing the inner portion. Again, record your observations. Add a few drops of the iodine solution to both the outer, toasted portion and the inner area. Observe and record what happens. On the basis of your observations, identify where any physical or chemical changes occur. List reasons for your explanation. [The heat will cause a chemical change in the starch contained in the bread breaking it down into less complex molecules. These portions of the toast will not give the starch test to the same degree as where the large starch molecules have not yet been degraded. This is why toast is recommended for people who have digestion problems. Now you know why your mother gave you toast when you were recovering from an illness!]

B. Station Setup

1. Materials at each identical station should include two pennies (one a pre-1982 and the other a post-1982 penny), a triangular file, 2 beakers or other similar containers, 50 mL of hydrochloric acid (3 M), and a balance.
2. "Observe carefully the two pennies at your lab station and record all visible properties in your notebook. Next, scratch the edges of both coins with the triangular file at 12, 3, 6, and 9 o'clock around the penny's circumference and place into separate beakers, containing 25 mL of hydrochloric acid. Observe and record any changes that occur within the class period. Allow the coins to remain in the hydrochloric acid overnight. During the next class period, have some of the students carefully remove some of the coins with forceps or tweezers from the hydrochloric acid and rinse in water thoroughly. Examine both coins carefully and record any changes that have taken place. Leave the other pennies in for one or two additional days. On the basis of your results, what kind of change has taken place in each case? List reasons for your answers." [In the post 1982 pennies approximately 95% of the penny is zinc covered with a thin copper shell. The cuts in the edge allow the acid to react with the copper forming hydrogen gas. Consequently the penny is eaten up from the inside. When sufficient zinc has been reacted, the penny will float in the acid solution. Because the pre 1982 pennies had only about 5% zinc in them very little reaction will take place and they should not float.]

C. Non-Newtonian Fluids

1. Fluids - Fluids are anything that flow, a gas, a liquid, or an avalanche. Fluids should not be confused with liquids.
2. Viscosity - All fluids have a property known as viscosity. It is the measurable thickness or resistance to flow in a fluid.
3. Newton's law of viscosity says that the viscosity of a fluid can be changed only by altering the fluid's temperature. A common example is honey. You warm it up and it flows more easily [becomes less viscous].
4. Non-Newtonian fluids have the same dependence on temperature but their

viscosity can also be changed by applying force or stress. Added force either increases (cornstarch/water, monster flesh, slime) or decreases the viscosity (spreading margarine over a piece of toast).

5. Because non-Newtonian fluids have the above property they are interesting to study. Do they act like liquids or solids?
6. Pour 1.5 cups of pure cornstarch slowly, with stirring into a plastic mixing bowl containing 1 cup of water. The mixture will get more viscous as more cornstarch is added. Slowly stick your finger into the white blob. Slam your fist down into the mixture. What happens when you apply pressure to the mixture? [Your finger will pass easily through the mixture when slow gentle pressure is applied. When much greater pressure is applied by slamming your fist into a pan of it, there is great resistance offered. In other words, the viscosity increases when subjected to greater pressure.] Roll some of the mixture up into a ball and set it on the table. What happens? [With almost no pressure being applied to it, it will slowly "melt" into a much more liquid-like material.]
7. Another non-Newtonian fluid is commonly referred to as Monster flesh.
   a.) Prepare a 4% solution of sodium borate (use 4 grams of 20 Mule Team Borax® and 96 grams of water).
   b.) Into a 100 mL beaker, carefully pour 20 mL of Elmer's glue. Add to this 20 mL of water. Stir with a pop sicle stick or spoon.
   c.) Pour 15 mL of the borax solution into the glue/water mixture. Stir for about 20 seconds. (The borax solution can be made different colors before adding to the glue/water mixture by adding a few drops of food coloring, or different colors of Elmer's glue are now available).
   d.) Remove as much of the product as possible (**it is entirely safe to handle**) from the beaker Pick it up in your hands and knead it.
   e.) Place it on a flat surface and watch what happens. Is what you have made a solid or liquid?
   f.) What are some of its physical properties? Does it bounce? Does it stretch? Does it pick up impressions from newsprint like Silly Putty?

DEFINITE PROPORTIONS

PROBLEM PRESENTATION / EXPLORATION

A. At each of six stations will be a balance, a bag of Tinker Toy® spools, and a bag of Tinker Toy® spokes.
   1. Students are to find the mass of the bag of spools, and the mass of the bag of spokes, separately.
   2. Each team of students should predict the mass of wheels they think can be constructed with their spools and spokes.
   3. Each team is then instructed to fill all the holes in the spools with spokes until they run out of materials.
   4. Next, the total mass of the wheels built is to be determined.
   5. Finally, the mass of any unused spokes or spools is to be determined

B. As the groups finish, have them transfer their findings to the class master transparency.

Mass of Spools	Mass of Spokes	Mass of Wheels	Mass of Unused Spools	Mass of Unused Spokes

CLASS RESPONSE / CONCEPT INVENTION

A. Ask the class what pattern they see in the reported data. The conclusion you hope they give at this stage is that there is a constant ratio between the mass of spools to the mass of spokes. In other words, whenever you make wheels from this kind of spools and spokes, you always get the same ratio of mass of spools to mass of spokes. [*This is our version of the Law of Definite Proportions.*]

Station #	Number of Spools	Number of Spokes	Number of Wheels	# Spools Left Over	# Spokes Left Over
1	3	18	3	0	0
2	3	24	3	0	6
3	3	30	3	0	12
4	4	12	2	2	0
5	5	12	2	3	0
6	6	12	2	4	0

   1. In two of the stations three spools and an excess of spokes were provided so that the spools were the limiting factor in the construction of wheels. [There doesn't have to be the same mass of spokes at each station as long as it is in excess.]
   2. In two of the stations 12 spokes and an excess of spools were provided so that the spokes were the limiting factor in the construction of wheels. There doesn't have to be the same mass of spools at each station as long as it is in excess.
   3. Ask them why the mass of wheels didn't turn out to be simply the sum of the starting masses of the spools and spokes. Try to show them that this is the kind of evidence that led the *Fathers of Modern Chemistry* to suspect that matter doesn't mix in a continuous way, but combines in definite proportions.

Their only explanation for this was that matter is made up of individual particles that can combine in a definite ratio.

B. Turn the students' attention to a chemical situation to investigate whether chemical reactions work the same way as Tinker Toys®.

1. Set up twelve stations. At each station there will be a test tube rack containing one test tube, a buret of solution labeled Solution A, and a second buret of solution labeled Solution B.
2. Students are to add the number of mL of Solution A and mL of solutions B into the test tube according to the following table.

Station #	mL Solution A	mL Solution B	Ht. of Ppt (mm)
1	10	2	
2	8	4	
3	6	6	
4	5	7	
5	4	8	
6	3	9	
7	2	10	
8	1	11	

3. After carefully adding the appropriate amounts of Solution A and Solution B the stopper is to be tightly inserted into the test tube and the test tube shaken for one minute.
4. The test tube is to be placed into the test tube rack and the precipitate allowed to settle for a few minutes. When most of the floating particles in the solution have settled, the height of the precipitate is to be measured and recorded.
5. The data from each station is to be transferred to the class master transparency for the whole class to see.
6. At which station(s) did we get the maximum amount of precipitate? (Station # 5 should give the maximum amount of precipitate.) Why did we get more precipitate here? [At this station we have mixed the solutions in the proper ratio to completely use up all of Solution A and all of Solution B with no excess of either A or B left over. In all other test tubes either A or B is in excess. Therefore this station give us the best approximation of the Definite Proportion for the precipitate formed.]
7. If we only knew the mass of each of the chemicals in Solution A and in Solution B, we could figure out the Definite Proportion mass ratio for the precipitate. Tell them at this point what the concentration was for the two solutions. Indicate this in grams of solute per mL of solution.
   a.) Solution A can be made up by dissolving 82.8 g of lead nitrate, $Pb(NO_3)_2$, in water to make a total volume of 500 mL of solution. There is 0.1036 g lead per mL of solution in solution A.

   CAUTION: Lead compounds are toxic and accumulate in body tissues. Wear gloves when preparing these solutions.

   b.) Solution B can be made up by dissolving 41.5 g of potassium iodide in water to make a total volume of 500 mL of solution. There is 0.06345 g iodide per mL of solution in solution A.
   c.) Therefore, the Definite Proportion for the precipitate Lead Iodide can be found in the following way:

   (0.1036 g /mL Pb) (4 mL) = 0.4144 g Pb

   (0.06345 g/mL I) (8 mL) = 0.5076 g I

   The ratio is 0.4144 g Pb/0.5076 g I = **0.8164 g Pb : 1.0000 g I**

8. Disposal

> The Lead Iodide formed here must be disposed of carefully. Collect all waste material from the experiment in a waste container especially for this purpose. It should be converted into its most insoluble form and then buried in a landfill approved for the disposal of hazardous waste. Any waste solution should be treaded with a threefold excess of sodium sulfide or thioacetamide and stirred occasionally for about one hour. Adjust the pH to neutral with 3M sodium hydroxide solution to complete the precipitation of the lead compound. Separate the solid lead sulfide by filtration and allow it to dry. Place the lead sulfide in a plastic container of appropriate size, and bury it in a landfill approved for such waste. The filtrate should be added slowly with stirring to an excess of ferric chloride. A precipitate will form. Neutralize the remaining solution with sodium carbonate (some evolution of CO_2 will occur). Allow the precipitate to settle . Flush the neutral solution down the drain with excess water. Allow the precipitate to dry and dispose of in an appropriate landfill.

CONCEPT EXTENSION

A. We have seen that one way to find out the definite proportion of two elements that have reacted is to react solutions with known amounts of the two elements dissolved in them in different proportions until we find the proportion giving the greatest amount of solid product. Another way to go about determining the correct proportion of two compounds reacting is to once again vary the proportion of two substances but instead of measuring the amount of solid product formed, measure the amount of heat given off. The correct proportion will give off the most heat.

1. Prepare a solution of 0.50 M sodium hypochlorite, NaOCl. (This is the active ingredient of Clorox.) Also prepare a 0.50 M solution of sodium thiosulfate, $Na_2S_2O_3$. (This is the substance that a photographer galls "fixer".)
2. Measure the NaOCl indicated in the chart into a Styrofoam cup. Measure the $Na_2S_2O_3$ indicated in the chart into a beaker. Place a thermometer that can be read to a tenth of a degree in the Styrofoam cup. Pour the solution in the beaker into the Styrofoam cup and swirl it for two seconds. Immediately note the temperature on the thermometer. Determine the highest temperature reached and record it.

Station #	mL NaOCl	mL $Na_2S_2O_3$	Starting T	Highest T
1	10	90		
2	20	80		
3	30	70		
4	40	60		
5	50	50		
6	60	40		
7	70	30		
8	80	20		
9	90	10		

3. Analysis of the table will tell you which proportion of solutions gave the largest change in temperature. This will be the correct proportion of the two compounds needed to react and form the product.

B. If you did not carry out the determination of the percentage of water in Epson salts in the Law of Conservation of Mass experiment, this would be a good time to perform this determination. Instructions are given on page 19.

MIXTURES

PROBLEM PRESENTATION / EXPLORATION

A. Ask students what they think would happen if we would put a magnet into a box of cereal. "Would the magnet have any effect?" Have them look at the content information on the box. (Cereal should be fortified with iron. One example is Total®.) Indicate that if we are going to "mine" this cereal for the iron we will have to break it up just like they do when mining for iron out of the ground. Then, maybe, our magnet will have an effect on the iron.

B. Mining Procedure
   1. Here are the instructions that are commonly given in some textbooks.
   2. Pour cereal into a 250 mL beaker up to the 100 mL mark and cover the cereal with 100 mL of warm tap water.
   3. Attach, with a rubber band, a bar magnet to a pop sickle stick. Wrap the stick/magnet combination with a plastic wrap such as Saran Wrap®.
   4 Stir the cereal/water mixture with the stick/magnet stirrer for about 3 minutes. A fine mush should result. Allow the mixture to sit for 10 minutes and then stir again. Leave the covered stick/magnet stirrer in the mush while not stirring. Allow it to sit for another 10 minutes. Stir one last time.
   5. Remove the stick/magnet stirrer and hold it over a white piece of paper. Is there any residue attracted to the magnet? (*Elemental iron that is included in food is called food-grade iron filings*..)
   6. Point out that the reason that the magnet did not attract individual flakes was that the flakes had so little iron and that their mass was so great that the magnet was not strong enough to attract entire flakes. However, when the "ore" was pulverized, the iron could be extracted form the other substances in the mixture.
   7. While these instructions probably work, it is much easier if you add a magnetic stirring bar to the beaker and place it on a heater/stirrer hot plate. Heating for about ten minutes with continual stirring results in a reasonable amount of iron filings adhering to the stirring bar.
   8. **A better way to show this phenomenon is to use the individual packets of Instant Cream Of Wheat®. You don't have to add any water or any heat. Simply allow the stirring bar to spin for about 30 seconds and when it stops there will be iron fillings all over the magnetic stirring bar.**

C. How can other mixtures that don't contain iron be separated? For example, without touching the mixture with your hands, how would you separate into three different containers a mixture made up of copper BBs, broken up toothpicks, and a spoonful of sugar? You may use other pieces of laboratory equipment, but you may not reach in with your hands and pick out the BBs. (No tweezers either!!) Have separate work stations set up for the students to carry out this separation. Include at the work stations beakers, a funnel, and filter paper (Mr. Coffee® filters are fine.)

CLASS RESPONSE / CONCEPT INVENTION

A. Various groups should report their technique for carrying out the separation. Have the class decide which was the best one. Why was it the best one? Things that should be considered in making these decisions are the purity of each final substance that they ended up with, and the ease of obtaining the individual pure substances.

B. Probably the best sequence for carrying out the above separation is to pour the whole mixture into water. The sugar will dissolve; the BBs will sink to the bottom; and the toothpicks will float. The toothpicks can be skimmed off with a spoon or strainer. The remaining mixture (water, sugar, BBs) can now be poured through the filter. The BBs will be caught in the filter paper and the water/sugar mixture will pass through the filter paper. Finally, the water can be evaporated off leaving the sugar crystals.

C. The idea to be invented at this stage is that the way we separate mixtures is to take advantage of the physical properties of the individual components of the mixture. In the cereal example, the property that was utilized was the magnetic nature of the iron. Iron is magnetic; cereal is not. In the BB/Sugar/toothpick mixture we took advantage of the large density of the BBs (sank to bottom), the small density of the wooden toothpicks (floated in water), and the solubility of sugar in water. Stress that when separating a mixture we carry out reactions that capitalize on the components' different physical properties. This means that when the substances have been separated, the individual components will retain their original properties; they will not have been changed into some new substance. If chemical changes would have been utilized, the properties of the resulting substances would be different from those that each component in the mixture had at the beginning.

CONCEPT EXTENSION

A. Set up the following situations. Instruct the students to carry out the separation of components in each mixture. Have them decide what physical property was utilized in making the separation.

1. Green pieces of paper and red pieces of paper [Color]
2. 5 circles cut out of green paper, 3 squares cut out of red paper, 6 circles cut out of red paper, and 2 squares cut out of green paper [Shape]
3. Pour a mixture of marbles and salt crystals through a wire mesh screen [Size]
4. Place a small piece of chalk and some sugar into a mortar. With the pestle grind it up. Now transfer the mixture into a small beaker. Add about 50 mL of water to the beaker and pour the contents through a filter paper. Catch the liquid in another beaker. [Solubility in water]

B. The idea of recycling plastics is becoming more of an everyday issue. Presently, we use these materials once and then discard them. There is growing concern about the environmental impact of plastic garbage. In many communities plastics are separated into a container different from the paper and aluminum and are picked up by the city to be recycled. A major drawback to recycling plastics, not experienced in recycling aluminum cans, is that there are many different types of plastics. Before they can be reused they must be separated. What physical property could we use to separate a mixture of various types of plastics?

1. A very simple way to separate a mixture of plastics is to sort them according to their density. As we saw in the DENSITY experiment, a candle will float in water but will sink in rubbing alcohol. Its density is less than water, so it floats; but its density is greater than rubbing alcohol, so it sinks.
2. If we extend this idea a little farther to the use of more than one liquid, we can sort the plastics according to their density. For example if we had four liquids arranged in density from low to high: rubbing alcohol, water, salt water, and Karo® syrup, what would happen if we dropped the candle into each liquid? Since the density of the candle is less than the Karo® syrup, the salt water, and the water it would float in each of these liquids. But because its density is greater than that of rubbing alcohol it would sink in only this liquid. If we would take a piece of plastic from a tape cassette box and drop it into each of the liquids, what would happen? It would float in the Karo® syrup; it would float in the salt water; it would sink in the water; and it would sink in the rubbing alcohol. From this we can tell that the cassette box must have a greater density than the candle.
3. The Society of the Plastics Industry, Inc., has developed a voluntary uniform coding system for plastic containers which identifies containers by material type for the convenience of sorting the containers. The code is a three-sided triangular arrow with a number in the center and letters underneath. The number inside and the letters indicate the resin from which the container is made. Each of these plastics differs in density.

PETE HDPE V LDPE PP PS OTHER

Five of the most common types and their densities (g/mL) are listed below:

PP	LDPE	HDPE	PS	PETE
0.90-0.91	0.92-0.94	0.95-0.97	1.05-1.07	1.39

4. Prepare the following liquids
   a.) 5:1 mixture of rubbing alcohol and water (5 mL of rubbing alcohol for every 1 mL of water)
   b.) 3:1 mixture of rubbing alcohol and water (3 mL of rubbing alcohol for every 1 mL of water)
   c.) water (distilled water)
   d.) salt water (use a 10% NaCl in H_2O solution; 10 g NaCl for every 90 g H_2O)
5. Prepare a mixture of plastics. The five liquids indicated in #4 above will not allow the separation of all plastics by density, but it will work on the most common types of plastics available to most classrooms. Some recommended plastics for this activity are
   a.) plastic from gallon milk jugs, detergent bottles, plastic flowerpots, and plastic lumber (HDPE, HIGH DENSITY POLYETHYLENE)
   b.) plastic from 2 liter soda bottles, plastic scouring pads, and Mylar tape (cassette & computer) (PETE, POLYETHYLENE TERE-PHTHALATE)
   c.) plastic from catsup bottles or yogurt cups (PP, POLYPROPYLENE)
   d.) transparent plastic drinking cups, the brittle ones, plastic in cassette tape boxes (PS, POLYSTYRENE)
   e.) plastic squeeze bottles, the type that are used for misting plants Elmer's® glue bottles (LOW DENSITY POLYETHYLENE)
5. Ask the students to separate the mixture of pieces of plastic by taking advantage of the physical property of density. Let them figure out the most efficient order in which they should test the samples that will result in the mixture of plastics being separated into piles having samples with like densities. [Probably should start with the most dense liquid, the salt water. Only the PETE will sink.] After skimming off all the pieces that did not sink in the salt water they should be added to the next most dense liquid, (water). *EACH PIECE MUST BE THOROUGHLY DRIED BEFORE ADDING IT TO THE NEXT LIQUID*. The remaining pieces can then be added to the water to separate out the next most dense ones. The same procedure should be then carried out in the two rubbing alcohol solutions.]

Liquid	Density g/mL	Plastics That Float in Liquid
Alcohol:Water (5:1)		PP
Alcohol:Water (3:1)	.945	LDPE, PP
Water (Distilled)	1.00	HDPE, LDPE, PP
Salt Water (10%)	1.05	HDPE, LDPE, PP, PS

6. If you prefer, the following scheme could be used to identify samples of plastic. It requires four test liquids, and based upon whether the sample floats or not the sample can be tentatively identified. The alcohol/water

mixture should be 3 parts rubbing alcohol to 2 parts water. The samples could be shredded and added to the liquids. If the sample does not sink immediately, push it down into the liquid with a pop sicicle stick.

	Floats in Vegetabl e Oil	Floats in Alcohol / Water	Floats in Water	Floats in Glycerin
PETE	NO	NO	NO	NO
HDPE	NO	NO	YES	YES
V	NO	NO	NO	NO
LDPE	NO	YES	YES	YES
PP	YES	YES	YES	YES
PS	NO	NO	NO	YES

NEWTON'S FIRST LAW OF MOTION

PROBLEM PRESENTATION / EXPLORATION

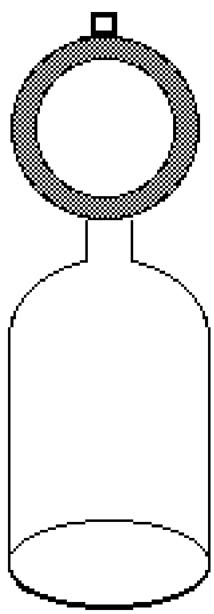
A. How many of you have ever seen a magician pull a tablecloth off a dinner table, complete with dishes, without breaking any of the dishes? Is it really magic, or is it science?

B. Station Setup

1. Each station should be identically equipped with a 12-inch wooden embroidery hoop, a narrow-mouth bottle, and sugar cubes. (A substitute for the embroidery hoop can be made by taking a large cylindrical plastic bottle and with scissors cutting out from the middle of it a hoop about one half inch high having a diameter of about six inches.)
2. Very carefully balance the embroidery hook vertically on the mouth of the bottle. Stack a sugar cube on top of the hoop.
3. The CHALLENGE in this activity will be to get as many sugar cubes as possible into the bottle by hitting the hoop with only one hand. With practice a stack of sugar cubes can be used in place of the single cube.
4. Students at each lab station constitute a team. The winning team is the one who gets the most sugar cubes in the bottle in a given time.

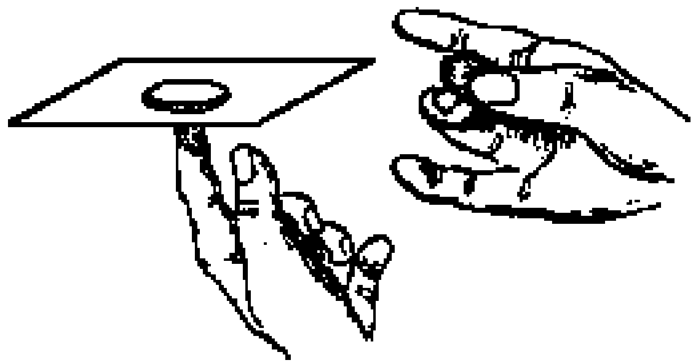
CLASS RESPONSE / CONCEPT INVENTION

A. Have each team report their results and describe the method they used in trying to get the sugar cubes into the bottle. (The best technique will probably be to face the hoop toward you so that you can see the full circle. Swing your arm across your body horizontally, quickly grabbing the far **inside** edge of the hoop while your arm is moving, and flicking your wrist to move the hoop from beneath the sugar cubes. The sugar cube should drop into the bottle.



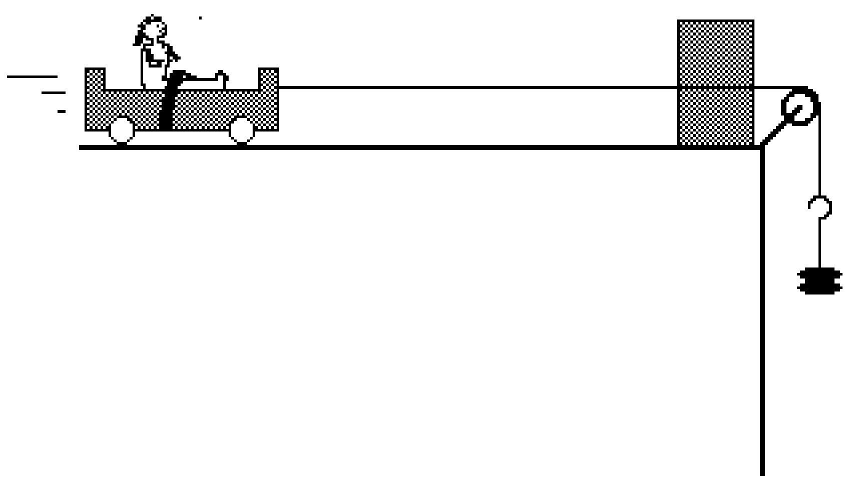
B. Why did the winning group win? What kept the sugar cubes from scattering? (At this point, students may not realize that inertia is involved, but they should come to the conclusion that the hoop moves while the sugar cubes do not, other than to fall into the bottle. As long as the sugar cubes rested on the hoop there were equal forces pushing up and pushing down on them and they didn't move. When, by snatching the hoop away, the upward force exerted by the hoop on the sugar cubes was taken away the sugar cubes experienced an unbalanced force and started to move. When they started moving they continued to move until another force, the bottom of the bottle, acted on them and brought them to a halt.)

C A slightly different example of this is to cut a 3 x 5 card in half, place a penny in the center of the card and balance the card and penny on your left index finger. With your right middle finger flick the card off of your index finger. If you do this so that the card moves in a horizontal plane, the penny should stay on the finger tip. If the removal of the card is not done quickly both the card and the penny will more. The inertia of the penny accounts for it remaining where it started while the card is set in motion.



D. In the next activity, students will be asked to discover the importance of wearing a seat belt.

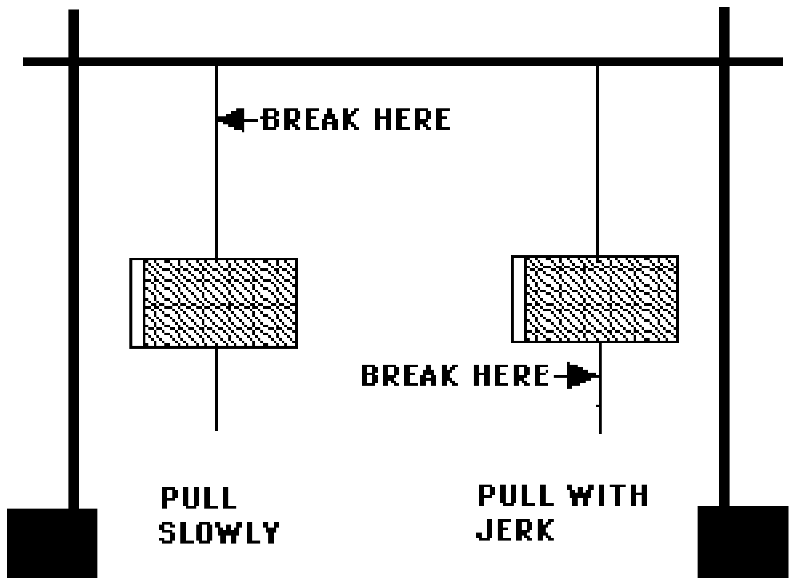
1. Each station should be identically equipped with a 2 meter piece of string, 1 dynamics cart, a 200-g hook mass, a rubber band, 1 doll (to fit the dynamics cart), 1 pulley, and 1 block of wood.
2. Attach one end of the string to the dynamics cart and the other end to the 200-g mass. Attach the pulley to the end of the lab desk and hang the mass over the pulley so that the mass is on the floor and the cart is on the desk. Place the block of wood on the table in front of the pulley (between the pulley and the cart). Then place Barbie on the cart. Next, pull the cart back and release it so that it accelerates toward the edge of the desk. Observe and record what happens. [Here, Barbie keeps on going when the car stops.]



3. Repeat this procedure, but this time, attach the doll to the cart with the rubber band or tape (the seat belt). Again, observe and record what happens to Barbie. [Here, Barbie stops when the car stops.]
4. These experiments illustrate Newton's First Law of Motion and the concept of inertia. Based upon the results of the class, formulate what Newton's First Law of Motion says. [An object at rest remains at rest or an object in motion remains in motion until acted on by an external force.]

CONCEPT EXTENSION

A. Setup
1. Suspend from the ceiling or other horizontal support two pieces of thread about 3 meters long.
2. Wrap the first piece of thread around a paperback book allowing it to hang down.
3. Wrap the second piece of thread around an identical paperback book so that it hangs down an identical distance from the ceiling.
4. Tie another piece of thread around the first book so that it hangs about one meter below the bottom of the book. Both strings tied to the book should be in the same vertical line.
5. Repeat step four on the second book so that there are two identical setups.



B. Prediction
1. Ask the students what will happen when you pull on the bottom thread attached to the first book.
2. If they say the thread will snap above the book, jerk rapidly and the thread below the book will snap.
3. If they say the thread will snap below the book, pull slowly on the thread and the thread above the book will snap.

C. Explanation
1. By pulling the thread slowly, we are not only putting a strain in the thread, but in the thread above the book, the book's weight adds to this pull. Thus compared to the strain below the book, this is much larger and the thread snaps wherever the strain is highest.
2. When a sharp jerk is exerted on the thread, the inertial of the book keeps the strain below the book. Although there is some strain in the thread above the book, compared to that below the book, the strain in the latter is still higher, and the thread snaps below the book.

HOW FAST DO DOMINOES FALL ?

PROBLEM PRESENTATION / EXPLORATION

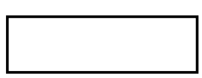
A. Most everyone has seen dominoes set up in some intricate pattern and then set off by tipping over one of them. What follows is often amazing, in that hundreds and even thousands of dominoes gracefully fall over after being hit by their neighboring dominoes. How fast does the pattern unfold? What is the maximum speed at which a row of dominoes can be made to fall when set off by a single domino toppling? The CHALLENGE of this activity is to maximize the speed at which a row of 100 dominoes falls down. Make sure that the dominoes are at least 0.2 of a domino length apart. Don't let them place the dominoes next to each other so that they touch. _A cheaper and more accessible alternative is to use a can of Lego® or Tyco® blocks. They are easier to count too if you use different colored blocks to mark every tenth block_.

B. Have students set up 100 dominoes in a straight row. Have them determine how they should be spaced to maximize the toppling speed. Are there any relationships between the average spacing distance between dominoes, the length of the domino, and the average speed at which the dominoes fall?

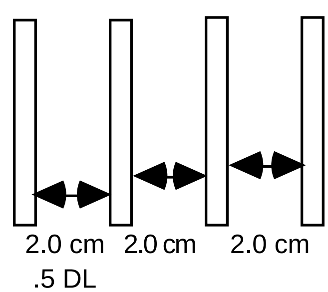
Domino Length	Ave Spacing		Row Length		Time	Ave Speed
cm	cm	Domino Lengths	cm	Domino Lengths	sec	cm/sec

CLASS RESPONSE / CONCEPT INVENTION

A. Point out that to compare results among groups investigating this problem a common unit of distance measurement must be used when referring to the average spacing between dominoes (To come up with enough dominoes to do this activity, different sets of dominoes may have to be used. Dominoes in different sets do not necessarily have the same length, therefore only dominoes from identical sets should be used in a single group. However, if the spacing is formulated in domino lengths, groups can compare their results with each other). We will use the domino length found by taking the spacing in cm and dividing by the length of the domino in cm. This gives us the spacing in domino lengths.



Domino Length = 4.0 cm



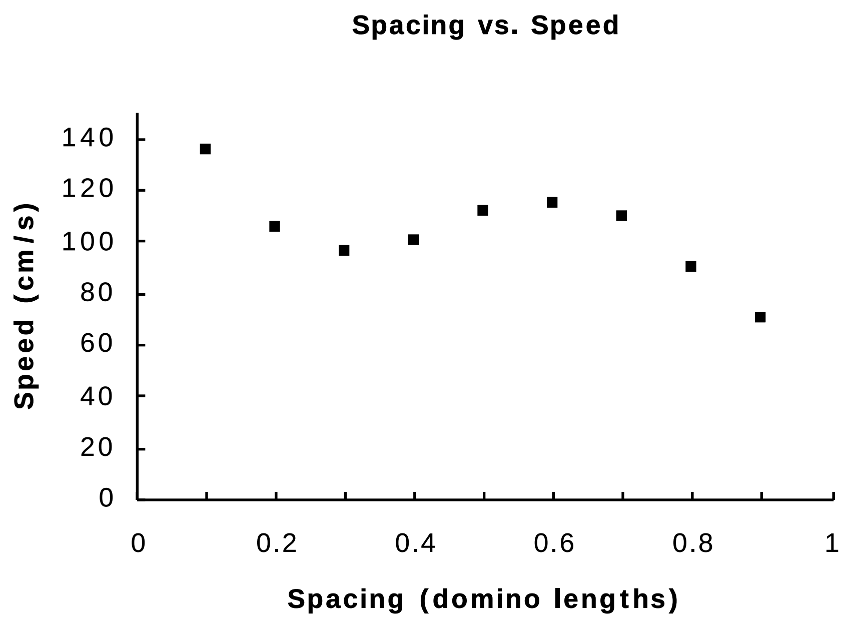
Spacing = 2.0 cm

Spacing in Domino Lengths = 2.0/4.0 = 0.5 DL

A good way to get equal spacing would be to take some adding machine tape and draw a continuous line on it. Make 100 marks at 0.3 of the domino length on this line. Then extend the line and tape it to the table. Repeat this for additional machine tapes with 0.4, 0.5, 0.6, 0.7, etc. spacings. The dominoes can now be set up evenly by placing them next to a tape on the table.

B. The concept of average speed can be demonstrated by this activity in that the total distance of the domino row divided by the time it took to topple is the average speed of the dominoes falling. The speed at which the dominoes fall is probably not constant. Possible reasons for this are that each domino is not exactly equally spaced and that all dominoes may not be uniform, and that the surface over which the dominoes are placed may not be uniform.

1. From the information accumulated by the various groups, construct a class graph of average speed (y axis) vs. spacing in domino lengths (x axis). At what predicted spacing would the dominoes topple with maximum average speed?
2. Explain the shape of the graph. (Rough sketch below)



When the dominoes are close together the speed is slower because the speed of falling over is less. When the dominoes are far apart the speed is slower because it takes longer to touch the next domino.

CONCEPT EXTENSION

A. Based on the observations and relationships developed above, predict how long a string of dominoes would have to be to take 1 minute to fall? At what average speed is this row toppling?

B. At what average speed would the dominoes topple if you arranged 75 of them at a spacing of 0.3 domino lengths and 50 of them at 0.6 domino lengths? (The row consists of 125 dominoes but there are two different spacings.)

C. Since you are playing with the dominoes, why don't you have the students simulate a chain reaction.

1. Instead of setting up the dominoes in a straight line where a domino simply hits the one in front of it, arrange the dominoes so that each domino hits two other dominoes and in turn each of these hits two other dominoes, etc.

2. Compare the amount of time for 100 dominoes to fall down. This shows how a large number of nuclear collisions in a short time can sustain a nuclear chain reaction.

ACCELERATION (Free-Fall)

PROBLEM PRESENTATION / EXPLORATION

A. This activity begins with a DISCREPANT EVENT involving acceleration. It is designed to facilitate the students' understanding of the differences between velocity and acceleration. To an eleven meter string (CD) attach seven weights at various intervals. Holding the string by one end drop it from a height of about five meters into a metal wastebasket. As the weights hit the wastebasket a series of sounds will be heard at evenly spaced time intervals. A second string (AB), identical in length and number of weights, is dropped, but this time when the weights hit the wastebasket the sounds are not evenly spaced. When the strings are retrieved from the wastebaskets and laid on the floor, students (who were not allowed to see the strings before or as they were dropped) are asked to pick the string that made the evenly spaced sounds. Common sense would dictate choosing string AB because the weights are attached to the string at identical intervals. (This, however, is not the correct choice!) Upon repeating the drop for the class, string AB can be dropped from either the A or B end and will result in sounds of hitting the wastebasket with unequal time intervals. If you drop string CD from the opposite end (C) that it was dropped from in the first time, once again unequal time intervals between the washers hitting will result. Only when CD is dropped from the D end will there be equal time intervals.

A-------------x-------------x-------------x-------------x-------------x-------------B

C-x---x-------x---------------x-----------------------x---------------------------------D

B. String AB should be prepared by attaching weights at even intervals of about 183 cm. String CD should be prepared by attaching weights at the following points along the string: 0 cm, 31 cm, 123 cm, 276 cm, 490 cm, 766 cm, and 1100 cm.

CLASS RESPONSE / CONCEPT INVENTION

A. To revitalize faulty memories and to eliminate unnecessary drops, have one or two of the student observers tape-record the two drops of each string. It would even be better if the tape-recorder was equipped to tape at two different speeds so that it could be taped at high speed and played back at the slow speed. In this way the intervals between the sounds will be more distinct, and the students will be sure of what they heard. [In real time there is 0.25 second between each plunk for string CD]. Have students try to explain what they have heard in terms of what they have seen concerning the spacing of weights on the strings.

B. Try to direct the students' thinking back to what we learned about velocity or speed. If the string was falling with uniform velocity, the one with the equally spaced weights would produce evenly spaced sounds, because each weight would be traveling the same distance in the same time. Since each weight on string AB travels the same distance before hitting the waste can (the weights are evenly spaced) and since each arrives in a shorter time interval (the tape-recording proves that), we need to get the students to conclude that each subsequent weight must be traveling faster. In other words, the velocity of the string is increasing as each weight falls through its 183 cm. This change in velocity per change in time is called ACCELERATION.

C. If the C end of the string was placed into the waste can so that washer #1 is just touching the bottom of the can when you let go, the second washer will have to fall 31 cm before it hits the bottom. As we have seen above, it takes 0.25 seconds for this to happen. The third washer hits 0.25 seconds later, the fourth washer hits 0.25 seconds later, etc. The following chart can be used to demonstrate the distances traveled by each of the washers at the end of each quarter second for a total time of 1.5 seconds.

	Washer #2 had traveled	Washer #3 had traveled	Washer #4 had traveled	Washer #5 had traveled	Washer #6 had traveled	Washer #7 had traveled
At the end of .25 sec	31 cm	31 cm	31 cm	31 cm	31 cm	31 cm
At the end of .50 sec		31+92 cm	31+92 cm	31+92 cm	31+92 cm	31+92 cm
At the end of .75 sec			31+92+ 153 cm	31+92+ 153 cm	31+92+ 153 cm	31+92+ 153 cm
At the end of 1.00 sec				31+92+153+ 214 cm	31+92+153+ 214 cm	31+92+153+ 214 cm
At the end of 1.25 sec					31+92+153+ 214+276 cm	31+92+153+ 214+276 cm
At the end of 1.50 sec						31+92+153+ 214+276+ 334 cm

D. Have students investigate the table above and determine the additional distance covered by each successive washer. They should find that between plunks the distance covered constantly increases at a rate of about 61 cm more than it covered in the last quarter of a second. This means that weight #3 travels 61 cm farther than weight #2 in the same amount of time; and weight #4 travels 61 cm farther than weight #3 in the same time interval, etc.. If they are having trouble seeing this from the above table, have them examine the table below.

	Washer #2	Washer #3	Washer #4	Washer #5	Washer #6	Washer #7
Distance traveled during 1st quarter of a second	31 cm	31 cm	31 cm	31 cm	31 cm	31 cm
Distance traveled during 2nd quarter of a second		92 cm	92 cm	92 cm	92 cm	92 cm
Distance traveled during 3rd quarter of a second			153 cm	153 cm	153 cm	153 cm
Distance traveled during 4th quarter of a second				214 cm	214 cm	214 cm
Distance traveled during 5th quarter of a second					276 cm	276 cm
Distance traveled during 6th quarter of a second						334 cm

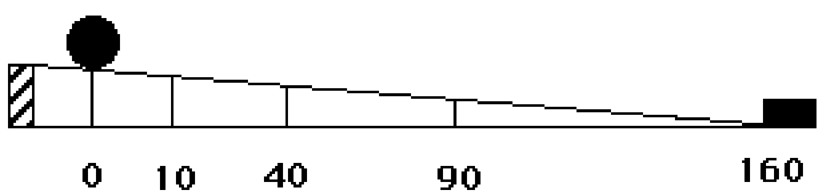
Since the time interval between plunks in the waste can for string CD is .25 second, the string is speeding up 61 cm per quarter second for every additional quarter second. Written another way 61 cm / .25 sec = 244 cm/sec. Remember the velocity is changing 244 cm/sec every .25 sec or in one whole second the velocity would have changed (4 x 244) a total of 976 cm/sec. This is written as 976 cm/sec/sec or 976 cm/sec^2. If they don't believe that the weight is accelerating, ask them from which height they would **not** want to catch a dropped baseball, from a height of one meter? from ten meters? or from 1000 meters? The ball weighs the same each time but the speed of the ball **is** increasing with time.

E. To facilitate the measurement of a falling body where the speed is constantly increasing, Galileo slowed down the motion by using an inclined plane. Because the change in speed occurs more slowly it is easier to measure accurately.

1. Set up a ramp with the angle of the incline at about 10° to the table.
2. Measure the length of the ramp and place a piece of tape at the half-way point.
3. Practice releasing a ball so that it can be released uniformly throughout the rest of the experiment. Using a stopwatch measure the time required for a ball to travel from the release point at the elevated end to the end of the ramp. Repeat this measurement two more times and determine the average time for this length.
4. Now determine the average time for the ball to roll from the same release point to the half-way mark.
5. What conclusion can be reached about the velocity of the ball through the first half of the trip and its velocity through just the second half of the trip? [The velocity for the first half of the trip is much less than for the last half of the trip. The ball is therefore accelerating.] Is the ball accelerating as it rolls down the ramp? What evidence do you have?
6. Repeat steps 3-5 with an angle of only 5° to the ramp. What happens to the acceleration as the angle is changed? [The acceleration is decreased with the smaller angle.]
7. Predict what will happen if a new ball (a heavier one) is allowed to roll down the ramp? Will its acceleration be greater, smaller, or the same as that of the lighter ball? [The mass of the ball has no effect on the acceleration, assuming all other factors remain the same.] What evidence do you have?

F. Readjust the inclined plane to an angle of 10°. This time mark off the ramp at 10 cm intervals, **starting from the bottom**. The plank should be at least 170 cm in length.

1. Release the ball from the 10 cm mark and record the amount of time it takes to roll to the end. Call this amount of time <u>one time unit.</u> (This should be done at least three times and an average value used in subsequent parts of the experiment.)



2. Predict from where the ball would have to be released to take twice as much time to roll down to the end of the plank. How does this distance needed for <u>two time units</u> compare with the distance required for only one time unit? [It is NOT twice as far. It will have to roll four times as far to take twice as much time.]
3. Predict from where the ball would have to be released to take three times as long as when released from the 10 cm mark to reach the end. How does this distance needed for <u>three time units</u> compare with the distance required for only one time unit? [It will have to roll nine times as far to take three times as

much time.]

4. Predict from where the ball would have to be released to take four times as long as when released from the 10 cm mark to reach the end. How does this distance needed for four time units compare with the distance required for only one time unit? [It will have to roll sixteen times as far to take four times as much time.]

Time	Predicted Distance	Actual Distance	Ave Speed cm/sec	Change in Speed
	10 cm	10 cm		

5. Is there a constant change in speed for every subsequent time unit? In other words, did the speed increase the same amount in going from time #1 to time #2 as it did from time #2 to time #3, etc.? This constant change in speed per each time unit is the acceleration.

CONCEPT EXTENSION

A. If a ball were dropped from a cliff and had both an odometer and speedometer attached to it, by how much should its speed change each second? How far would it go each second? The acceleration due to gravity is about 10 m/sec^2.

Elapsed Time (sec)	Odometer (m)	Speedometer (m/sec)	Distance Covered During the Last Second (m)
0	**0**	**0**	**0**
1	**5**	**10**	**5**
2	*20*	*20*	*15*
3	*45*	*30*	*25*
4	*80*	*40*	*35*
5	*125*	*50*	*45*
6	*180*	*60*	*55*

1. Can you devise a way to check the numbers that you think should go in the table? Remember, there is a constant acceleration of 10 m/sec every second.
2. Do not encourage students to use canned formulas to arrive at the answers.

B. When a ball is thrown straight upward, by how much does the speed **decrease** each second? After it reaches the top and begins its return downward, by how much does its speed **increase** each second? How much time is required in going up compared to coming down? [It decreases at the same rate in an upward direction as it increases in a downward direction. It decelerates at -10 m/sec^2 upward and accelerates at +10 m/sec^2 downward.]

1. Devise an experiment to show that your answers make sense. Since it might be difficult to throw a ball with the same force each time, you might want to think of some other uniform way of projecting an object upward. [Ping pong ball guns are good; guns that shoot rubber darts; any kind of spring-loaded projection device that you can find at the toy store.]
2. If you are riding your bike along at 20 mile/hr and you put on your brakes, what starts happening to your velocity? Are you accelerating? Are you decelerating? How are acceleration and deceleration related?
3. Experimentally determine what the acceleration is for a student riding his/her bike when they slam on the brakes and leave them locked until he/she comes

to rest.

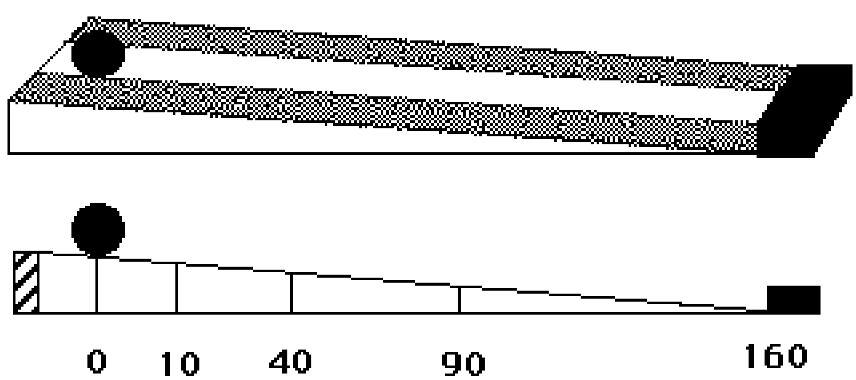
ACCELERATION (Inclined Plane)

PROBLEM PRESENTATION / EXPLORATION

A. In the experiment where we looked at the acceleration due to gravity the measurement of very short times was required because the acceleration due to gravity is pretty large. Hundreds of years ago Galileo found out that you could "slow down" the acceleration by not letting things fall straight down. Rather, he made them "fall" at an angle; in other words he let them fall down an inclined plane. In this way they didn't cover as much distance in a given time interval and the change in speed was slower. We are going to let a rubber ball roll down an inclined plane and measure the time and distance it requires to make the trip. As we saw in the domino experiment we can determine the average speed of a moving object by dividing the distance covered by the time required. In addition to computing the average speed we will want to examine the change in speed as the ball covers different parts of the trip. Just as a car accelerates, meaning that it goes slower in the first second of its trip than it does in the fifth second of its trip, we will want to examine the ball and compute its average speed during each successive part of the trip to confirm that the ball is accelerating as it moves down the inclined plane. Then as in the experiment on acceleration due to gravity we will compute the change in velocity and call this acceleration. The purpose of this experiment is to allow the students to learn how to determine acceleration, since we are going to need to know how to do this for the Newton's Second Law experiment that we will do later.

B. Setup

1. Set up a ramp (about two meters long) with the angle of incline at about 5° with respect to the table top. Put a block of wood at the bottom of the ramp to stop the ball. Lay down some old "Hot Wheels" track on top of the ramp.
2. Measure down from the top about 20 cm and draw a zero line. Place tape marks at 10 cm, 40 cm, 90 cm, and 160 cm measured down from the zero line.
3. Use a ruler or pencil to hold the ball at its starting position then pull it away quickly to release the ball.
4. Place a wooden block or book at the "finish" line to stop the ball from rolling off the ramp. You might also be able to hear when it hits the block and aid in knowing when to click the stopwatch.



5. Use a stopwatch to measure the time it takes the ball to cover the various distances.
6. Practice removing the ruler or pencil so that a smooth start can be carried out. Also practice using the stopwatch so that it can be reliably started and stopped at the beginning and finish of the trip.

C. Data Collection

1. Release the ball first from the zero position and time it to the 10 cm position, then to the 40 cm position, to the 90 cm, and finally to the 160 cm position. Make at least three time determinations for each distance and enter them into

TABLE 1. Average the three times and use this average in further calculations and graphs.

TABLE 1

Distance (cm)	Time (sec)			
	Trial 1	Trial 2	Trial 3	Average
10				t_1 =
40				t_2 =
90				t_3 =
160				t_4 =

2. Compute the amount of time needed for the ball to travel between each of the release points. What conclusion can you draw about the time interval between any two consecutive release points?

TABLE 2

Finish Point (cm)	Average Time (sec)	Time Differences Between Successive Intervals (sec)	Distance Covered in this Time Interval (cm)
10	t_1 =	t_1-t_o =	(10-0) = 10
40	t_2 =	t_2-t_1 =	(40-10) = 30
90	t_3 =	t_3-t_2 =	(90-40) = 50
160	t_4 =	t_4-t_3 =	(160-90) = 70

3. If the data were collected carefully, the time differences between successive intervals should be the same. Since for an equal amount of time, the ball is traveling farther as it rolls down the ramp (10 cm during the first interval, 30 cm more during the second interval, 50 cm more during the third interval, and 70 cm more during the last interval), the average speed must be getting greater. This is just another way of saying that the ball is accelerating down the ramp. Remember, acceleration is the rate of change of velocity or the change in velocity per change in time.

CLASS RESPONSE / CONCEPT INVENTION

A. Computing Acceleration

1. As we have already seen average speed can be computed by dividing the distance traveled by the time it took. (We will call this Method A.)
2. Another way of finding the average speed for a certain portion of the trip is to take how fast something is going at one point of the trip add it to how fast it is going at some point later in the trip and divide it by 2. In other words, we find the average speed by finding the sum of the initial speed and final speed and then dividing by two. (We will call this Method B)
3. For the ball rolling down the entire ramp, the average speed can be determined by either of the methods above, in fact they are the same because the .$speed_{(initial)}$ is zero.
4. The second method does have another feature that is sometimes useful. Lets look at the formula that represents this method.

$$\frac{speed_{(final)} + speed_{(initial)}}{2} = \text{Average speed}$$

If we use a little simple algebra to rearrange it, we get:

$$2\ (\text{Average speed}) - \text{speed}_{(\text{initial})} = \text{speed}_{(\text{final})}$$

5. We now can calculate the speed at the end of any distance interval for which we know the following: how fast it was going at the beginning of the interval, and what its average speed was through that interval.
6. Since we know how much time it takes to travel the first 10 cm (see TABLE 1) and that it takes the same amount of time to travel the next 30 cm and that it takes the same amount of time to travel the next 50 cm and that it takes that same amount of time to travel the last 70 cm (see TABLE 2), we can start to fill in the TABLE 3.

TABLE 3

Time (sec)	Total Distance Traveled (cm)	Average Speed (cm/sec)	Speed$_{(\text{final})}$ (cm/sec)	Acceleration by Method #1* (cm/sec^2)
	10			
	40			
	90			
	160			

7. Acceleration is the change in speed divided by the change in time. In TABLE 3 above we have calculated the velocity of the ball when passing by the 10 cm mark as well as its velocity when passing by the 40 cm, the 90 cm, and the 160 cm marks. With this information there are two methods for calculating the acceleration.

<u>*Method #1</u> says that the speed of the ball when crossing one of the tape marks minus the speed of the ball at the starting line divided by the amount of time need to reach the tape mark gives us the acceleration

$$\frac{\text{speed}_{(\text{final})} - \text{speed}_{(\text{initial})}}{\text{time}} = \text{Acceleration}$$

Since the speed$_{(\text{initial})}$ is always zero we can find the acceleration of the ball by dividing its speed going past one of the tape marks by how long it took to reach that spot. The units for acceleration will be (cm/sec) / sec. We read these units as cm per sec^2. Now calculate the acceleration for the ball going from the starting line to each of the tape marks and enter your calculation into the TABLE 3.

<u>Method #2</u> uses the same formula as was used in Method #1. However, initial speeds other than zero can be inserted into the formula. If we wanted to calculate the acceleration through each of the distance intervals between tape marks, all we would need to know was the speed the ball had when crossing each mark.. From TABLE 3 we have the speed$_{(\text{initial})}$ at the beginning of each interval. Notice that if we start from the top of the ramp, the speed$_{(\text{final})}$ for the first interval is the speed$_{(\text{initial})}$ for the second interval. In turn the speed$_{(\text{final})}$ for the second interval will be the speed$_{(\text{initial})}$ for the third interval, and so on. Now calculate the acceleration for the ball traveling between each of the tape marks.

TABLE 4

Distance Interval (cm)	Time Differences Between Successive Intervals (sec)	Speed$_{(final)}$ (cm/sec)	Acceleration by Method #2 (cm/sec^2)
(10-0) = 10	t_1-t_o =		
(40-10) = 30	t_2-t_1 =		
(90-40) = 50	t_3-t_2 =		
(160-90) = 70	t_4-t_3 =		

8. You should get roughly the same acceleration for all of the distance intervals regardless of whether you used method #1 or method #2. In other words **the acceleration that the ball experiences is a constant throughout the whole trip**. This is an extremely difficult concept for most students to accept. The mix up the fact that the velocity is constantly increasing but the acceleration is remaining constant. The reason is that they forget that acceleration is the change in velocity per unit time. This change is remaining constant throughout the entire trip down the ramp.

B. Will balls of different mass roll down the ramp with different accelerations?
1. Obviously the way to answer this question is to have some of the students use balls with different masses.
2. Before you do this, however, ask them what they think will be the answer. I bet most of them will tell you that the heavier ball will have a greater acceleration.
3. **The mass of the ball has no effect on the acceleration**. Many students will not believe this is true before testing it out. Some will even not accept this after the experiments have been done.

CONCEPT EXTENSION

A. What happens to the acceleration if the angle of the ramp is increased?
1. Repeat the same experiment with only one change. Have one group raise the ramp so that the angle that the board makes with the table is 10°. Have another group raise it to 15°.
2. The acceleration increases as the angle increases.
3. Ask the students whether they think that there is an upward limit to the acceleration that the ball could reach. If someone relates this experiment back to the one on acceleration due to gravity and they picture the angle of the board getting steeper and steeper so that it is straight up and down, they might see that the upward limit is the acceleration due to gravity (9.8 m/sec^2).

B. If you consult your physics book you will find another formula with acceleration, distance, and time in it. If you have students who have had algebra, they could invent this formula from the ones we used to fill in our tables.

1. The standard formula is $d = \frac{at^2}{2}$

2. See if any of your students can come up with this equation from the ones we used.

$$\frac{d}{t} = \text{Average speed}$$

$$\frac{\text{speed}_{(\text{final})} + \text{speed}_{(\text{initial})}}{2} = \text{Average speed}$$

$$2\ (\text{Average speed}) - \text{speed}_{(\text{initial})} = \text{speed}_{(\text{final})}$$

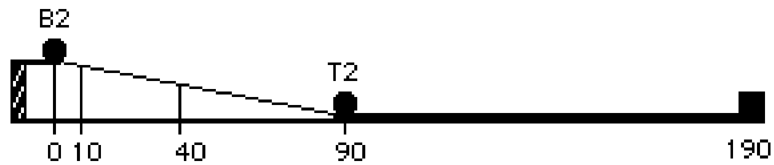
$$\frac{\text{speed}_{(\text{final})} - \text{speed}_{(\text{initial})}}{t} = \text{Acceleration}$$

NEWTON'S SECOND LAW OF MOTION

PROBLEM PRESENTATION / EXPLORATION

A The purpose of this investigation is to formulate some idea about what effect a moving steel ball has on a stationary target ball.

1. Set up a one meter long ramp (old "Hot Wheels" track resting on a wooden board) with the angle of incline at about 5° with respect to the table top. Measure 10 cm from the top of the ramp and draw a starting line and label it 0 cm. Place a tape marker at the 40 cm and 90 cm marks. The 90 cm mark should coincide with the end of the ramp.
2. Place another one meter long track flat on the table so that it extends from the bottom of the ramp. Place a wooden block at the end of this second section of track to stop the rolling balls. The entire course is now 190 cm long.



3. Place the target ball (T2) at the bottom of the ramp at the position where the horizontal track attaches to the ramp. Before you release the smallest steel ball (B1) from the starting line of the ramp and allow it to roll down the ramp and hit the target ball, predict what will happen.
4. As in the previous experiment where we learned how to measure acceleration, determine what will be the acceleration of B1 is as it rolls down the ramp. (See the table in the CONCEPT INVENTION section of that experiment if you need to review how to compute the acceleration.) What value for the acceleration of B1 did you obtain? What happened to the target ball?

TABLE 1

Average Time (sec)	Total Distance (cm)	Average Speed (cm/sec)	$Speed_{(final)}$ (cm/sec)	Acceleration cm/sec^2
	10			
	40			
	90			

5. Replace B1 with the medium sized steel ball (B2). Place it at the starting line of the ramp, and roll it down the ramp at the same target ball (T2). What would you have to do to determine the acceleration of B2 down the ramp? [Nothing, remember we said that with all other conditions remaining constant that the mass of the ball doesn't effect the acceleration of the ball. Acceleration is constant.] Note what happens to the target ball when B2 hits it. Compare to when B1 hit it.
6. Replace B2 with the largest steel ball (B3), place it at the starting line of the ramp, and roll it down the ramp at the same target ball. Note what happens to the target ball when B3 hits it.

B. Now that you have had some experience with this experiment, repeat the experiment first with B1 but time how long it takes the target ball to cover the 100 cm distance. Repeat this three times so that an average time can be computed. which will then be entered in TABLE 3 (p. 3) for use later

B1 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

Now do the experiment with B2. Repeat this three times so that an average time can be computed. Enter this average in TABLE 3.

B2 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

Now do the experiment with B3. Repeat this three times so that an average time can be computed. Enter this average in TABLE 3.

B3 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

C. What general conclusion can you formulate about how the target ball reacted when hit by each of the other three balls? [The larger the mass of the impacting ball, the faster the target ball covered the 100 cm.] In all of these experiments the target ball (T2) has been the same mass.

CLASS RESPONSE / CONCEPT INVENTION

A. Constant Mass and Changing Force

1. According to Newton's First Law, an object at rest remains at rest unless it is acted on by an unbalanced force. During the PROBLEM PRESENTATION we saw that the target ball was always at rest and when acted on by the different forces of B1, B2, and B3 began to move across the horizontal track at different rates of speed.
2. The force imparted to the target ball can be found by multiplying the mass and acceleration of B. Fill in the table below.

TABLE 2

Balls	Mass (g)	Acceleration* (cm/sec^2)	Force ($g\ cm/sec^2$)
B1			
B2			
B3			

* Remember the acceleration for B1, B2, B3 will be the same because acceleration is not dependent on mass.

3. Now lets turn our attention to the target ball and find the acceleration it had as it moved horizontally across the table when hit by B1, B2, and B3. The same type of calculation used to fill in TABLE 1 can be used to fill in TABLE 3 at the top of the next page.

TABLE 3

Impact Ball	Average Time of Target Ball (sec)	Distance Target Ball Moved (cm)	Average Speed of Target Ball (cm/sec)	Speed$_{(final)}$ For Target Ball (cm/sec)	Acceleration of Target Ball (cm/sec^2)
B1		100			
B2		100			
B3		100			

4. Let's sum up what we have found about force, mass, and acceleration for the target ball.

TABLE 4

Impact Ball	Force Imparted by Impact Ball (g cm/sec^2)	Mass of Target Ball (T2) (g)	Acceleration of Target Ball (cm/sec^2)
B1			
B2			
B3			

5. Focus on the force and acceleration columns. What happens to the acceleration when the force goes up? What kind of relationship is this in mathematical language? [This is called a direct relationship. As one variable goes up, the other one goes up proportionally. In other words, if you work twice as long, you expect twice as much pay.] So we can say that **if mass is held constant, that the force and acceleration are directly proportional**.

B. Constant Force and Changing Mass

1. There are only two more sets of collision experiments that we need to do to finish up this part of the experiment. We need to use B2 to hit two different target balls. The target ball that we have used for all of the experiments above has been the same size and mass as B2. What do you think would happen if we hit a target ball the same size and mass as B1 with B2? What do you think would happen if we hit a target ball the same size and mass as B3 with B2? Just to keep everything straight lets call the target ball that we have used in all the other experiments T2 (because it is the same as B2). Lets call the target ball that is the same as B1, T1; and lets call the target ball that is the same as B3, T3.
2. Repeat the experiment you did above in the PROBLEM PRESENTATION for B2 but substitute T1 for T2 that you used there. Remember, you are still using B2 for the impact ball.

B2 (T1)	t_1 =	t_2 =	t_3 =	t_{ave} =

Impact Ball	Average Time of T1 (sec)	Distance T1 Moved (cm)	Average Speed of T1 (cm/sec)	Speed$_{(final)}$ For T1 (cm/sec)	Acceleration of T1 (cm/sec^2)
B2		100			

3. Repeat the experiment you did above in the PROBLEM PRESENTATION for B2 but substituting T3 for T2 that you used there. Remember, you are still

using B2 for the impact ball.

B2 (T3	t_1 =	t_2 =	t_3 =	t_{ave} =

Impact Ball	Average Time of T3 (sec)	Distance T3 Moved (cm)	Average Speed of T3 (cm/sec)	Speed$_{(final)}$ For T3 (cm/sec)	Acceleration of T3 (cm/sec^2)
B2		100			

4. Let's sum up what we have found about force, mass, and acceleration for the target balls that were hit with the same force.

TABLE 5

Target Ball	Force Imparted by Impact Ball* (g cm/sec^2)	Mass of Target Ball (g)	Acceleration of Target Ball (cm/sec^2)
T1			
T2			**
T3			

* This will be the constant. B2 imparted the same force each time.
** This value can be found in TABLE 3.

5. Focus on the mass and acceleration columns. What happens to the acceleration when the mass goes up? What happens to the mass when the acceleration goes down? What kind of relationship is this in mathematical language? [This is called an indirect or inverse relationship. As one variable goes up, the other one goes down proportionally. In other words, if you drive your car twice as fast, you get where you are going in half the time.] So we can say that **if force is held constant, that the mass and acceleration are inversely proportional**.

C. Constant Acceleration and Changing Mass
1. Lets see if we can figure out what should happen here without actually doing another experiment.
2. If we think about it we have already done an experiment almost identical to this. In parts A and B above we looked at the acceleration, mass, and force exerted on the target ball and its subsequent motion along the horizontal track. But the ramp works the same way as the horizontal track except that gravity imparts the force instead of another ball hitting it to impart the force.
3. If you think back to the experiment on Acceleration (Inclined Plane) we found that the acceleration remained constant as balls with different masses rolled down the ramp. We found out in TABLE 2 that the force of impact was found by multiplying the mass and acceleration; and that the larger the mass, the larger the force.
4. So putting all of this together, we see that **if the acceleration remains constant, the force is directly proportional to the mass**. See the table in CONCEPT INVENTION part A2 to review this.

D. Now how can we put together what we have found out in parts A, B, and C?

Part A: **if mass is held constant, the force and acceleration are directly proportional.**

Part B: **if force is held constant, the mass and acceleration are**

inversely proportional.

Part C: **if the acceleration remains constant, the force is directly proportional to the mass.**

The only way that all three of these conclusions from parts A, B, and C can be true is to put them together like this:

$$F = m \bullet a$$

This is one of the most famous equations in all of science. It is known as Newton's Second Law of Motion.

As in any equation, if you know two of the variables, the third one can be computed from the equation. Lets say that F = 100 and m = 20, what must the value be for **a**? What multiplied by 20 gives 100? Obviously **a** must be 5.

$$F = m \bullet a$$
$$100 = (20) \bullet (5)$$

1. Okay, lets see whether part A holds true for Newton's Second Law. If mass is held constant (20), what happens to **F** if **a** is doubled? Well, 20 x 10 must give us 200. Did **F** double as **a** doubled? YES!!
$$200 = (20) \bullet (10)$$
2. Lets see whether part B holds true. If force is held constant (100), what happens to **m** if **a** is doubled? Well, 10 x what number will give 100? The value that for **a** must be 10 so that 10 x 10 can equal 100. Did **m** get half as big when **a** doubled? YES!!
$$100 = (10) \bullet (10)$$
3. Finally, lets see if part C holds true. If acceleration is held constant (5), what happens to **F** if **m** is doubled? Well, 40 x 5 is 200. Did **F** double as **m** doubled? YES!!
$$200 = (40) \bullet (5)$$
4. What this says is that if we know any two of the three variables for the balls rolling down the ramp, we can find the other one from **F = ma**.

CONCEPT EXTENSION

A. How could you go about finding the acceleration of the target ball T2 if the impact ball B2 were rolled down the ramp but the ramp had been raised so that it made and angle of 10° with the table instead of 5°.
   1. Do you think it would be twice as much as you found when the angle was only 5°?
   2. What would be the fewest steps you would have to carry out to find out the answer? [We want the a of the target ball. We already know the mass of the target ball. So the only thing we need to use F = ma is the force imparted to the target ball by B2. To find this we need the mass of B2 (which we already know) and the acceleration of B2 down the steeper ramp. Therefore all we have to do is start the ball at the starting line and measure the time it takes to reach the bottom of the ramp. From knowing that it traveled 90 cm in time t we can get the average speed. Knowing the average speed we can calculate the speed at the bottom of the ramp. Taking the final speed and subtracting the initial speed (which was zero at the top of the ramp) and dividing by t we get the acceleration. It should only take about 10-15 minutes to get the information to solve this problem. This will really give the students a chance

to apply what they have done in this experiment.]

B. Can they extend F=ma to a slightly different setting?

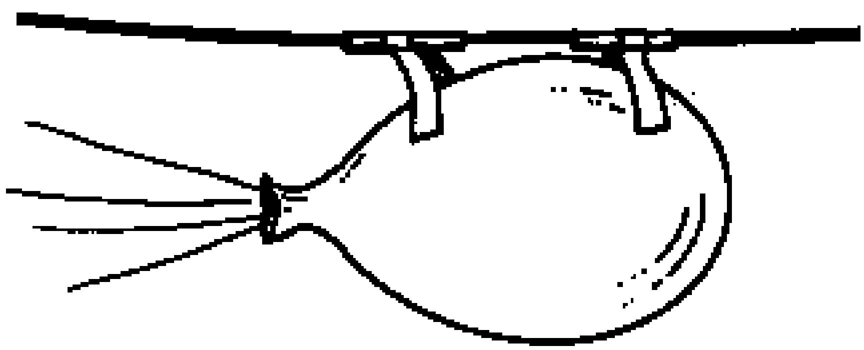
1. Place a student on roller skates. The skater must hold a spring balance by its hook.
2. A second student must grasp the other end of the spring balance and exert a constant pulling force on the skater . The puller must maintain a constant force throughout the distance over which the skater is pulled. Do not pull harder to get going.
3. What is the acceleration experienced by the student on the skates?
4. If a student who weighed more than the first student put on the skates, what would his acceleration be, if the puller pulled with the same force?
5. Just out of curiosity, now that the acceleration for a skater has been found using F=ma, would you get the same value if you measured off on the floor distances similar to those you marked off on the ramp and measured the time it took for the skater to reach these marks. To make it easier to time use 900 cm, 400 cm, and 100 cm instead of 90 cm, 40 cm, and 10 cm. The calculations could be done the same way that they were done in the experiment named Acceleration (Inclined Plane).

NEWTON'S THIRD LAW OF MOTION

PROBLEM PRESENTATION / EXPLORATION

A. Balloon Race

1. Let's have a balloon race.
2. Divide the class into groups and give each group a balloon, a plastic straw, some tape and a 10 meter length of fishing line.
3. The purpose is to figure out how to shoot the balloon from the back of the room to hit the blackboard at the front of the room, using the fishing line as a track for the balloon to follow.
4. The race will be timed and a winner determined.
5. The fishing line will be attached to the top of the blackboard. The other end may be held in a team member's hand so that the line is taut throughout the time of the flight. The line may not be moved up and down to help the balloon move toward the blackboard, however.
6. After blowing up the balloon and pinching off the mouth, the straw should be taped to the balloon.
7. Still holding the balloon closed, the fishing line should be threaded through the straw.



8. Upon releasing the balloon it should take off up the fishing line toward the target.

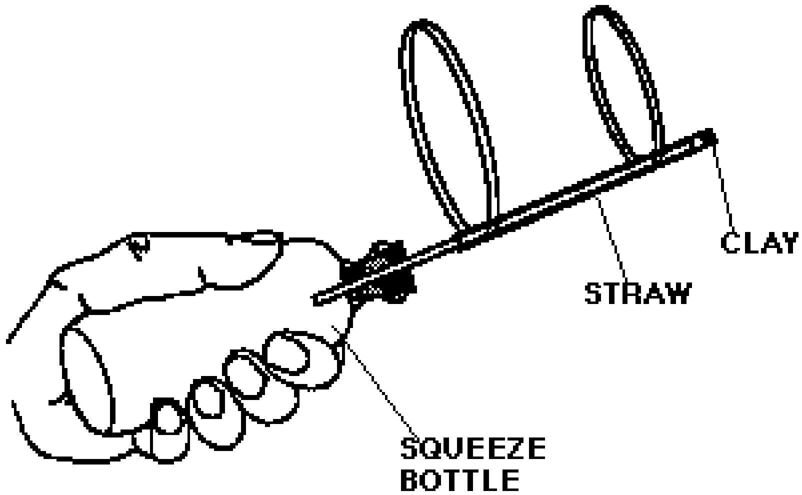
B. Straw Rockets

1. If you don't want to use fishing line to restrict the path of the balloon rocket, a straw rocket can be constructed that needs no string or balloon. Instead, a bottle launcher is required and can be made from a flexible plastic bottle.
2. A piece of glass tubing should be inserted into a rubber stopper.

CAUTION: Either you should insert the glass tubing ahead of time, or you must provide careful instruction on this process. Inserting glass into rubber stoppers and the resulting accidents that occur from the glass snapping are very common and dangerous.

The rubber stopper should fit the bottle tightly. The length of the glass tubing should be about 30 cm and its diameter must be smaller than the straw that will be used in the rocket.

3. The straw rocket is made by tightly closing one end of the straw with a wad of modeling clay. Tape two paper loops to the straw. The smaller one should be toward the end with the clay and the larger one attached close to the other end. These give stability to the projectile.
4. Slip the straw rocket over the glass tubing of the launcher.
5. Aim the rocket at the blackboard and squeeze the bottle with a sudden motion.



CLASS RESPONSE / CONCEPT INVENTION

A. Common Misconception

1. Nine out ten people would probably explain the balloon rocket's motion in the following way: "The air issues from the back of the balloon, pushes against the air at the rear and propels the balloon rocket forward."
2. It is said that when Robert Goddard, one of the modern day fathers of space travel, proposed that rockets could be sent to the moon, he met strong opposition. Many told him that this would be impossible since everyone knows that there is no air in outer space and the rocket could not work unless it had air to push against.
3. Since rockets do work in outer space, the exhaust gases apparently don't push against air to propel them forward. How do we explain their motion?

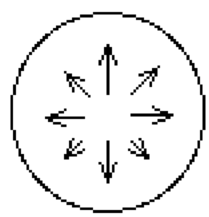
B. Demonstration

1. Obtain a cardboard box and remove the top. Cut out a flap (X) according to the picture below.

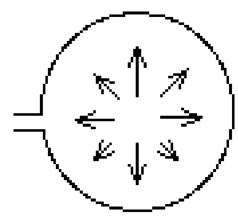
2. Begin the demonstration with the flap bent upward with the box resting on the table or floor.
3. Take a meter stick and move it repeatedly from A to B to A and also from C to D to C in rapid motion. This is to simulate the molecular motion inside the balloon where gas molecules hit all sides with about equal frequency.
4. Because balanced collisions (and thus balanced forces) are operating on each wall of the box in the four main directions equally, the box does not move very far, if at all, in any one direction. This would be analogous to the balloon that is sealed sitting motionless on the table.
5. Now open the flap X and repeat the hitting action. This time the forces at A and B still balance each other but the "molecules" striking the D wall are now unbalanced by no collisions at C. Consequently, the box moves forward (in the direction of D). This is analogous to the balloon with its nozzle open that results in forward motion.

C. Conclusion

1. It appears that the forward motion of the box is due to the "molecules" inside the box pushing on the box resulting in the forward motion, not the "molecules" pushing backward on the air outside the box.
2. Many students are going to have difficulty with accepting this idea. The forward propulsion of the balloon is due to the molecules inside the balloon pushing on the wall of the balloon not due to them rushing out the rear of the balloon and pushing on the outside molecules of air.



NO MOTION OF BALLOON



BALLOON MOVES TO RIGHT

3. In the case of the straw rocket, the air from the bottle launcher coming out of the glass tubing pushes forward on the blob of clay sending the rocket forward.
4. In both types of rockets the air inside the system pushing on the rocket sends it forward. But at the same time the rocket (balloon or wad of clay) is pushing back on the air!! This is what accounts for the air coming out the back.
5. In a general way we sum this up by saying that whenever one object exerts a force on another one, the second one exerts an equal and opposite force on the first one. Note that the two forces are not on the same object, however. This is generally known as **Newton's Third Law of Motion**.

D. Further examples

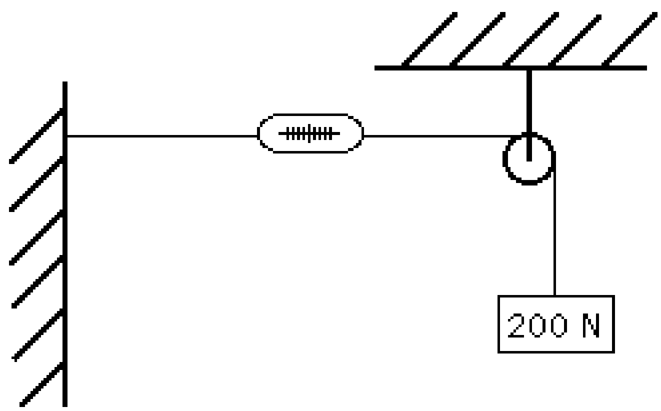
1. If you push against a wall, the wall pushes back on you with an equal force. It this wasn't true and you pushed harder on the wall, the wall would move. If, on the other hand, the wall pushed back harder on you, you would fall over backwards!
2. When you go swimming, you push the water backward with your arms, and the water pushes you forward with an equal force.
3. When you walk across the ground, you push against the ground and the ground pushes against you.
4. When the tires of a car push against the road, the road pushes back on the tires.
5. When the gases that come from combustion of the fuel in a rocket push

forward on the rocket the rocket pushes backward on the gases which move backward out of the rocket.

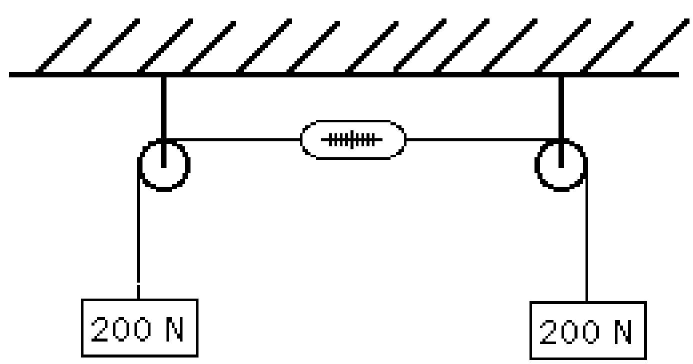
6. What happens when you fire a rifle? The rifle acts on the bullet and the bullet acts on the rifle. The bullet goes forward and the rifle kicks backward.
7. In talking about Newton's Third Law it is often stated that for every action there is a reaction. What is often omitted is that the action force is on one object and the reaction force is on a different object. A simple method of determining these forces is to reverse the subject and the direct object of the sentences describing the forces.
   - a.) The <u>boy</u> pushed the <u>wall</u>. The <u>wall</u> pushed the <u>boy</u>.
   - b.) The <u>ground</u> pushed <u>me</u>. <u>Me</u> pushed the <u>ground</u>
   - c.) The <u>rocket</u> pushed the <u>fuel</u>. The <u>fuel</u> pushed the <u>rocket</u>.

E. Tug-of-War

1. Lets assume that a boy is pulling by way of a rope on a wall with a force of 200 Newtons. This is almost enough force to break the rope but not quite.
2. Another boy equally as strong as the first boy removes the rope from the wall and now both boys pull in opposite directions on the rope. Will the rope break? [The rope will not break, however this is hard to convince many students of. Boy 1 is pulling on boy 2 while boy 2 is pushing on boy 1. The rope serves only to transfer the force.]
3. Lets use a spring balance, a pulley, a weight and some fishing line to illustrate this. See diagram below.



4. Have students predict what the reading on the spring balance will be. Most students will correctly predict 200.
5. Set up the situation depicted below and have students predict what the reading on the spring balance will be this time. If there are no guesses, give them three choices: 0, 200, or 400. If some still contend that it should be 400, ask them if the spring balance would read any differently if the left-hand pulley and weight were removed and the string was attached to the wall.

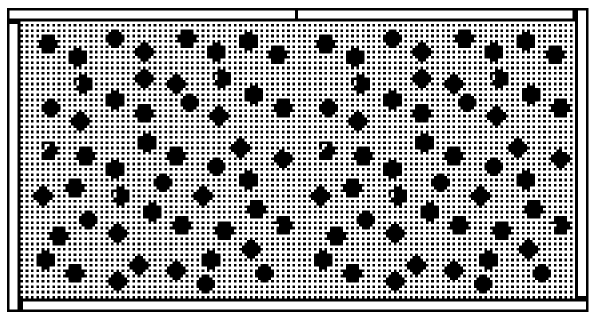


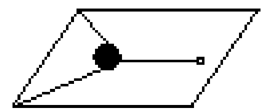
6. Remember these are examples of Newton's Third Law. In the first diagram the weight is pulling on the spring balance with a force of 200 while the spring balance is pulling on the weight with a force of 200. The force of 200 is transmitted through the spring balance to the wall. In other words the force of 200 of the weight is really pulling on the wall while in reality it is the wall pulling with a force of 200 on the weight. In the second diagram, the wall has just been replace by another weight pulling with a force of 200. This is no different than the wall pulling with a force of 200 as in the first diagram.

CONCEPT EXTENSION

A. The Rubber Band Roller-skate

1. Cut a rubber band and attach the two ends to the front sides of a roller-skate. (In place of a skate you could use a piece a wooden board resting on a large number of marbles. Use thumbtacks to attach the rubber band to the front of the board. Six meter sticks can be taped to the table to confine the marbles to provide a relatively friction-free surface upon which the board can ride. Obviously, if you have an air table, use it!!)





2. Tie a string to the center of the rubber band. Pull it back, (this obviously stretches the rubber band), and attach the string to the back of the skate. If using the board/marbles setup, attach the string to back of the board with another thumbtack.
3. Place a lump of clay at the center of the V made by pulling back the rubber band.
4. Predict what will happen when either the string is cut or a candle is put to the string to burn through it. What will happen to the clay? What will happen to the skate or board? If either, or both, moves, in which direction(s) will the motion be? How does Newton's Third Law explain what happens?
5. [The skate or board should go in one direction and the clay go in the other direction. the clay will shoot off fast while the motion of the skate or board will be much slower. The potential energy built up in the skate by stretching the rubber band pushes on the clay while at the same time (if we really believe in Newton's Third Law) the clay will push back with equal force on the skate. The reason the skate doesn't go as fast as the clay even though forces of equal magnitude are applied to the clay and the skate has to do with the larger mass of the skate. If the clay would weigh as much as the skate, then the clay and the skate would have equal speeds.]

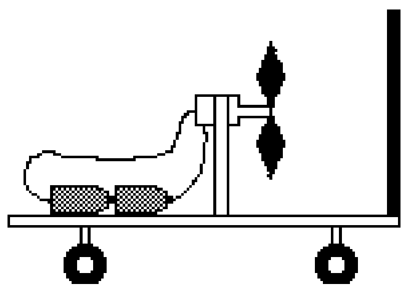
B. Questions That Make You Go Hummmm

1. Why can you exert greater force on the pedals of a bicycle if you pull up on the handlebars? [When you pull up on the handlebars, the handlebars push down on you, and this force is transmitted to the pedals.]
2. Lets say you are weighing yourself on a set of bathroom scales. You are standing next to the sink in the bathroom. If at the same time while you are standing on the scales you reach under the sink and pull up on the sink, will the scales register your weight to be more or less than what they would register if you didn't pull up on the sink?

3. Lets repeat the question in the situation above except that you push down on the top of the sink instead of pulling up on the bottom of the sink. What will your weight be this time compared to what it would be if you did not push down on the sink?
4. [In #2 the scales would register heavy. Since you are lifting up on the sink, the sink is pushing down on you with an equal but opposite force and this would be transmitted to the scales. In #3 the scales would register lighter. Since you are pushing down on the sink it is pushing up on you with an equal force which tends to lift you up off the scales some and therefore they register light.]

C. Will It or Won't It Work

1. Obtain some type of device with wheels. Some options would be a roller-skate, a toy car, a dynamics cart, etc.
2. You also need some type of portable fan, possibly like one of those battery operated ones that you can attach to your visor in your automobile. If you wanted to do this on a large scale you could use a movable chair with wheels and a large electric fan with a long extension cord.
3. Affix to the rear of the cart a piece of cardboard (10 cm x 10 cm) that is perpendicular to the bottom of the cart.
4. Aim the fan at the sail (the cardboard).

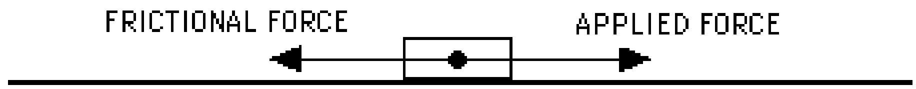


5. Have students predict what will happen when the fan is turned on.
6. Have them predict what will happen if the sail is removed and the fan turned on.
7. Have the students explain what happens. This may prove more difficult for them to explain even though their predictions will probably be correct.

FRICTION

PROBLEM PRESENTATION / EXPLORATION

A. Frictional force is a force acting in the opposite direction of an object's motion. If the object is at rest, the frictional force (static friction) is equal to the force it takes to just get the object moving. If the object is in motion, the frictional force (sliding friction) is the force it takes to keep the block moving at constant velocity (this means that the acceleration is zero.)



1. At least four different blocks should be provided at each station. Two of the blocks must be of the same kind, only differing in weight. The other blocks can be of the same or different types of wood.
2. Weigh each of the wooden blocks by suspending them, individually, from a spring balance.
3. Attach a spring balance to each of the different wooden blocks and pull it horizontally over the table top. Determine the amount of force to overcome a block's inertia and start it moving. This is the static frictional force.
4. Attach a spring balance to a each of the wooden blocks and determine the amount of force needed to keep each block moving at a constant velocity. This is the sliding frictional force.
5. **Is there any relationship between the weight of the block and the frictional force for the same type of wood?**

Block #	Force to Get Going	Force at Constant Velocity	Weight of Block	μ_{static}	$\mu_{sliding}$
Example	100 N	30 N	200 N	0.5	0.15

CLASS RESPONSE / CONCEPT INVENTION

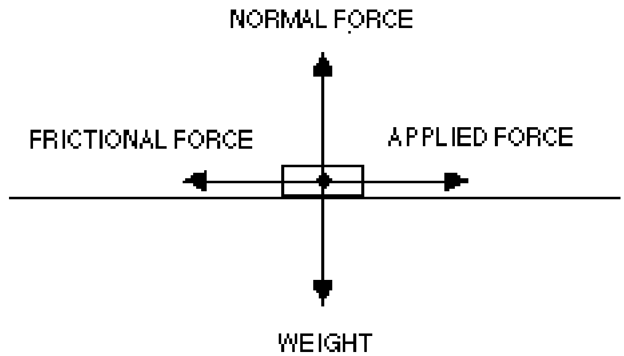
A. A ratio between the frictional force and a force equal to the weight produces a relationship known as the coefficient of friction. In its simplest form:

Frictional Force
44444444 = μ or Frictional Force = μ (Weight).
Weight

But really

Frictional Force
44444444 = μ or Frictional Force = μ (Weight).
Weight

The normal force is the perpendicular force with which the supporting surface pushes on the sliding object. The magnitude of this normal force, F_N and the weight, F_W, is the same but the direction is 180° different. Note also that these two equal but opposite forces are on different objects. F_W pushes down on the table; F_N pushes up on the block. These are an example of the two opposite but equal forces discussed in Newton's Third Law of Motion.

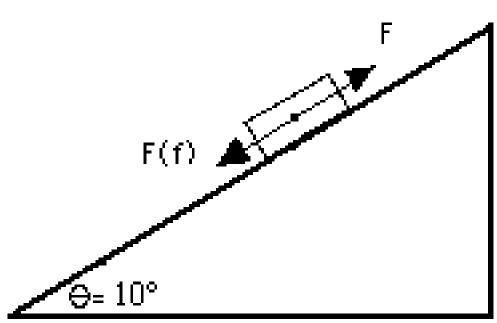


1. Within the experimental fluctuations of the spring balances, this ratio (μ) should remain constant no matter what the weight is for the same type of wood. The reason is that as the downward weight becomes larger the frictional force proportionately becomes larger too. This ratio, therefore, does not change to any large degree with respect to weight.
2. Both the coefficient of static friction, μ_{static}, and the coefficient of sliding friction, $\mu_{sliding}$, remain relatively constant as the weight increases. The two constants do not equal each other, however.

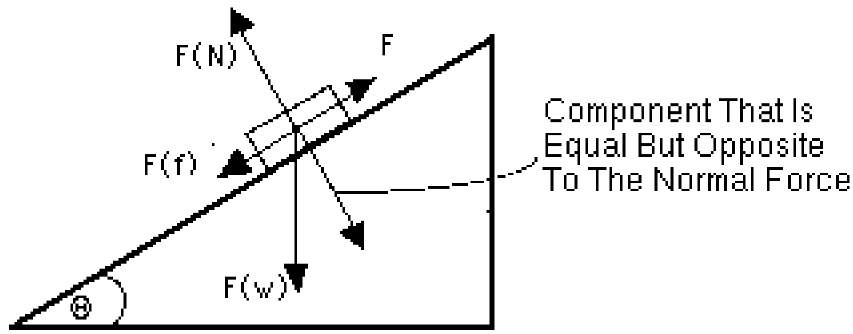
B. Will the surface area of the block in contact with the table top or floor affect the coefficient of friction?
1. Take each block and systematically turn it so that different sides come in contact with the table top (this allows a different amount of surface area to come in contact with the table but does not change the weight). Determine how much force it takes to keep the block moving at constant velocity for each of the three sides.
2. What is the relationship between the frictional force and the amount of surface area in contact with the table top? [They are independent of each other. There are some students who will not be convinced right away about this. Let them try to find examples that refute this. As we saw in the acceleration experiments where we found that the acceleration of a ball rolling down a ramp is independent of its mass, some students hand on to old but incorrect intuitive ideas for a long time.]
3. What is the relationship between the coefficient of friction and the amount of surface area in contact with the table top? [They are independent of each other.]

CONCEPT EXTENSION

A. Place the blocks on an inclined plane (= 10°).
1. Attach the spring balance to each block. Predict whether the frictional force will be larger than, smaller than, or equal to the frictional force when the same block was being pulled on the horizontal table top.
2. Pull the block up the plane maintaining constant velocity and read the amount of force required.
3. Remember friction always acts in a direction opposite to the motion. Therefore, the frictional force is the equal and opposite force directed down the plane to the force pulling the block up the plane.



4. The force of the surface pushing upon the object is equal to the entire weight of the object only when the supporting surface is horizontal. When the object is on an incline, this force is less than the object's weight. Because of our definition of μ we see that the force of friction, F_f, depends on μ and this normal force. (If we broke F_W into its two components, we would see that F_N = the Y component of the object's weight. From basic geometry we can see that this component must be less than F_W.



$$\frac{\text{Frictional Force}}{\text{Weight}} = \mu \quad \text{or} \quad \text{Frictional Force} = \mu \text{ (Normal Force).}$$

5. Because the frictional force decreases on an inclined plane and the normal force also decreases in the same proportion, the coefficient of friction on the inclined plane is the same as on the horizontal table.

B. What do you think would happen to the frictional force and the coefficient of friction if the angle of the inclined plane increased? [The frictional force will decrease (but the normal force will also decrease in the same proportion), and the coefficient of friction will remain constant.]

1. What would happen if the angle became 90° ? [F_N = 0 ; F_f = 0 ; the object is no longer sliding down the table but is in free-fall.)
2. What will happen if the mass of the block is increased:
   a. to the frictional force? [Increase]
   b. to the μ ? [Remain the same]
   c. to the normal force ? [Increase]

RECYCLING

PROBLEM PRESENTATION / EXPLORATION

A. Collecting trash for a day

1. Give each student a 13-gallon plastic trash bag.
2. Instruct each student to place his/her name on the bag with a label or permanent marker.
3. Ask students to collect everything in the plastic bag that they would throw away during the school day, beginning with this class and continue with their collecting until the beginning of this class tomorrow.
4. Tell students that collection should take place during school hours only and that collection bags should remain at school overnight.
5. No food waste or wet material should be placed in the bag.
6. The next day, begin the class by having groups of four students combine their trash and categorize what they have collected. List categories on the chalkboard or overhead. Make sure that the entire class agrees on these categories (i.e. paper, plastic, glass, etc.).
7. Have each group construct a data table containing each of the categories that were agreed upon by the class and record the total numbers of each item in the appropriate category.

Group	Glass	Paper	Aluminum	Plastic	Other
1					
2					
3					
4					
5					
6					
7					
8					

B. Estimation of volume of trash collected

1. Now, ask each group to devise a method for estimating the volume of trash collected by their group, assuming that the 13-gallon bag will hold about 12 gallons of trash when full. (Check with each group to make sure that they understand that if the bag is only half full, it will contain about 6 gallons of trash, etc.)
2. Once the method for estimating volume has been established, have each group record their total volume of trash in a separate data table on the chalkboard or overhead.

GROUP #	Volume of Trash	Volume of Compacted Trash	Difference in Volume of Trash
1			
2			
3			
4			
5			
6			
7			
8			
TOTAL			

3. Next, have each group compact their trash as much as possible and again record their estimates of volume in the data table on the chalkboard or overhead. Explain that compacting occurs in garbage trucks and in landfills.
4. Using the average volume of the eight groups of students in the class, compute how much trash an average student in your school discards daily.
5. Assume that there are 70 million students in schools across the United States. How much trash is discarded daily?
6. Carry out these comparisons for both the compacted and uncompacted trash. What difference did compacting make? Was there a difference in weight as well as in volume? [The volume got smaller, but the weight stayed the same.]

CLASS RESPONSE / CONCEPT INVENTION

A. Recyclable vs. nonrecyclable
   1. Instruct the groups to look back at their first data table and to separate their items into recyclable and nonrecyclable products.
   2. Which items can be recycled? Which are in the greater amount, those that can be recycled or those that cannot be recycled?

B. The landfill problem - volume and mass
   1. In this experiment, the needed materials are 2 large cardboard boxes of equal size and 1 set of bathroom scales.
   2. Label one cardboard box "A" to receive crushed containers and the other "B" to receive uncrushed containers.
   3. Instruct students to use the bathroom scales to measure the mass of each empty box, devising their own method. (Since boxes may not sit alone on the scales, students should come up with the idea of standing on the scales first with the box and recording the mass, and then standing on the scales without the box and recording the mass, and finally subtracting the two to find the mass of the box.)
   4. Explain that the two boxes represent the last two available landfills in the county (or city).
   5. Instruct students to bring in empty aluminum cans that have been rinsed each day. (Plastic containers may be used instead.) They may decide each day whether or not to crush their cans before placing them in the appropriate box.
   6. All students should monitor the boxes daily and keep a record of the number of cans being placed in each.

DAY #	Number of Cans (Box A)	Number of Cans (Box B)

   7. When a box is completely filled, announce that the "Landfill is full," and close the lid to the box.
   8. When both boxes have been filled, ask, "Which landfill was better and why?"
   9. "Which box contained more cans and why?"
   10. "Which box contained the greatest mass of cans?"
   11. "Which box contained the greatest volume of cans?" (Note: The volume for both boxes is the same.)

C. Identifying plastics
   1. More and more people are beginning to recycle plastics in addition to such items as aluminum cans and paper.
   2. The Society of the Plastics Industry, Inc., has developed a voluntary uniform coding system for plastic containers which identifies containers by material

type for the convenience of sorting the containers. The code is a three-sided triangular arrow with a number in the center and letters underneath. The number inside and the letters indicate the resin from which the container is made.

PETE **HDPE** **V** **LDPE** **PP** **PS** **OTHER**

3. Not all plastics will contain a code because it is up to manufacturers to decide whether to place the code on their product.

   (1) **PET** soft drink bottles
   (2) **HDPE** milk bottles, detergent bottles, orange juice bottles
   (3) **V** shampoo bottles, salad dressing bottles, vinyl seats
   (4) **LDPE** shopping bags
   (5) **PP** catsup bottles, yogurt cups
   (6) **PS** foam cups, prescription bottles, plastic knives, forks, and spoons
   (7) **Other**

4. Have students bring to class as many different containers or substances as they can that contain this symbol. Determine, based on your study, which type of plastic seems to be used most often in making things that your students contact in their daily lives.

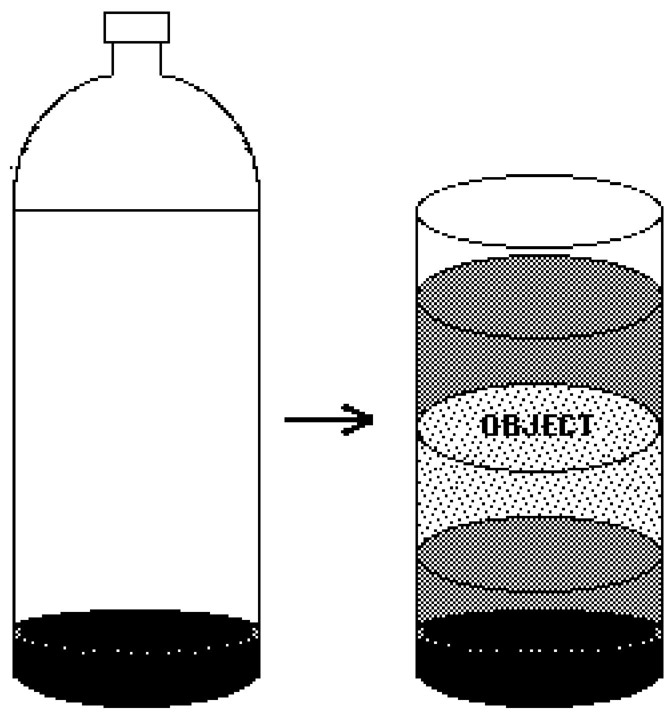
D. Instructions for separating the different classes of plastics by their differences in density are given in the experiment entitled **Mixtures** starting on page 36 of this manual.

CONCEPT EXTENSION

A. To decompose or not to decompose
1. The materials needed for this experiment for the class include:
   a. samples of various materials that might be found in landfills (aluminum cans, disposable diapers, pieces of catalogs, newspapers, plastic containers, coffee grounds, polystyrene pellets, cardboard, etc.)
   b. enough 2 or 3 L bottles or milk containers so that there are 2 for each of the above materials
   c. plastic trash bags or Ziploc® bags
   d. hammers and nails
   e. soil
   f. sand
   g. metric rulers
   h. larger tray or broiling pan to hold all containers
   i. a small block of wood (should fit inside containers)
   j. graduated cylinders
2. Divide the class into equal groups, so that each group is responsible for one container.
3. Have students predict how long it would take each of their samples to decompose and record in the data table.
4. Ask, "How could you design an experiment to check out your predictions?" If students have trouble designing their own experiment, have them complete the procedure below.

	Appearance of Item #1 After	Appearance of Item #2 After	Appearance of Item #3 After	Appearance of Item #4 After
Prediction				
1 Week				
4 Weeks				
8 Weeks				
12 Weeks				
16 Weeks				
20 Weeks				
24 Weeks				

5. Cut the tops off the 2 or 3-L bottles so that all bottles are the same size.
6. Using a hammer and nail, punch four equally spaced holes in the bottom and four equally spaced holes along the sides of the container.
7 Fill the container with a 5 cm layer of dirt and cover with a piece of plastic..
8. Cover the plastic with 3 cm of sand and then cover the sand with another piece of plastic.
9. Place 2 cm of moist soil around the sides of the container.
10. Add a small piece of one of the samples.
11. Compress all of the above as much as possible using a small block of wood.
12. Add 3 cm of dirt on top of all of the above.



13. Add 200 mL of water.
14. Place all containers on a large tray to catch water.
15. Add 100 mL of water every third day.

16. At the end of 1, 4, 8, 12, 16, 20, and 24 weeks dig up the samples and record their appearance.
17. Have students evaluate the accuracy of their predictions at the end of the experiment.

B. The packaging problem

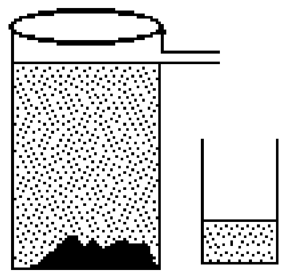
1. Ask students to bring in various packaged food products from home.
2. Give each group of four students a balance and ask them to devise a method to determine what percent of the product is waste (packaging).
   (% packaging = mass of the package/mass of the product X 100)
3. Compare various brands of food products as well as different sizes of products. For example, does a larger size laundry detergent contain more or less waste, percentage wise than a smaller size?
4. Another alternative is to calculate the amount of waste produced from eating a meal at a fast food restaurant.

FLOATING OBJECTS

PROBLEM PRESENTATION / EXPLORATION

A. Predict which things will float in water

1. At each station place various objects. Make sure that at least one of them is a piece of paraffin or a candle. Have students predict, by just looking at them, whether they will float or not. Record the consensus in the appropriate column in the chart on the transparency or on the board.
2. Now have the students find the mass of each object. Let them once again predict whether each object will float or not. Record.
3. Have each object carefully placed into an overflow can and catch the displaced water in a graduated cylinder. Record whether it floated or not. (If a couple of drops of liquid detergent have been mixed in with the water in the can, there will not be as much trouble with the water not flowing smoothly. The detergent lowers the surface tension of the water.)



4. The mass of the dry cylinder should be determined before the experiment begins. The mass of the cylinder + water displaced should be measured.
5. The volume of displaced water can be read directly from the graduations on the graduated cylinder.

Object	Predict if it Will Float or Not		Did it Float?	Mass of Object	Volume of Water in Cylinder	Mass of Empty Cylinder	Mass of Cylinder + Water	Mass of Water
	After Inspec-tion Only	After Weighing						

CLASS RESPONSE / CONCEPT INVENTION

A. What consistent relationship is there for those objects that floated?

1. Care must be taken to insure that the mass of the dry object and the mass of the displaced water are determined accurately. The reason for weighing the graduated cylinder dry and then weighing it after the displaced water had been collected was so that the mass of the water could be determined by difference rather that transferring the water and taking the chance of losing some of it.
2. **For all the objects that floated, the mass of the water displaced is equal to the mass of the object.**
3. Would this be true if the objects were dropped into a different liquid than water? Try it in rubbing alcohol.

Object	Did it Float?	Mass of Object	Volume of Alcohol in Cylinder	Mass of Cylinder	Mass of Cylinder + Alcohol	Mass of Alcohol

4. Note that this relationship holds true in the alcohol as well as in the water.
5. Depending on the objects that are being tested, there might be one or more that floated in water but sank in alcohol. (The paraffin or candle falls into this category.) The relationship about the mass of the displaced fluid and the mass of the object only refer to those objects that floated.

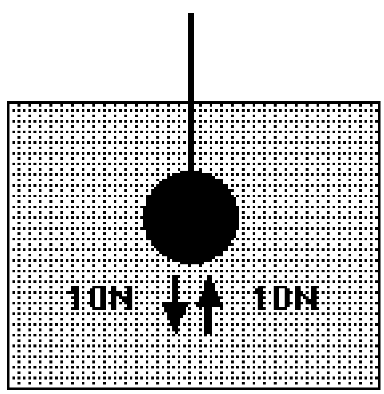
B. What consistent relationship is there for those objects that sank?

1. **For all the objects that sank, either in water or alcohol, the mass of the fluid displaced was less than the mass of the object.**
2. For even those objects that floated in water and sank in alcohol, comparing the mass of the fluid displaced and the mass of the dry object gives consistent results with the above two generalizations (**A2 & B1**).

C. The conclusions that we came to in A2 & B1 are know as **Archimedes' Principle**.

D. How do we explain why some objects float and some sink?

1. Do all heavy objects sink? [No] Do all light objects float? [No].
2. Lets consider what happens when an object is placed into a fluid. The object by being placed into the fluid takes up space and pushes the fluid out of the way. As we learned in Newton's Third Law, the fluid that is pushed out of the way in effect pushes back on the submerged object. For example, if the object pushes a volume of water with a weight of 10 Newtons out of its way, then the water reacts by pushing back on the object with a force of 10 Newtons. We then say that the object is buoyed upward with a force of 10 Newtons. In other words 10 Newtons of the downward force of gravity is being counteracted by the upward buoyant force.



3. Use a spring scale to determine the mass of a rock or piece of pipe. Now submerge the object with the spring balance still attached. What does it read now? Lighter, heavier, or the same as out of the water? How much buoyancy is the rock experiencing?

weight of object in air = ___________
apparent weight of object in water = ___________
buoyant force on object = ___________

4. Refill an overflow can with water. Tape a marble or other object in the beaker so that it will float upright in the overflow can. This will allow you to measure the volume of water that the beaker system displaces. Now ask students to predict what will happen when 50.0 g of sand is added to the beaker floating in the overflow can. Assuming the beaker doesn't sink, what will be the increase in buoyancy? Will it be more than, less than, or equal to 50.0 g more? [Equal to 50.0 g]

Mass of Empty Beaker	Volume of Water Displaced	Mass of Dry Cylinder	Mass of Water + Cylinder	Mass of Water Displaced	Buoyant force

Mass of Beaker + 50 g. of Sand	Volume of All Water Displaced	Mass of Dry Cylinder	Mass of All Water Displaced + Cylinder	Mass of All Water Displaced	Buoyant force

5. What needs to be emphasized here is that, as we saw earlier, **the buoyant force for floating objects is equal to the weight of the displaced fluid**, and the total weight of the displaced fluid will equal the weight of the object (beaker + sand).

CONCEPT EXTENSION

A. Give each group of students an empty 35 mm film canister, one penny (minted after 1982), a balance, a graduated cylinder, an overflow can, and some water. Ask them to find out the greatest number of pennies that they could put into the film canister and not sink it. The only limitation to this investigation is that they can not arrive at their answer by trial and error by adding pennies one at a time until it sinks. They can, however, use the materials to do individual experiments, but they can never put the pennies in the film canister to see if it will float or sink. **[This is a direct application of determining the buoyant force and its relationship to the mass of the object. First the volume of water that the film canister would displace if it was submerged must be determined. The mass of this displaced water is the buoyant force. This mass is the maximum mass that the canister + pennies can have. Subtract the mass of the empty canister from this and you have the maximum mass of the pennies. Divide the mass of one penny into this mass and the number of pennies is determined.]**

B. What will happen if you drop a ball of clay into a graduated cylinder of water? What will happen if you shape the same clay into a boat? Calculate the buoyant force on first the ball of clay and then on the clay boat. Why do you get different buoyant forces for the same mass of clay? **[The boat displaces a larger amount of water, in other words, has a larger buoyant force.]**

C. Consider a rowboat loaded with sand in a swimming pool. If the sand is thrown overboard into the pool, will the water level in the pool rise, fall, or remain unchanged? What will happen to the water line on the boat? Will it be higher up on the boat, lower on the boat, or the same level on the boat when the sand is thrown out?

1. Lets use a large graduated cylinder for our lake, and lets use a large test tube for our boat.
2. Float the test tube in the cylinder by putting sand into it so that at least 3/4 of the testtube is submerged.
3. With a grease pencil mark on the testtube the water level on the "boat". Also mark on the cylinder the level in the "lake".

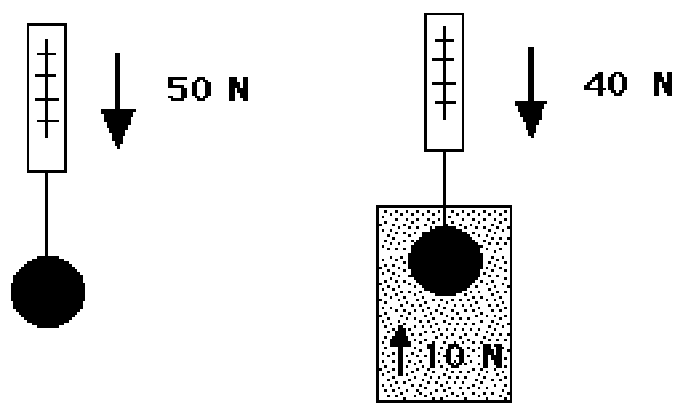
4. Now have the students predict what will happen to the level in the tube if half of the sand is poured out into a clean and dry beaker.
5. Have them predict what will happen to the level in the cylinder when the sand is poured into the clean and dry beaker.
6. Pour half of the sand into the clean and dry beaker. Note the water level on the testtube and on the graduated cylinder.
7. Now, pour the sand into the cylinder. Where did the final level in the cylinder come in relation to the original level before the sand was taken out ?
8. **The water level in the cylinder will fall, because the sand will displace less water submerged than when floating. When floating it displaces its weight of water. When submerged it displaces only its volume (remember, this will be less because sand is more dense than water.)**

D. How could we determine the density of a block of wood that floats in water without measuring its mass?

1. To check our results lets first determine the density of the block.
2. Measure the mass on a balance.
3. Measure the length, width, and height with a ruler.
4. The volume is equal to length x width, x height.
5. The density is equal to mass/volume.
6. Now that we know the density of the block, how could we find it without ever measuring the mass?
7. Students should have seen by now that the mass of the displaced fluid is equal to the mass of the floating object. Since the density of water is 1 g/mL the volume in mL is the same as the mass in grams. Therefore, the volume of the displaced water expressed in grams is the mass of the block of wood. To get the density, the mass need only to be divided by the volume of the block. This volume can be obtained by either measuring length x height x width, or by simply submerging the entire block under water and collecting the volume of water displaced by the entire block.

E. Find the density of an object that sinks without measuring the volume of the object. The only materials that can be used are a balance, a piece of string, and a glass of water.

1. This is probably the toughest task in this whole activity, but it will indicate whether the concept of buoyancy and Archimedes' Principle are thoroughly understood.
2. Weigh the object in air.
3. Weigh the object submerged in the glass of water.



4. Since the buoyant force equals the mass of water displaced this is the difference between the two weights.
5. Because the density of water is 1 g/mL, the mass of water displaced also equals the volume of the object in mL.
6. Now the density is simply the mass of object divided by the difference in the

two weights of the object. Remember, this difference in the air weight and the submerged weight is the buoyant force of the water.

CENTER OF GRAVITY

PROBLEM PRESENTATION / EXPLORATION

A. Balancing a meter stick
   1. Tie two objects with identical weight to opposite ends of a meter stick, at the 5 cm mark and the 95 cm mark.
   2. Balance the system on your forefinger, horizontally, by sliding it along the meter stick until one side or the other doesn't dip down.
   3. Now, substitute for the object at the 95 cm mark something that doesn't have the same weight as the one at the 5 cm mark. Can you find a place where this system can be made to balance?

B. Balancing a broom
   1. Find the place where you would have to move your finger on a broom handle so that it will balance when held horizontally. Is it closer to the heavier or lighter end?
   2. Now hold it vertically and balance it on the tip of your finger.
   3. If the top end tends to fall to the left, what do you do to keep it balanced? If the top end tends to fall to the right, what do you do to keep it balanced?

C. Balancing the state of Tennessee
   1. Cut out a map of Tennessee and paste it to corrugated cardboard. Now cut the cardboard around the boundary of the map. This will give you a flat map of Tennessee about 1 cm thick.
   2. Holding the map horizontal to the floor, where would you place your finger underneath it to make it balance on the tip of your finger?

CLASS RESPONSE / CONCEPT INVENTION

A. The point at where all the mass seems to be concentrated (right where your finger can balance the whole system) is called the CENTER OF GRAVITY.
   1. For a symmetrical object the center of gravity is located exactly at the heart of the object.
   2. For a nonuniformly weighted object, like the broom, the center of gravity is located more toward the heavier end.
   3. For an irregular object, like the map of Tennessee, the place where all of the mass seems to be concentrated (in other words where could we put our finger to support the whole state) must be found experimentally.

B. Finding the center of gravity of Tennessee
   1. Stick a long straight pin through Chattanooga on the map and push it through so that the pin will stick to a cork bulletin board on the wall (or large cardboard box sitting on the table). The map must be able to freely swing around the pin.
   2. Attach a heavy object such as a lead fishing sinker to a piece of thread and tie the thread to the straight pin so that it hangs down vertically. About 20 cm down the thread put a second straight pin right next to where the thread crosses the map.
   3. Remove the thread and heavy object and connect the two pins by stretching a thin rubber band from the first to the second pin. This will indicate where the thread hung down.
   4. Proceed to Memphis and repeat steps 1, 2, and 3.
   5. Because the map was hanging freely, the center of gravity must be somewhere on the line made up of the first two pins. Likewise, it must be on the line joining the second two pins. Where is the only point common to both of those lines? This must be the center of gravity. Place your finger under this point and attempt to balance the state of Tennessee. [The center of gravity is somewhere around Murfreesboro.]
   6. If you put another pin through Martin or Knoxville and repeated steps 1, 2, and 3, would this line cross at the same place as the other two? Try it!

C. Balancing a broom
   1. If the broom is held out **horizontally**, the pivot point [this is where your

finger can support the broom] and the center of gravity are at the same point.

2. Where must the pivot point be in relation to the center of gravity for the broom to balance **vertically**?

2. As long as the pivot point and center of gravity lie along the same vertical line the object will balance at the pivot point. But when the center of gravity starts to move right or left so that the pivot point and center of gravity are not on the same vertical line, the broom will tip. If we move the pivot point back under the center of gravity the broom can once again be brought into equilibrium.

C. Balancing a book

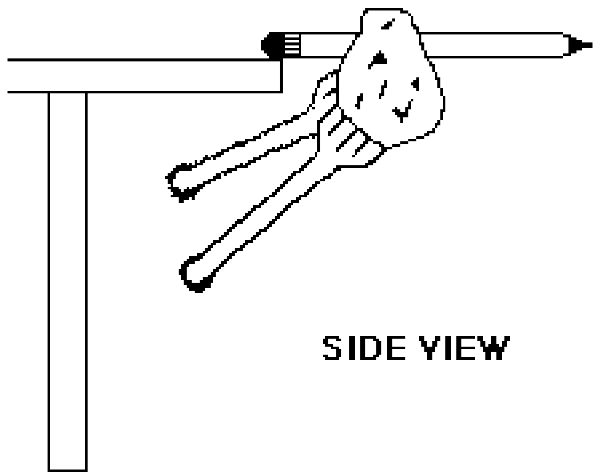
1. Place a book face down on a table. Now set it on its side. Finally, set it on its end. Which of these positions is the most stable for the book? In other words, which would be least likely to tip over if a small force were applied to it?
2. Where is the center of gravity with respect to the table for each position of the book? Are you more stable standing up in a row boat or sitting down in the row boat? Where is the center of gravity in with respect to the floor of the boat in each of these situations? Does the position of the center of gravity have anything to do with the stability of a system?
3. Try and stand a raw egg on its fat end. After a few tries, shake the egg vigorously and immediately set it down on its fat end. The yolk will become more mobile within the egg while shaking and will move down lower in the fat part of the egg. This lowers the center of gravity and the egg is much more stable.
4. In each of the three cases above t**he lower the center of gravity the more stable the system.** This is why powerful race cars are build low to the ground so that they are stable when cornering.
5. Arrange the angle of an inclined plane so that a book may be motionless while lying flat, but will fall over when placed on end.
6. In addition to raising the center of gravity when the book was stood on end, what other observation about the position of the center of gravity can you make that contributes to the book falling? [Setting the book on end not only raises the center of gravity (making it more unstable) but also moves the center of gravity so that it lies outside of the base of the book in contact with the plane and will result in the book toppling.]
7. What is the tallest stair step that can be made, before toppling, with 25 Lego® or Tyco® blocks. Each step may be no more that 1 cm steep. What key adjustment did you have to make to allow the stair step to get higher than 4 or 5 blocks? [The base had to be enlarged so that the center of gravity would not hang out over the base.]

CONCEPT EXTENSION

A. Locating the center of gravity when it falls outside the system

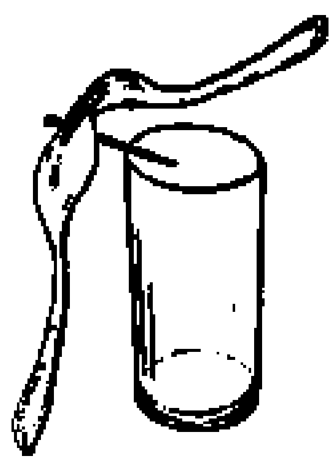
1. In every example above, except possibly the construction of the Lego® block stair step, the center of gravity has physically resided within the object under consideration.
2. At first, it might seem as though the center of gravity must remain within the object. To prove that this is not always the case do the following. Obtain a large fork and spoon, possibly those big wooden ones used for tossing salad, or two large barbecuing utensils. Interweave them so as to make a curved system. (The tines of the fork should fit around the spoon or spatula.) Another way would be to stick two large utensils into opposite end of a potato. Now, using the procedure for finding the center of gravity that we employed to find the heart of Tennessee, find the G.G. of this system. This will show that the center of gravity falls somewhere in between the utensils but not residing within either. It just hangs out there in the open air.
3. We have learned that as long as the center of gravity and pivot point are in the same vertical line that a system can be made to balance. Also we have seen that a system is more stable if the center of gravity can be lowered. Therefore, we should be able to make the spoon/fork combination balance

on the eraser end of a pencil by adjusting the position of the pencil so that the pivot point is directly below the center of gravity. This same feat is often illustrated by supporting a belt in a wooden holder and suspending the whole system on one's finger.



B. Challenges

1. It might be interesting for students to devise other seemingly impossible feats of balancing. Possibly a contest could be conducted for the most amazing system that can be constructed from common objects located around the home. Below are two that should get the ball rolling.
2. Take an ordinary spoon and fork. Attach the spoon to the fork by pushing it in between the tines. Place a toothpick between two of the fork's tines and let the system balance from the toothpick resting on the rim of a drinking glass. What do you think would happen if you lit the toothpick with a match? Light it from both ends. [Because it is perfectly balanced the toothpick will burn down to where it makes contact with the utensils and from the inside of the glass to the rim. During the whole process the system remains balanced.]



2. A hammer, a plastic ruler, and a short string can be made to hang over the edge of a table to seemingly defy gravity. But really all that is happening is that the center of gravity is directly below the pivot point and when adjusted place the system in equilibrium.

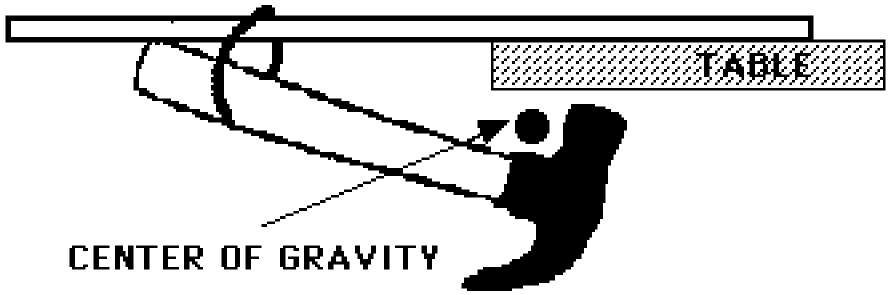


TABLE
CENTER OF GRAVITY

PRESSURE

PROBLEM PRESENTATION / EXPLORATION

A. CHALLENGE: What is the farthest distance a stream of water can be made to squirt out of a hole poked into a half gallon milk carton (or 2 liter bottle)? What are the factors (that you can manipulate) that govern how far the water will travel?

B. Rules

1. Everyone must use the same type of container.
2. The only thing that may be put into the container is tap water.
3. The only "tools" that may be used are a pencil, scissors, nail, or other device for putting the hole in the milk carton. (If plastic bottles are used, a smooth hole can be made by heating the nail, etc., in a flame. The hot nail melts the plastic quickly and neatly.)
4. Any other equipment for carrying out the exercise must be approved by the teacher.
5. To make ready for judging, the student must put a piece of tape over the hole and present it to the teacher. The teacher will quickly remove the tape to allow the water to squirt. An alternative way that this can be done is to place the water in the container with your finger over the hole, then put a rubber stopper into the hole at the top of the 2 L bottle. Removing your finger will not result in the water squirting out. WHY? When you want the water to squirt out quickly remove the rubber stopper.
6. Distances will be measured from the base of the milk carton to the farthest point that the water squirts.

CLASS RESPONSE / CONCEPT INVENTION

A. After the competition, have the class decide which variables they considered in trying to squirt the water the greatest distance. Some important ones that they should have considered are:

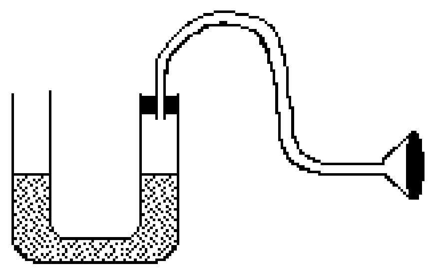
1. Amount of water put into the carton
2. Size of the hole
3. Distance of the hole from the bottom of the carton

B. Which of these variables had the most effect? Which had none? How could you prove this? This is a classic example of a separation and control of variables exercise. Use this opportunity to reemphasize the importance of holding all other variables constant while a single variable is changed.

1. Poke the same size hole, 5 cm above the bottom of the container, in three different milk containers. Put tape over the holes. In the first carton add enough water to bring the level up to 10 cm high; in the second container add enough water to bring the level up to 15 cm high; and in the third container add enough water to bring the level up to the 20 cm level. After pulling the tape off the hole measure how far the stream of water goes for each of the three containers. Decide whether the amount of water in the carton makes any difference in the distance traveled by the water. [The higher the water level, the farther it squirts.]
2. Poke different sized holes in three containers at the same height above the bottom of each container. Place tape over the holes. Fill the container completely full with water. Pull the tape off each hole and observe the streams of water. Decide whether the size of hole makes any difference in the distance traveled by the water. [The smallest hole will squirt the water the farthest]
3. Poke the same size hole in each of three separate containers but at different heights from the bottom. After putting tape over the holes, fill each container with the same amount of water. Pull the tape off the holes and observe the streams of water coming out. Decide whether the height of the hole makes any difference in the distance traveled by the water. [The hole with the shortest distance from the bottom squirts the farthest.]

C. One of the key conclusions that should be achieved in investigations B1 and B3 above is that **there is more force exerted** (evidenced by the longer stream of water) **when the column of water above the hole is higher**. To show this more clearly have the students determine at what position there is the greatest force exerted on the rubber diaphragm (see description below).

1. Fill a U-tube about one third full with water. Attach a rubber hose to one side of the U-tube. On the other end of the hose attach a funnel. Over the mouth of the funnel stretch a piece of rubber sheeting (balloon). Affix it with a heavy rubber band.



PRESSURE DETECTOR

2. Have a student press on the rubber diaphragm and observe what happens to the level of water in the U-tube. [It goes up.] This can now serve as visual evidence of different force being experienced at the mouth of the funnel.
3. Submerge the funnel to different depths in a large graduate cylinder, sink, bucket, or aquarium and observe the changing heights of water in the U-tube.
4. If the container is large enough, point the mouth of the funnel up, down, sideways but always keeping it at the same depth and observe the U-tube.
5. At which depth did the greatest amount of force register? [The greater the depth, the greater the force on the diaphragm.] Did it make any difference in the level of water in the U-tube when the position of the funnel was altered? [No, pressure is equal in all directions if at the same depth.]

D. In addition to the conclusion that the height of water affects the distance the water squirts, the area to which the force is applied will also effect how far the water squirts. In other words the size of the hole is also important in determining the **FORCE PER UNIT AREA** which is our definition of **PRESSURE**.

1. A sugar cube measures about 1 cm on a side. The area of one face then would be about 1 cm^2.
2. Place a cement block (or other heavy object) on the single sugar cube. The huge amount of force concentrated on 1 cm^2 will smash the sugar cube immediately.
3. Now take 100 sugar cubes and lay them out on the floor to make a square 10 sugar cubes on a side. If the cement block is placed on this area (about 100 cm^2) the cement block should be supported without crushing the sugar cubes. In this case each sugar cube is supporting only 1/100 of the force. The pressure experienced by the single sugar cube was 100 times greater because of its smaller area. Therefore, with the same height of water pushing down on the small hole and the larger hole in the water container, the pressure experienced at the little hole was much greater and the stream of water squirted out farther.

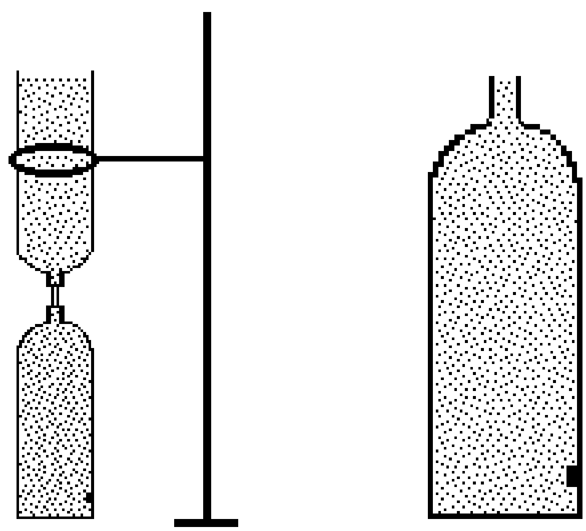
CONCEPT EXTENSION

A. CHALLENGE: If two milk cartons (half gallon and quart) or two plastic Coke® bottles (2 L and 1 L) are both filled to the height of 25 cm with water and both have holes of equal size spaced at 5 cm above the bottom of the carton, which carton will squirt the water farther?

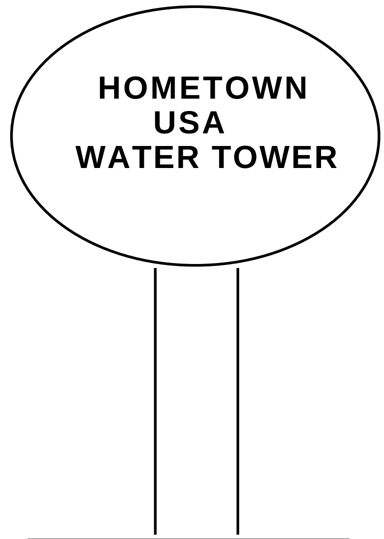
1. It is probable that many students will predict that the half gallon milk carton with squirt the water farther. They are centering on the fact that there is more water in the carton and consequently that there is more force being exerted at the hole.
2. But contrary to this assumption the streams of water should cover the same distance. It is the height of the column of water that is important not the amount of water.

B. If there are doubters in the class, try to give them a concrete example of the importance of the height of the column of water rather than the amount of water being the factor that dictates the amount of pressure.

1. Use a total of one half gallon of water for both of the following tests.
2. Both containers must have a hole of the same diameter punched at 5 cm above the bottom of the container.
3. After taping over the hole, all of the water should be put into the first container (2 L bottle).
4. You will need two 1L bottles for the second test. The lower one should have the hole punched out in the same way, same size, and distance above the bottom as was done the 2L bottle. Make sure you tape over the hole. Cut off the bottom of the second 1L bottle. Prepare two one holed stoppers that will fit into the 1L bottles. Into each stopper insert the opposite ends of a short piece (4 cm) of glass tubing. Submerge all three pieces (the two bottles and the rubber stoppers/glass tubing) into the sink or large tub so that everything is filled with water. While still under water insert the stoppers into the two 1L bottles so that the two bottles are now connected. There should not be any air bubbles. Remove the setup from the tub of water placing the bottle with the hole on the table and elevating the bottle without a bottom above the table. Support the upper bottle with a ring and ring stand.
5. Now both bottles have approximately 2L of water in them. All that remains now is to remove the tape and see how far the stream shoots in each case. The demonstration can be even more graphic if a piece of rubber tubing was linked to the two 1L bottles. Now by physically lowering or raising the upper bottle the pressure can be decreased or increased according to the height of the column of water above the hole.



C. How would you design a water tower to maintain water pressure for a small town? Where would you locate the water tower? [At the highest point in town.] What shape would you make it to insure the greatest water pressure? [Since height is the most important factor, many towns use a large water tank that is high in the air with a pipe coming out of the bottom that extends down to the ground instead of a cylindrical tank of the same height. In this way it does not require as much water to get the same water pressure. (See diagram below.)



AIR PRESSURE

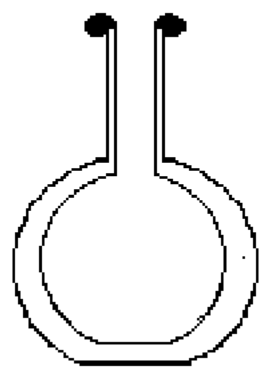
PROBLEM PRESENTATION / EXPLORATION

A. Drinking Straws

1. Every kid knows how to make a straw work, but does he know why it works?
2. At the first exploration station have the following setups:
   a.) A straw resting in a paper cup of Kool Aid® or punch.
   b.) A straw with a couple of pin holes punched in halfway up the straw resting in a paper cup of Kool Aid® or punch.
   c.) A straw inserted through a cork or one-holed rubber stopper into a 125 mL Erlenmeyer flask containing Kool Aid® or punch.
   d.) Two straws and a cup of Kool Aid® or punch with a card having instructions to put both straws into your mouth, to place only one of the straws into the liquid, and to suck simultaneously on both straws.
3. Ask the students to relate what happened or didn't happen in each instance and to explain these observations. Ask them to pay particular attention to what they did with their mouth and jaw as they sucked.
4. Have them to advance an idea of what caused the liquid to rise.

B. Balloons

1. At the second exploration station challenge students to reproduce:
   a.). A flask or jar lined with a balloon fitting snugly to the interior surface of the flask or jar. The mouth of the balloon is folded over the mouth of the container.



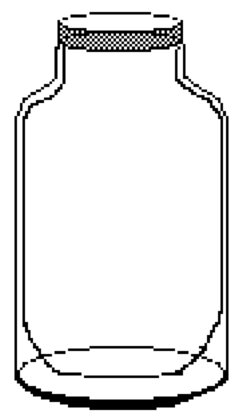
   b.) Provide for them a balloon and container and indicate that upon their request you will provide for them anything else they think they will need to carry out this challenge. Emphasize that they must first clear their projected activity with you.
2. At the third exploration station challenge students to reproduce:
   a.) A jar containing a fully inflated balloon filling the entire volume of the jar.

b.) Provide them an empty jar (the jar needs to have a wide mouth, possibly a mayonnaise jar) with a screw-on cap and an inflated balloon. Once again, tell them that you will provide for them anything else they need to carry out this challenge, but they must first clear their projected activity with you.

C. It is very likely that the students will show an understanding of how straws work and that air pressure is involved, but it is highly unlikely that they will be able to complete the balloon challenges. Hopefully, at the completion of the CONCEPT INVENTION phase students will have the appropriate understanding of how air pressure can be utilized to meet these challenges

CLASS RESPONSE / CONCEPT INVENTION

A. Obtain a large mouth jar (a large institutional sized pickle jar from the cafeteria works well). Get a large plastic sandwich bag and invert over the mouth of the jar. Push it into the jar and smooth it out so that it clings to the inside surface. Securely tape the bag to the mouth of the jar



1. Challenge a student to come up and reach into the jar and pull the bag out.
2. They will not be able to do this unless they rip the bag. Why? Point out that there is no glue or other type of adhesive holding the bag to the jar.
3. Quickly, the students will conclude that it must be something **pushing** down on the bag that is causing this action. Try to reinforce this point of view. Undoubtedly, someone will try and explain this phenomenon by saying that there is a suction that is **pulling** the bag down. **This is not what is happening and hopefully will be dispelled as the lesson proceeds**. Definitely it is not a pulling but rather a pushing action that is keeping the bag in the jar.

B. Proceed next to a demonstration that many of the students will have probably already experienced.

1. Place a stick of pine wood (approximate dimensions 0.3 cm x 3 cm x 75 cm) on the demonstration table. Allow about 8 cm of the stick to overhang the table.
2. Ask: "What will happen if I hit this protruding end with my hand?' No doubt the students will indicate that it will go flying up. Do it.
3. Now replace the stick and cover it with one or two full sheets of ordinary newspaper so that the edge of the paper is flush with the edge of the table. Smooth the paper out so that there is no air trapped between the table and paper.
4. Ask: "What do you think will happen if I hit the stick again?" If the students don't offer any answers, suggest that the paper might tear and the stick will fly up again.
5. Hit it sharply with your hand and the stick will instantly break.
6. Remove the paper and replace it with a stack of books at least two feet high

sitting on the stick. Ask: "What will happen if I hit the stick this time?" With no hesitation this time they will predict that the stick will break. Do it.

7. Indicate that both times the stick broke because there was a tremendous weight resting on the stick. The second time it was the weight of the books, but the first time it was the weight of the air above the paper.
8. Introduce the situation of what would happen to a diver standing on the bottom of the ocean if he didn't have on a pressurized diving suit. The weight of all the water above him would crush his lungs.
9. Even though none of us has stood at the bottom of an ocean and felt the weight of the water above us, we all live at the bottom of an ocean of air. This ocean of air rises forty or fifty miles above the surface of the earth. The weight of this air is tremendous on every square centimeter of our body.
10. Draw a square centimeter on the floor, or put a single sugar cube on the floor. The column of air above that cm^2 weighs 1030 g
11. Determine how many square centimeters of stick were covered with the newspaper. If 65 cm x 3 cm is covered by the paper, the weight of air pushing down on the stick is 200850 g or 200.85 kg or 442 pounds!! No wonder the stick broke.
12. Is it now clear why the sandwich bag can't be pulled out of the jar? If the diameter of the bottom of the jar is 25 cm, then the area is πr^2 or 3.14 x $(12.5 \text{ cm})^2$ = 491 cm^2. Now the weight of the air pushing down on the bottom of the jar is 491 x 1030 = 50560 g, or 50,56 kg, or 1114 lb of air!!

C. Barometer

1. The traditional way to talk about how much air pressure is present is to use a barometer. Although students may have aneroid barometers at home, they may never have seen a mercurial barometer. If you have one, show them how it works, if not, a working barometer can be constructed. **This should be done only as a teacher demonstration**. [Mercury is dangerous and students should not be allowed to come into direct contact with it.]
2. Fill a long glass tube (80 cm) with this mercury. To get an 80 cm tube two 40 cm tubes can be connected with a short piece of Tygon® tubing. Only use this type of plastic tubing; do not use regular rubber tubing. You do not want to take any chance of developing a leak at the junction of the two pieces of glass tubing. Seal one end of the glass tubing in the oxidizing part of the flame of a Bunsen burner. Make sure that it is completely sealed. Fill the tube slowly with mercury until all air has been removed. Place a piece of Saran wrap over the open end, Invert the tube so that the sealed end is at the top, and move the tube to the dish of mercury. Lower the bottom of the tube below the surface of the mercury (take care not to put your finger in the mercury) and remove the Saran wrap. **Before removing the Saran Wrap have students predict what will happen when it is removed.**
3. The level of mercury in the tube will fall some but the liquid will not drain out of the tube if the bottom is below the surface of the mercury in the dish. Point out that the weight of mercury is 13.6 times heavier than if the tube was filled with water. Why doesn't the heavy mercury fall all the way out of the tube?
4. The reason that it falls but not all the way has nothing to do with a partial vacuum above the liquid pulling up the liquid (it is true that a partial vacuum is created), but the reason the liquid stays up in the tube is that the pressure of the air pushing down on the liquid in the dish supports the column of mercury.
5. Now by using a meter stick to measure how high the column of mercury is above the surface of the liquid in the dish is a measure of the air pressure. The normal air pressure is a column of mercury 760 mm high. Students may be more familiar with the barometric pressure given in inches of mercury but in science we prefer to use mm of Hg. [760 mm of mercury is equal to 29.92 inches of mercury.]
6. Would the atmospheric pressure be higher or lower than 760 mm Hg on top

of Mt. Everest? Why? [Because the column of air above you when standing on top of Mt. Everest is shorter and contains a smaller amount of air, the pressure pushing down on the barometer would be less than 760 mm Hg.

7. What would be the atmospheric pressure if you were standing on the canyon floor of Death Valley? [More than 760 mm Hg.]

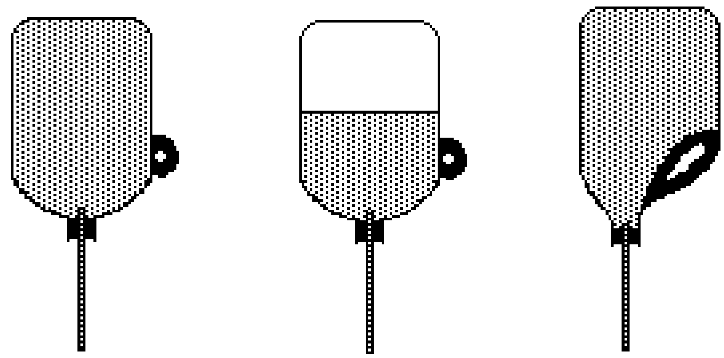
D. Rubber Plungers

1. Have two students come up and get two rubber plungers (the type you would use to unplug a sink) and push them against each other.
2. Ask them now to pull them apart. They will come apart very easily.
3. Tell the students that whether they know it or not you have secretly been exercising for today's lesson. Tell them that you have developed fingers that are exceptionally powerful, and to prove it you want them to reattach the plungers and with your two fingers you will hold the plungers together so that they cannot pull them apart.
4. Naturally there is something funny going on here. One of the plungers has a small hole it. When you put your fingers on the plungers to hold them together make sure that you cover the hole with your thumb. It works even better if your thumb is wet.
5. Now when they pull on the plungers the rubber plungers will stick together and most likely the wooden handle will come off before the plungers come apart.
6. After having some fun with this try to determine why it was so easy to pull the plungers apart before you held them. Because there was a hole in one of them air was allowed to come into the gap. This meant that the pressure on the inside and on the outside was the same. Pulling them apart was relatively easy.
7. The pushing together of the plungers rapidly forced air out. When you plugged the hole with your thumb, air was prevented from coming into the gap and equalizing the pressure. Now when the plungers are pulled apart the volume of the air trapped inside increases, lowering the pressure.
8. Because all of the outside air pressure pushing on the outside of the plungers is many times greater than the small pressure on the inside, the plungers are not easily separated.
9. The total force that was holding them together can be calculated from the total surface area of the two circles multiplied by 1030 g. If the plungers have a 10 cm diameter there is about 150000 g, or 150 kg, or 330 lb of pressure holding them together.

E. Predict which jug of water will drain the fastest

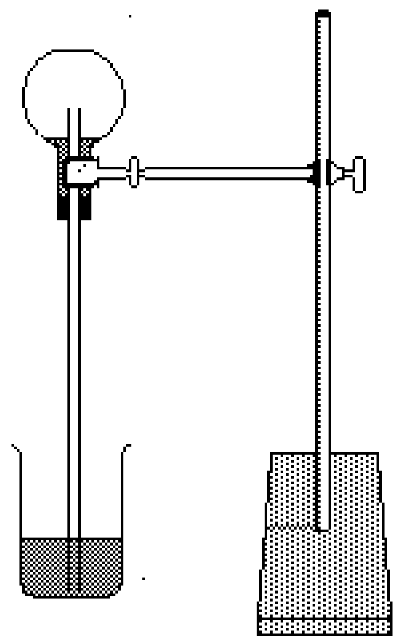
1. Prepare three jugs of water, 1 one gallon plastic milk jug, and 2 one gallon glass jugs. Fill the plastic and one of the glass jugs with water. To the other glass jug add water to the half way mark. Prepare identical one-holed rubber stoppers for each jug. Insert one end of a short piece of glass tubing into the stopper and attach to the other end some rubber tubing.
2. Run water through the tubing to remove all the air and pinch off the end of the tubing with your fingers so that water doesn't fall out the end with the rubber stopper. Now insert the stoppers into the three jugs still pinching the rubber hose.
3. Ask the students to predict from which jug the water will drain out the fastest when the jugs are elevated above the sink so that the rubber tubing is hanging down and you unpinch the tubing.
4. Have three students carry out the actual draining process. Question the class as to why the water drained out of the plastic jug but not out of either of the glass jugs. [The atmospheric pressure is pressing on all sides of the jugs equally. In the plastic jug the pushing of the air on the outside of the jug in addition to the weight of the water in the jug overcome the pushing in of the air experienced at the mouth of the jug. Consequently the water can drain out. Only because the plastic collapsed in response to the air pressure can we have enough downward force to overcome the upward force and have

the water flow.



In the case of the glass jugs the solid container does not allow the outside air pressure to be transmitted to the water. The upward air pressure is greater than the downward weight of the water and no draining from the full jug takes place. A small amount of water may drain from the half-filled glass jug. Turning the jug upside down forces a little of the water in the tube to drain out. Because no air entered, as some water drained out of the flask it lowered the pressure above the water (remember, when volume increases, pressure decreases) in the jug low enough that after a few seconds the upward air pressure is greater than the combined air pressure and water pressure in the jug, and the draining ceases.

F. Magic Fountain



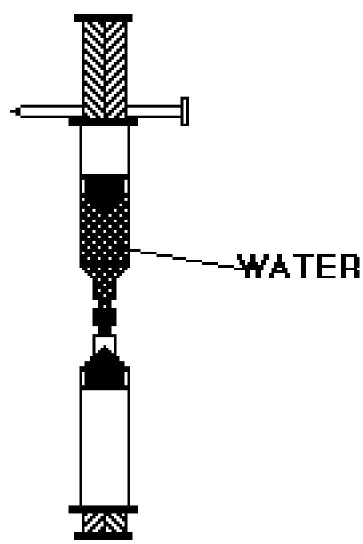
1. Pour 50 mL of water into a 1000 mL Florence flask. Add a small amount of vinegar and a few drops of phenolphthalein.
2. Fill a large beaker with water and add a some sodium hydroxide.
3. Insert a 40 cm piece of glass tubing into a one holed rubber stopper that will fit snugly into the flask. Make sure that the glass tubing extends through the rubber stopper about 10 cm.
4. Turn the flask at right angle to the table so that the 50 mL of liquid rests in the curved portion of the flask. Now insert the rubber stopper with the short end of glass tubing protruding into the flask. Take care that no liquid gets into the tube. Push the rubber stopper in so that there is a snug fit. Slowly rotate the

flask 90 degrees so that the long end of the tube is pointing down and the flat portion of the flask is pointing up The short piece of glass tubing should be situated about 7 or 8 cm above the surface of the liquid which has now fallen into the neck of the flask.

5. Take an iron ring and support the flask by putting the neck of the flask through the ring. Attach the ring to a ring stand.
6. With a Bunsen burner heat the flask. Shortly you should see air bubbles come out the bottom of the long glass tube into the liquid in the beaker. Continue until the liquid in the flask boils. **Be sure and use safety glasses for this demonstration**. Remove the heat. Shortly thereafter, as the liquid begins to condense, liquid should rise up the tube and rapidly spray into the flask. After a few mL of the liquid has entered the flask the entire contents should turn bright pink. The sodium hydroxide entering the flask neutralizes the vinegar creating a basic solution and is indicated by the phenolphthalein turning the whole solution pink.) The liquid should continue to rise until the beaker has been emptied.
7. Did the atmospheric pressure ever change on the surface of the liquid in the beaker? NO. Therefore, since there was upward movement and this requires a difference in pressure, the pressure inside the flask must have become lower. That is exactly what happened when the vapor in the flask condensed. As it changed back to liquid its volume decreased drastically. There are not enough vapor molecules trapped in the flask to counteract the outside air pressure, and the liquid moves in to fill up the extra space.

G. Pulling or Pushing?

1. Students still may think that liquids are drawn up by suction rather than this rise being explained by the pushing force of air pressure. This last demonstration should show that suction does not work.
2. Obtain two 50 mL plastic syringes. In one of these with a hot nail make a hole in the middle of the plunger of the syringe. This insures that when pulled back to the point where the nail can be inserted into the hole that the volume of the cavity created will remain fixed.
3. Cut a small piece of Tygon® tubing and attach it to the first syringe. Now draw water up into the syringe by moving the piston up. Insert the nail so that the piston can no longer move and that the water remains in the barrel of the syringe.
4. Attach the second syringe with its piston fully closed to the first syringe by means of the piece of Tygon® tubing. Make sure there are no leaks.



5. Now, have the students explain how we can move water from the first syringe

into the second. The obvious answer will be to pull the plunger of the second syringe out to suck the water out of the first syringe. It will become quickly clear that pulling the moveable plunger does not do the job. **Suction does not work**. The only way that liquid can be moved into the second syringe is to remove the nail and **push** the water.

H. Reexamination of the Drinking Straw Problem

1. The straw with the holes in it would not allow the liquid to rise. Why? Lets review what we know about air pressure and rising liquids. Ordinarily when you drink through a straw your jar lowers with the volume in your mouth becoming larger, hence the pressure gets lower. Since this is lower than the outside atmospheric pressure, the liquid can be pushed up through the straw. Using the straw with pin holes in it constantly repressurizes your mouth making it the same as the outside atmospheric pressure. Consequently you can never draw the liquid up into your mouth.
2. The soda did not come up the straw that was stuck in the rubber stopper. Why? Since there is no way for the atmospheric pressure to come in contact with the liquid's surface and push it up the straw, you may suck on the straw forever without quenching your thirst. Remember, it is the pushing of the air not the sucking that raises the liquid up the straw.
3. Drinking through two straws simultaneously produced the same problem encountered with the straw having pin holes. Since the pressure in your mouth is constantly being made equal to the outside atmospheric pressure, the outside pressure is pressing against itself.

I. Reexamination of the Unsealed Balloon Problem

1. Do you think the balloon was sucked in or pushed in?
2. We know that the atmospheric pressure could push the balloon in if the pressure on the top side of the balloon was less than the under side. What ways of reducing the pressure have we seen? The best way has been to have a change of state from vapor into liquid.
3. Take the empty flask and add about 20 mL of water. Heat it to boiling until all the air has been forced from the flask. It will now contain only water, some in the gaseous phase and some in the liquid phase.
4. Carefully (the flask is hot) lower the balloon into the flask and fold the lip of the balloon over the mouth of the flask. Allow it to cool. As the vapor turns to liquid the pressure is reduced tremendously inside the flask. Since the atmospheric pressure remains great it pushes in through the mouth of the balloon and forces the balloon firmly against the inside of the flask or jar. How would you remove the balloon from the flask? [By heating it the pressure of the water trapped between the balloon and the wall of the container will increase. When the inside and outside pressure on the balloon are the same the balloon can easily be removed.]

J. Reexamination of the Sealed Balloon Problem

1. If the balloon is going to inflate this time, it does not seem likely that the outside atmospheric pressure is going to be able to do the pushing. Instead, it seem reasonable that the pressure inside the balloon must be doing the pushing. That would mean that the outside pressure will have to be decreased to allow the inside pressure of the balloon be larger.
2. Students should be encouraged to figure this out before you give them help. Tell them to consider the solution to the first balloon challenge and see how this might be changed to achieve our desired outcome in this challenge.
3. Because mayonnaise jars can't be heated with Bunsen burners our heat source will be a pan of boiling water.
4. Add a small amount of water to the jar. Introduce the sealed balloon into the jar. Transfer the jar and its contents to the pan of hot water. After a few minutes use oven mitts or other types of protection to remove the jar from the water. Quickly screw on the lid.
5. Transfer the jar and contents to a container of cold water and roll it around quickly so that it is cooled off evenly on all sides.

6. Observe the balloon inside. It has expanded to fill the entire volume of the jar.
7. The small amount of water vaporized driving out all the air in the jar. Screwing on the lid keeps any additional air from entering the system. When the jar is placed in the cold water the gaseous water changes into liquid water with a drastic drop in pressure. The pressure inside the balloon now is greater that the pressure in the jar and the balloon expands because the trapped air is pushing against the lower outside water pressure.

CONCEPT EXTENSION

A. Upside-down Glass

1. Obtain two 8 ounce plastic drinking glasses. With a hot nail or ice pick melt a small hole through one of the gasses at the bottom edge. Try not to make the hole obvious to the casual glance.
2. Have a student volunteer come up to join you in a demonstration. Give the student the glass with the hole at the bottom. Do the following demo over a large sink or use a large pan or aquarium to catch any water that spills.
3. Indicate to the student that we will do this demo together. Say, "Watch and do as I do."
   a.) Fill the glass with water.
   b.) Place a 3 x 5 notecard on the mouth of the glass so that it covers all the opening.
   c.) Quickly turn the glass and card upside down while keeping your hand on the card which is now in contact with the water. Ask the students what will happen when the hands are taken away.
   d.) Your card will stay on with all the water trapped in the glass. There is enough air pressure to support the weight of the water. The student's card will fall off and the water will pour out.
   e.) Tell the student that your glass was a special anti-gravity glass and that you are willing to switch glasses. When the demo is repeated water does not pour out of either glass. When they inquire why water didn't come out of your glass, tell them that you have been developing special anti-gravity "mind-over-matter" powers.
   f.) When you use the glass with the hole in it casually cover the hole with your finger and everything will work well and the water won't come out.
   g.) Try to solicit explanations from the class. If they are not forthcoming quickly, tell the students that you can turn gravity off or on at will. Give them some crazy story such as if they close one eye and hold their mouth open that you have found that you can temporarily turn off gravity. Even if you can't get them to enter in, you do it. At just the right moment remove your finger from the hole and the card and water will come falling down.
   h.) Try and liken this to what happens if you have a straw full of water and you put your finger over the top end. As every student knows, the water will stay up in the straw, but when your finger is removed it streams out. Removing the finger allows the atmospheric pressure to be the same on the top and bottom of the straw. By this time some curious student will have found the hole in the bottom of the glass. If not, by all means **don't tell them what was happening**. Make them figure it out.

B. Diet vs. Classic Coke® Cans (See Gas Law Lesson, p. 114-115)

1. When the students enter the room have two Coke® cans heating on the hot plate. Using tongs pick up the Classic Coke® can, rapidly turn it upside down, and thrust it into a pan of ice water. Instantly, it will be crushed.
2. Repeat using the Diet Coke® can. This time there will be only a slight implosion of the can.

3. Students should have a good appreciation for what happens here. In the Classic Coke® can a few mL of water had been added to the can and the heating had filled the can with gaseous water. In the Diet Coke® can no water had been added, and only hot air filled the can
4. Upon rapid cooling the gaseous water changed to liquid water (the volume changed by a factor of 70) reducing the pressure inside the can drastically. The air pressure pushing in on the can and down on the water in the pan immediately crushed the can and forced water inside. In the Diet Coke® can the cold water merely cooled the hot air down with very little decrease in volume.
5. This can be demonstrated in a less dramatic way by using a plastic milk jug instead of an aluminum can. Fill the jug with hot water and let sit for a couple of minutes. Pour the water out and cap the plastic jug. In a short time the jug will start to collapse because the warm air inside is cooling which reduces the pressure, allowing the outside atmospheric pressure to push in on the walls of the jug.

C. This activity is patterned after the "old" egg in the milk bottle demonstration. In recent years it has been almost impossible to find a milk bottle, and for those of you who have done this you might also remember that sometimes the egg takes a beating and gets messy. The demo that follows is the modern day version.

1. Obtain a glass bottle (Ocean Spray® juice bottles work well).
2. Our modern day version of the egg is a water balloon having a diameter of about 10 cm. You might have to adjust this size to your specific bottle.
3. Have students try to push the balloon into the bottle. It should be large enough so that they cannot put it into the bottle by merely pushing.
4. Challenge them to get the balloon in the bottle without removing any water from the balloon.
5. It is possible that they will want to add a small amount of water, heat it, put the balloon in the mouth of the jar, and cool the jar by pouring cold water on it. I am sure that they could make this work this way, and this does show the carry-over from the CONCEPT INVENTION phase.
6. Ask them if they could do it without using additional water in this way.
7. As we remember from the old egg in the milk bottle version, a small strip of paper can be set on fire and dropped into the bottle. If the balloon is quickly put into the mouth of the bottle, the air cools in the bottle in just a few seconds which reduces its volume and the balloon is pushed in the by the greater outside air pressure.
8. How can the balloon be removed from the bottle without puncturing the balloon?
9. For those who added water to the bottle and cooled it to get the balloon in, maybe heating it would increase the pressure in the bottle enough to push it out. This is worth trying. Be careful when heating the bottle. It is not made out of Pyrex® glass and won't take a direct heat. It would probably be safer to place it in a pan of boiling water.
10. Probably an easier way is to insert a straw into the bottle, turn it upside down so that the narrow end of the bottle is pointing down, and push the straw in between the glass and rubber. A few sharp puffs of air through the straw should dislodge the balloon nicely.

D. How Tall Can a Straw Be?

1. Ask students to predict what would be the tallest straw that they could build that would allow them to drink a soda.
2. Indicate to them that they can join two, three, or more straws together to make a super straw. A short slit in one straw will allow the joining together of two straws. A tight strip of tape to prevent leakage is also recommended.
3. Have teams work on this problem. Eventually they will want to drink from the second or third stories of the school. Let them try to work it out and overcome the engineering problems.

4. The maximum height that they will be able to draw the liquid up is about 33 ft. This is equivalent to a pressure of 760 mm of mercury. In other words, the outside air pressure can only push up water to a height of about 33 feet. No matter how hard they suck, air pressure will only push water up 33 feet.
5. Because Coke® has all that sugar in it and its density is greater than pure water, they may not even be able to get it to rise 33 feet.
6. Essentially, the students have demonstrated how a water barometer could be constructed. After this activity it should be obvious why we use mercury in our barometers instead of water.

E. Ask students to research why their ears pop when ascending in an airplane?

1. When a quick and drastic change in altitude occurs a difference in pressure is created between the air in the middle ear and the air outside the body.
2. This difference is equalized either by air rushing into the Eustachian tube or escaping from it by way of a valve-like flap, and causing the eardrum to bend inward (if the plane is descending) or outward (if the plane is ascending).
3. This is why many people chew gum when flying since this type of activity keeps the Eustachian tube open and the air pressure equalized.

F. Ask students to research what causes their knuckles to crack or pop when they pull on their fingers. Ask them to crack the same knuckle twice within five minutes. They will not be able to do it!

1. Physicians have discovered that the noise we hear is caused by exploding gas bubbles.
2. Joints have fluid in them containing dissolved gases. When the joint is stretched, the pressure is reduced because the volume is increased and the gas bubbles pop out of the solution. (Same thing happens when a bottle of soda is opened.) Since the gas can't escape from the joint, in about fifteen minutes it is reabsorbed by the joint fluid. Only then can the knuckle be cracked again.

BERNOULLI'S PRINCIPLE

PROBLEM PRESENTATION / EXPLORATION

A. Set up three stations with the following challenges.

1. Suspend two apples, or ping pong balls, about 3 cm apart from a horizontal support.

   INSTRUCTIONS: What do you expect will happen to the apples when you blow in between them? Do it and observe what happens.

2. Take a 3 x 5 index card and draw two lines each 1 inch in from the end. This will produce a 3 x 3 square and two 3 x 1 in rectangles. Fold the two one inch flaps at right angles to the card Place the card on the table so that it is resting on its folded edges.

   INSTRUCTIONS: Predict what will happen when you blow air through a straw at the card. Do it and observe what happens.

3. Light a candle and set it on the table. Direct a funnel at the center of the candle flame and blow the candle out. Blow through the narrow end.

   INSTRUCTIONS: Predict what will happen when you blow through the funnel at the candle flame. Do it and observe what happens.

B. At each station students will not be able to accomplish what appears to be the common sense outcome.

1. At the first station the apples will move closer together instead of farther away.
2. At the second station the center of the card will bend downward and the card will not flip over.
3. At the third station not only will the flame not go out but it will actually be drawn back toward the center of the funnel.

CLASS RESPONSE / CONCEPT INVENTION

A. Fluid Motion and Pressure

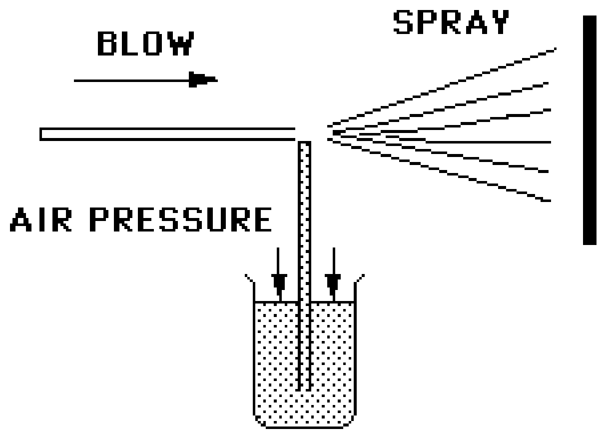
1. In each of the above examples the key ingredient was the presence of a moving fluid. The fluid common to these three examples was air, however, we will see that other fluids also demonstrate the strange properties we encountered above.
2. The next time you take a shower make some observations about the shower curtain. Before the shower head is turned on the curtain is hanging vertically. But when the fast moving water is moving past the inside surface of the curtain what does it do? The curtain moves inward. Why? From our lesson on air pressure we know that when the curtain was handing vertically that there was the same pressure on one side as there was on the other side. Also from the lesson on air pressure we know that when pressure is lowered there is an unbalanced force and something must move in response to the unbalanced condition. On which side of the curtain is there lower pressure when the shower is running?
3. Situations similar to the shower curtain caused Daniel Bernoulli to propose that there is a relationship between the speed of a moving fluid and the pressure it creates.
4. Most people think that the atmospheric pressure is very high in a tornado. Actually, the opposite is true. Even though the winds are blowing fiercely, the pressure within the tornado is much lower than normal moving air on a nice spring day. From this we might suspect that Bernoulli's Principle states that as the speed of the fluid increases the pressure in the fluid decreases.
5. What if we could measure the pressure being exerted by a moving fluid? We

would be in a position to see if Bernoulli was correct in his observations.

6.. We have all seen streams where water was gently moving along in the stream. Suddenly the stream narrowed. What happened to the velocity of the water passing through the more narrow portion of the stream? The water must speed up in the constricted region if the flow is to be continuous. Did the pressure exerted by the water decrease as predicted by Bernoulli?

C. Experimenting with a homemade atomizer

1. What do carburetors and perfume atomizers have in common? Almost everything except the liquid involved.
2. How does a perfume atomizer work? You squeeze the bulb and force air over the opening to a tube that is reaching down into the liquid perfume.
3. The fast moving air moves across this opening, lowers the pressure. The atmospheric pressure pushes down on the surface of the liquid perfume which pushes the perfume up the tube where it is mixed with the fast moving air. The liquid is broken into many small particles (atomized) and sprays out into the room.



4. The basic atomizer
   a.) Put about 300 mL water in a 400 mL beaker and add some food coloring.
   b.) Cut a plastic straw with a knife or scissors but leave a slight hinge connecting the two pieces. Bend the one half at a 90° angle.
   c.) Lower the vertical portion into the water. Blow through the open end of the horizontal part of the straw.
   d.) Aim the atomizer at a piece of white paper a few centimeters away. Observe what happens.
   e.) If you have difficulty getting it to spray, cut the straw through thoroughly and try moving the horizontal part slightly with respect to the vertical straw.
5. If you blow harder one time than another, what effect will it have?
   a.) Lengthen the vertical portion of the setup by using the entire length of another straw.
   b.) Blow with different intensities and see if you can detect any difference in how far up the liquid rises in the vertical straw. Did the times when you blew hardest, which would mean that the air was moving faster across the top, result in the liquid rising higher?
   c.) Does this match with what Bernoulli said? [Faster moving air lowers the pressure more at the top of the straw so that the atmospheric pressure can push the liquid up higher.]
6. We saw that as the water in a stream was constricted that the water flowed faster through the constriction.
   a.) Examine an eye dropper. If you blow through it, the air will be moving faster through the narrow point that it is moving through the barrel of

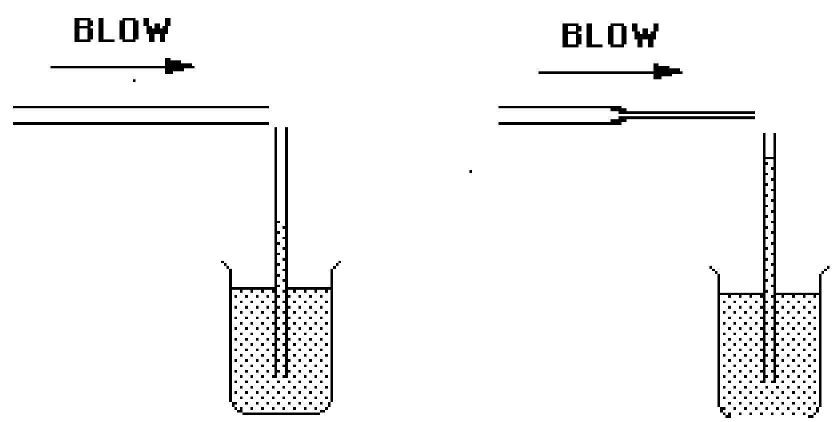
the dropper.

b.) Rather than using a commercial eye dropper lets make one. Simply take a piece of glass tubing and heat it up in a Bunsen burner flame or a propane torch flame. After a short time the glass will start to sag in your hands. Take it out of the flame and pull on both ends of the tubing. It will stretch and be constricted in the middle. With a file score and break the constricted tubing in the middle. You now have two long needle nosed eye droppers. Adjust the length of the dropper so that the opening of the small end is only about one fourth as big as the diameter of the original tubing.

c.) Cut another piece of tubing, that has not been heated, to the same length as your needle nosed dropper.

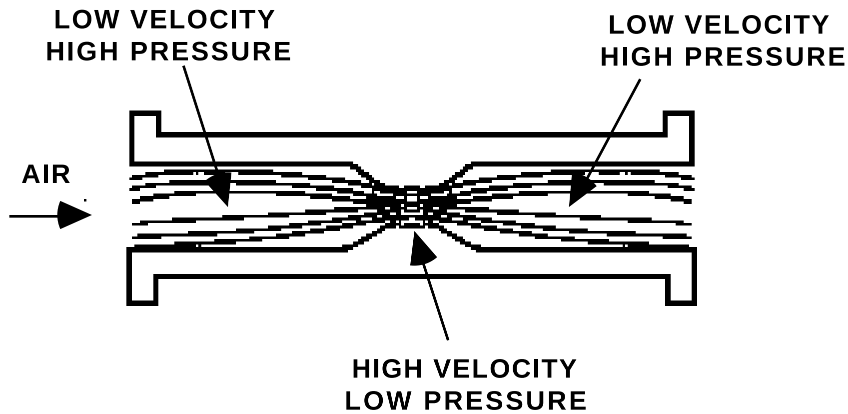
d.) We now can blow into these two droppers with the same amount of breath and feel confident that the air rushing out of the needle nosed dropper will be moving faster when it comes out than the air coming out of the normal piece of glass tubing.

e.) This time we can compare how high the water climbs in the vertical tube of the atomizer when the speed of the moving air is different.

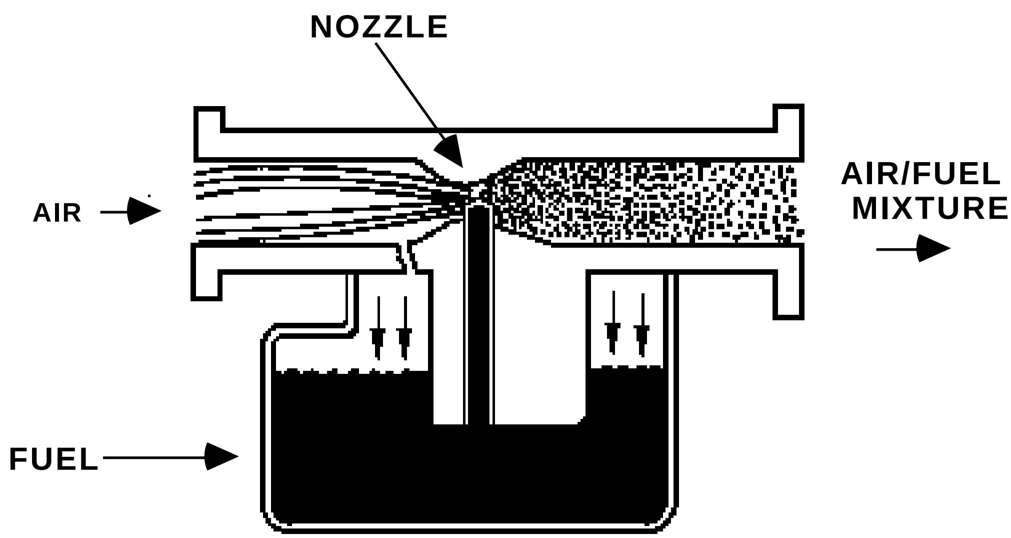


D. The Venturi tube in a carburetor

1. Using the Bernoulli principle the diagram below should be easy to understand.



2. This type of configuration is referred to as a Venturi tube. The portion of the tube where the fluid is moving the fastest is where the pressure is the lowest.
3. A simple sketch of a portion of a carburetor employs the idea of both the atomizer and the Venturi tube.



4. As the air enters the line on the left it has low velocity and high pressure. As it comes to the restricted part the velocity increases and the pressure decreases. This is the position at which the nozzle coming from the fuel bowl is attached to the air line. This lower pressure allows the fuel to be pushed up the nozzle and enter the air flow. On the other side of the restriction the velocity lowers and the pressure increases.

E. Using the Bernoulli principle to explain the opening discrepant events
1. Blowing in between the two apples that were hanging down vertical speeded the air flow on the side of the apple facing the center. This lowered the pressure on this side and the apples. Because the air pressure on the side furthest from the center did not change, the apples moved toward the center.
2. Blowing air underneath the index card lower the pressure on the under side and the card sagged. It could not be tipped over by blowing unless someone tried blowing of the top of the card. This might work. Since the pressure on the top of the card is lower providing enough air might turn it upside down.
3. No matter how strongly you blow through the funnel the candle flame will not

go out. In fact it is actually drawn toward the funnel instead of being blown the other way. How does Bernoulli explain this? The air you blow in has a tendency to flow along the inside surface of the funnel. Almost none of your breath travels down the center of the funnel. This rapidly moving air rushes along the sides and creates a low pressure area in the center. Since the pressure on the other side of the flame is higher than this newly created low pressure area, air moves toward the funnel making the flame to flicker toward the mouth of the funnel.

CONCEPT EXTENSION

A. Floating a hard boiled egg

1. Hard boiled eggs normally sink when placed in water. Place one in a tall narrow glass.
2. CHALLENGE: How can you lift the egg up to the surface without turning the glass upside down. You many not reach in with your hand or any tool to grab it and raise it to the surface.
3. If there are no forthcoming suggestions from the students, tell them that all they need is water.
4. Move the glass and egg under a water tap. Turn the water on and adjust the flow to be steady. (You need to test out what flow you need before giving this challenge to the students.)
5. Hold the vial with the glass and egg under the water stream. The water must fall directly on top of the egg. Mysteriously the egg will rise to the water surface!
6. Ask the students what will happen if the water stream suddenly stopped?
7. Have students explain what is going on here. [Bernoulli's Principle says that the fast moving fluid (water in this case) cause lower pressure. At the correct flow of the stream of water there will be a pressure above the ball low enough so that the upward force of the overflowing water will cause the egg to rise to the surface. A sudden stop of the water flow will make the egg sink.]

B. Ping pong balls and funnels

1. Place a long-stem funnel next to a ping pong ball. "I bet you can't pick up the ball with the funnel without sucking through it. You may not touch the ball with your hands or any other tools. The funnel must at all times remain above the table."
2. Someone will surely figure out that instead of sucking air up through the funnel they need to blow air out through the funnel, especially since this is in a Bernoulli's Principle lesson.
3. Pick up the funnel and place it over the ball and blow through the stem while picking up the funnel. The ball will come with it.
4. As we saw when trying to blow out the candle flame through the funnel, there is a region of lower pressure in the center of the funnel. Since this is over the top of the ball the pressure is lower here that underneath. If you have enough wind you can point the funnel at all different directions and it won't come out of the funnel. Even pointing straight upward and blowing as hard as you can won't dislodge the ball from the funnel.

C. Ping pong balls and wine glasses

1. You will need two identical wine glasses (plastic are safer) and a ping pong ball (The old party trick books say you can use a hard boiled egg, but I have never had very good luck with the egg.)
2. CHALLENGE: Place the two wine glasses about 3 cm apart. Its a good idea to tape them down or at least have someone hold them down. Challenge a student to move the ball from one glass to the other without touching the ping pong ball with your hands.
3. After awhile you can demonstrate that it is possible. Blow a short and hard puff of air into the far side of the wine glass holding the ball. Magically, it leaps from one wine glass to the other wine glass.
4. Blowing obliquely over the top surface of the ball does two things. It lowers

the pressure on the top edge of the ball. It also directs the flowing air to the far side which bounces off the far wall of the glass down to the bottom and upward carrying the ball. Because the pressure is lower on the top of the ball, it jumps out of the glass. The harder you blow the farther apart the glasses may be positioned. [Try it; it really works!]

D. One more funnel trick

1. You will need a funnel and a coin. Hold the funnel upright and place the coin inside the funnel.
2. CHALLENGE: Try to turn the coin over by blowing into the wide mouth end of the funnel.
3. It will be almost impossible to blow the coin over without covering the spout with a finger. When the spout is covered, it is very easy to flip the coin.
4. With the spout uncovered, some of the air passes through the small spaces between the coin and the side of the funnel, tending to equalize the pressure below and above the coin. When the spout is covered air cannot get out below the coin, and more is blown across the top of the coin. According to the Bernoulli principle, the moving air above the coin has less pressure than the still air below, and tends to lift the coin slightly. Then the air catching below it flips it over.

E. The spool and the card

1. Take an ordinary index card and hold it up close to the mouth and blow against it. The card will float off toward the ground. Blow through the opening of a spool at the card. This card too will float off toward the ground.
2. Now Push a straight pin through the center of the card. With the card resting flat against the spool make sure that the pin is loosely hanging in to the hole.
3. With your finger on the pin and card raise the spool/card to your mouth and blow hard. Have students predict what will happen. When you blow hard and let go of the card with your finger the card will stick against the spool. You may aim it upward, outward, or even downward and the card will float at the surface of the spool. Of course when you run out of air to exhale, the card will fall to the ground.
4. Have students reason through this one.
5. By blowing in the hole of the spool the air is moving fast when it comes out the other end. It moves over the surface closer to the spool at this rapid pace. According to Bernoulli the pressure on this side of the card will be higher than on the other side of the card. The normal air pressure will then hold the card to the spool as long as the fast moving air is moving over the surface of the card.
6. The reason that the straight pin is needed is to keep the card from moving horizontally away from the source of the steady stream of air.

F. Some questions to ponder

1. When high-speed trains pass each other, they must slow down or their windows will be broken. Why? Will the windows be pushed into the train or sucked out. If you are standing near a high-speed train, will you be pulled toward or pushed away from the tracks? [The fast moving air between them lowers the pressure so much that windows will be pushed outward by the normal air pressure inside the train which is now so much higher than the low pressure outside the train.]
2. Are insects squashed directly on the windshield of fast moving cars, or do they rupture in the air and then splatter on the windshield? [As the air is accelerated up over the hood and windshield the pressure becomes so low that the bugs actually rupture because the pressure on their insides is greater than the lower pressure they are feeling on their outsides.]

BAKED ICE-CREAM

PROBLEM PRESENTATION / EXPLORATION

A. What happens if you leave ice cream at room temperature? What would happen to ice cream if you put it in the oven?

B. The CHALLENGE in this experiment will be to make **baked ice cream.**

C. The materials needed are 3 egg whites; spoon or egg beater; 125 mL sugar; a big, thick, hard, cookie (such as a Chinese almond cookie); 250 mL ice cream, any flavor; a cookie sheet; aluminum foil; and an oven. (Depending upon school facilities, you may want to make this a homework assignment.)

D. Heat the oven to 500°F (260°C). Cover the cookie sheet with aluminum foil. Beat the egg whites until they form soft peaks. Add the sugar to the egg whites, 15 mL at a time, beating after each addition. Continue to beat until the mixture is thick and glossy. Next, place the cookie on the cookie sheet and place the ice cream on top of the cookie, taking care to insure that the ice cream does not spill over the edge of the cookie. Next, spread the egg white and sugar mixture over the ice cream, covering it completely. Bake on the bottom rack of the oven for 3 to 5 minutes until the mixture is light brown. Stick a thermometer into the middle of the baked ice cream and record the temperature at the center. Remove and taste the results.

CLASS RESPONSE / CONCEPT INVENTION

A. What happened? Apparently not enough energy was transmitted through the outside layer of meringue to melt the ice-cream at the center. What caused this to happen?

B. Many times we want to keep hot things hot and cold things cold. This is accomplished by insulating the substance so that very little energy can travel out (if we want the object to remain hot) or so that very little energy can travel in (if we want the object to remain cold.)

C What are some insulating materials.
  1. Styrofoam
  2. Fiberglass
  3. Shredded newspaper
  4. Wool
  5. Feathers

D. Setup
  1. The day before conducting this activity pour exactly 120 mL of water into each of five clean, half-pint milk cartons. Freeze them overnight.
  2. Obtain different insulating materials to be tested.
  3. Surround the first carton with one insulating material (newspaper, for instance).
  4. Put the second carton into a small ice chest and close the top.
  5. Surround the third carton with Styrofoam peanuts.
  6. Surround the fourth carton with fiberglass.
  7. Set the last carton on a table with no cover or insulation.

E. Results
  1. Wait three hours.
  2. Measure the amount of water (melted ice) in each container separately by pouring it into a graduated cylinder.
  3. Determine which insulator best prevented the flow of energy into the milk carton of ice.
  4. Obviously some materials are much more effective insulators than others. Most insulating materials are poor conductors of heat themselves, but almost all insulators have another feature or ingredient in common. What is this? [Air itself is a poor conductor and is incorporated into almost all insulators to make them an overall more effective insulator.]

F. How can we account for the results witnessed in the baked ice-cream? [The purpose of whipping the egg whites was to incorporate a lot of air. These air pockets in the meringue act as barriers to the energy from the oven penetrating the outside meringue layer around the ice-cream.

CONCEPT EXTENSION

A. How do Eskimos survive in the winter in an igloo? Why don't they freeze to death? What is the temperature inside an igloo? [Ice is a good insulator. Ice 12 inches thick has an R-value of 9 which is much higher than wood, newspaper, or rigid foam board.]

B. How do storm windows cut down on heat loss in the winter? [Air is trapped between the regular window and the storm window. Since air is a poor conductor of heat, it does not transfer much heat from in inner window to the outer window.]

HEAT

PROBLEM PRESENTATION / EXPLORATION

A. How does the temperature of water change as chemicals are added to it?
   1. Arrange three test tubes in a test tube rack.
   2. Add 5 mL of water to each test tube and insert a thermometer in test tube A.
   3. After one minute record the temperature of the water.
   4. Using a plastic spoon add 3 pellets of chemical A to the test tube. Record the starting time and temperature.
   5. Now read the water temperature every 15 seconds for a total of three minutes.
   6. In the second test tube insert a thermometer and record the starting temperature of the water after one minute.
   7. Using a plastic spoon add one half spoonful of chemical B to test tube B.
   8. Read the water temperature every 15 seconds for a total of three minutes.
   9. In the third test tube insert a thermometer and record the starting temperature of the water after one minute.
   10. Using a plastic spoon add one half spoonful of chemical C to test tube C.
   11. Read the water temperature every 15 seconds for a total of three minutes.

B. Endothermic vs. Exothermic
   1. Obviously, all chemicals don't act the same way when dissolved in water. The sodium hydroxide (chemical A) dissolved and released energy in an exothermic process; the ammonium nitrate (chemical B) removed energy from its surroundings (an endothermic process) as it dissolved ; and the table sugar (chemical C) did neither as it dissolved.
   2. After the students have had some hands-on experience with exothermic and endothermic reactions you might like to demonstrate a very interesting one for them.
      a.) Set the top of a Petri dish on the demonstration table. Place 1 mL of water in the dish.
      b.) Place 20 g of $Ba(OH)_2 \cdot 8\ H_2O$ in a clean, dry 50 mL beaker. To this same beaker add 10 g of NH_4Cl.
      c.) Place the beaker in the water in the Petri dish.
      d.) Carefully, stir the mixture inside the beaker with a stirring rod. [No water is added to the beaker.]
      e.) Wait several minutes and carefully lift the beaker. Because this reaction is so endothermic, it removes enough energy from the water that the water freezes.
      f.) DISPOSAL: *Dissolve the reaction mixture in the beaker in the smallest possible volume of water. Add 5 volumes of 10% aqueous sodium sulfate. Set aside for one week. Filter. Discard the filtrate at the sink. Discard the solid with ordinary trash.*
   3. Another very interesting demonstration that is not as messy and with no disposal problems illustrates a spectacular exothermic reaction.
      a.) A portable hand-warmer can be purchased from Wal Mart for three or four dollars that appears to be a clear liquid in a flexible plastic package. (The brand name for this warmer is Heat To Go®. It is made by Sunbeam.)
      b.) Inside the plastic package is a little metal clicker. Upon clicking it an instantaneous reaction takes place. White solid crystals start to come out of solution.
      c.) At the same time a large amount of heat is released. The directions on the package indicate that the hand warmer will stay hot for up to an half hour.
      d.) The solution inside is a supersaturated solution of sodium acetate. Upon disturbing the equilibrium by clicking the metal disk the excess

solute comes out of solution. Since dissolving is an endothermic process, the reverse is an exothermic process.

e.) In addition to the spectacular reaction this process is entirely reversible. By dropping the pouch into boiling water (or placing into a microwave oven) the white solute will go back into solution. Allowing the pouch to cool leaves the original clear solution ready to be released when the metal disk is clicked again.

CLASS RESPONSE / CONCEPT INVENTION

A. Heat vs. Temperature
   1. Quite often students confuse temperature and heat.
      a.) Heat is the measure of the quantity of energy in a system.
      b.) Temperature is the measure of the intensity of that energy in the system
   2. If you have a bathtub full of water and a bathroom sink full of water, both having a temperature of 30°C, which will be able to melt more ice cubes?
      a.) Both have the same intensity of energy meaning that for each cm^3 of water in both cases there is the same amount of thermal energy concentrated; therefore, they both have the same temperature.
      b.) But, it is obvious that the bathtubfull of water could melt a lot more ice cubes that the sinkfull of water can because the bathtub contains a lot more energy or heat than the sink.
   3. From the above example it should be clear that one can not measure the amount of heat a system contains by measuring just its temperature.
   4. Different instruments are needed to measure temperature and heat.
      a.) A thermometer is used to measure temperature.
      b.) A calorimeter is used to measure heat.

B. Heat can only be measured when energy is being transferred from one object to another.
   1. To measure temperature we simply stick a thermometer into the substance and read the intensity or concentration of the thermal energy in the substance.
   2. Unfortunately, there is no instrument that we can stick into a substance and determine its heat content.
   3. The best we can do is to measure the amount of energy that is being transferred from the hot source to the cold source.
   4. Heat will always flows spontaneously from the hot source to the cold source. In the case of the ice cubes and the bathtubfull of water, energy from the water (hot source) flowed into the cold source (ice cube) which melted the ice cubes and then even heated the ice cold water up to produce warm water.
   5. Just for the record, there is no such thing as a substance called COLD. Cold is merely the lack of heat or energy.
   6. To measure the heat being transferred from one object having a lot of energy (hot source) to an object having less energy (cold source) we use a calorimeter.
   7. The Law of Conservation of Energy says that in all reactions energy is neither created nor destroyed. Analyzed in terms of the ice cubes and bath water from the above example, this means that the energy lost by the hot bath water was gained by the ice cubes. In other words, no energy was lost, it simply was transferred from one place to another.

C. The Law of Heat Loss and Heat Gain
   1. We know that temperature is measured in °C. Since temperature and heat are different, we can not measure heat in °C, rather, it is measured in calories (or joules).
   2. A calorie is defined to be the amount of energy needed to raise a gram of water by one °C.
   3. Place 50 grams of water in a Styrofoam® cup, measure its temperature with a thermometer, and record.

4. We need some type of heat source for our experiments. Probably the best would be one of those immersion heaters made to put into a single cup to heat water for making coffee. They cost about $2.50 apiece. Candles could also be used. If candles will be used, the water must be put into a beaker rather than a Styrofoam® cup.
5. Place the heater in the cup and allow it to put heat into the water for a constant time in each experimental trial. (Probably one minute will be enough. It depends on how much heat your heater puts out. It would be nice to get a change in temperature of at least 10°C.)
6. Record the change in temperature for this standard amount of heat being added to 50 grams of water. After determining the change in temperature pour the water down the sink.
7. Repeat the experiment using 100 grams of water and record the results.
8. Finally, repeat the experiment using 150 grams of water.
9. What pattern seems to be developing? [**With the quantity of heat being added constant**, the change in temperature gets smaller as the mass of the water gets larger. In other words, the **mass is inversely proportional to the change in temperature**.]
10. This time lets hold the amount of mass constant and develop the relationship between the change in temperature and the quantity of heat.
11. Place 100 grams of water in three Styrofoam® cups and record their initial temperatures. (They should all be allowed to come to the same temperature if they are not so when poured into the three cups.) Place the heater in cup #1 for 30 seconds and record the rise in temperature.
12. Place the heater in cup #2 for 60 seconds, record the temperature. Place the heater in cup #3 for 90 seconds, record the temperature.
13. What pattern seems to be developing? [With the mass of water remaining constant, as the amount of heat added goes up, the change in temperature also increases.] In other words**, if the mass is held constant the quantity of heat is directly proportional to the change in temperature**.]
14. The third relationship is more cumbersome to carry out. This time we want to make the change in temperature remain constant for the three experiments. Lets pick an arbitrary change in temperature that we want to use. Lets pick 10°C.
15. Place 50 grams of water in the Styrofoam cup. Measure its initial temperature and leave the thermometer in the cup as the heater is introduced. Lower the heater and watch the change in temperature while your partner watches the time. When the temperature has risen 10°C record how much time the heater has been putting heat into the water. The measure of time will substitute for our measure of heat since we are assuming that the heat being put into the water is constant with respect to time.
16. Pour out the water from the first trial and add 100 grams of fresh water. Repeat the procedure from step #15 with 100 grams of water. Make sure that you do everything in the same way for all three trials. Record how long it takes for the 100 grams of water to increase 10°C. Carry out the same procedure for 150 grams of water.
17. What pattern seems to be developing? [With the change in temperature being held constant, as the mass of water increases so does the amount of heat added. In other words, **if the change in temperature is held constant, the quantity of heat added is directly proportional to the mass**.]
18. So far, we have only investigated the relationship of the quantity of heat, the change in temperature, and mass with one substance, water. Do the relationships we have developed hold true for other substances? The answer is yes. But before we sum up all of our findings into a neat package, one small detail must be considered. We need to look at the idea of specific heat.

D. Specific Heat

1. Would equal masses of **different** substances contain the same amount of energy if heated to the same temperature?
2. For this comparison you will need 100 g of pennies, 100 g of nickels, 100 g of aluminum nails, and 100 g of water. Make sure you use pennies minted after 1982 so that all of the pennies will have the same composition. As we have seen in other experiments the government mint changed the composition from about 95% copper and 5% zinc to 95% zinc and 5% copper in 1982. Since each penny weighs about 2.5 g, it will take about 40 pennies to make up 100g . Stack the pennies one on top of each other and wrap masking tape lengthwise around them so that you will have a cylinder of pennies. It will probably take about 20 nickels to weigh 100 g. Wrap the stack of nickels in the same fashion as you prepared the pennies. Weigh out 100 g of aluminum nails and place some masking tape around them to keep them in a bunch. To get 100 g of water simply measure out 100 mL.
3. A large Styrofoam calorimeter should be prepared by weighing out 300 g of room temperature water and pouring it into the cup. A thermometer must also be introduced into the cup and the initial temperature noted. The calorimeter should be emptied after each trial and filled with new water before testing the other substances.
4. A large beaker of water needs to be heated up to boiling over a Bunsen burner. The roll of pennies, roll of nickels, and the bunch of nails should be placed into the boiling water and left there for at least five minutes to insure that they have heated up to the boiling point of water (100°C).
5. With tongs reach into the boiling water and pull out the pennies, quickly pat them dry with a paper towel and quickly lower them into the first calorimeter cup. Take care not to splash any of the water out of the cup. Immediately note the rise in temperature and record the highest temperature the thermometer reaches. This will probably be in less than a minute.
6. Repeat the procedure of step #5 with the roll of nickels and bunch of nails in separate calorimeters.
7. Finally, quickly measure 100 mL of the boiling water into a graduate cylinder and add it to the fourth calorimeter cup.

Substance (100 g)	Initial T (°C)	Final T (°C)	ΔT (°C)
Pennies			
Nickels			
Nails			
Water			

8. We assume that the quantity of heat that each of the substances above gave up was all absorbed by the water in the calorimeter cup. From the above table we see that equal masses of different substances heated to the same temperature do not contain the same amount of heat since each substance made the 100 g of water at room temperature heat up to different final temperatures.
9. The property of matter that describes how much heat it takes to raise the temperature of 1 gram by 1°C is known as the substance's specific heat. (abbreviated with a small **c**) .
10. From the data in the table we can see that water has the largest specific heat, followed by aluminum nails, followed by nickels, and finally last the pennies.

E. $q = mc\Delta T$

1. Finally we are ready to summarize all of the experiments that we have done and put them into an equation that can be used to determine the heat absorbed or lost by any substance.
2. We have seen that the mass, the change in temperature, and now the

specific heat all are important in determining the quantity of heat lost or gained by a substance.

3. Mathematically they can be combined into $q = mc\Delta T$.
   a.) We see that the mass is directly proportional to the quantity of heat absorbed or lost.
   b.) We see that the change in temperature is directly proportional to the quantity of heat absorbed or lost.
   c.) We see that the mass and change in temperature are inversely proportional.
   d.) For every different substance there is a constant specific heat that does not vary .

F. The importance of $q = mc\Delta T$ can be seen in the following investigation.

1. Of almonds, cashews, and walnuts which has the greatest number of calories. In other words, if burned which would release the most amount of heat?
2. We can set up the experiments to find out the answer to this problem.
3. We will burn equal masses of the three types of nuts. The heat lost by the nuts will be collected by heating up a known quantity of water. By measuring the change in temperature of the water we will be able to calculate the quantity of heat given off by each of the different types of nuts. (Remember, the heat lost by the nuts equals the heat gained by the water.)
4. We will need a beaker with 100 g of water, a thermometer, the three kinds of nuts, a paper clip, some clay, a tin can, a nail, and a hammer.
5. Prepare the small tin can by removing either the top or the bottom with a can opener. With the nail, punch at least ten holes through the can.
6. Bend a paper clip so that it has a flat triangular base with the short prong bent upward. This will be used to spear the nut. Firmly place the paper clip base on the wad of clay. The clay can be used to adjust the height so that the flame hits the top of the can.
7. The beaker with the water should be placed on top of the can. The initial temperature reading must be taken and recorded.
8. The nut must be ignited with a match. Quickly the can should be lowered over the burning nut. The flame should be directed at the top of the can upon which sets the beaker of water.
9. Monitor the change in temperature, recording the highest temperature reached by the water. Check to see that all of the nut has burned and not fallen onto the table.
10. Using $q = mc\Delta T$ calculate the amount of heat gained by the water. [m = 100 g; c = 1 cal/g °C; ΔT will be determined by finding the difference between the initial temperature and the final temperature.]
11. Determine which type nut releases the most heat. [Walnuts should have the most, and the cashews the least.]
12. As the students can see, we have an indirect way of measuring the amount of heat transferred in reactions by capturing it in a calorimeter and then using $q = mc\Delta T$ to determine the quantity of heat lost or gained.
13. Other interesting fuels are Cheeze Puffs®, marshmallows, and some breakfast cereals.

CONCEPT EXTENSION

A. Does Sand or Water Hold More Heat?

1. It would be very bothersome to determine whether sand or water had the larger specific heat by repeating the experiment we did with the pennies, nickels, and nails. But there is an easy way to make the comparison between sand and water.
2. Partially inflate a balloon and then add 200 g of water. Tie off the balloon. To a second balloon add 200 g of sand, blow it up to about the same total volume as the water balloon, and tie it off. Finally inflate a third balloon with air to about the same volume as the other two balloons.
3. Ask the students to predict what they think will happen when a flame is

brought near each of the three balloons.

4. Tell them you will volunteer to test the balloon having only air. As the flame comes near the balloon the balloon will burst due to the heat rupturing the stretched surface of the balloon.
5. Have a student put on safety glasses and hold a lit match under the balloon with the sand. Allow the flame to almost touch the balloon. Observe what happens.
6. Have another student put on an apron and hold a lit match under the balloon with the water. Once again, allow the flame to almost touch the balloon. Observe what happens.
7. The balloon with water will not burst. The balloon with sand will heat up and burst. Ask the students to explain why this apparently happens. [The specific gravity of water is very high, so high that it can absorb the heat from the match and not increase the temperature of the system enough to rupture the balloon. On the other hand, the sand can not absorb very much heat and soon the heat will all be going into the rubber of the balloon which means the balloon will burst and all the sand will scatter.

B. Boil Water in a Paper Bag

1. Most students will not believe that you can boil water in a paper bag, but you can. The specific heat for water is so high that the temperature of the bag never reaches its kindling temperature.
2. The bag may look a little worse-for-wear but it will not catch on fire while there is still liquid water inside absorbing the energy from the flame.
3. Do not try plastic bags.

C. Predict the final Temperature When Hot and Cold Water are Mixed

1. In a final challenge have the students predict what the final temperature will be when
   - a.) 60 g of water at room temperature (22°C) are mixed with 60 g of water at 50°C [36.0°C]
   - b.) 30 g of water at room temperature (22°C) are mixed with 60 g of water at 50°C [40.6°C]
   - c.) 30 g of water at 50°C are mixed with 60 g of room temperature [33.2°C] water [31.3°C]
   - d.) 40 g of water at 50°C are mixed with 60 g of room temperature (22°C) water [33.2°C]
2. Each of these can be intuitively solved but for that student who has had algebra the equation $q = mc\Delta T$ could be used to help solve this problem.

D. Have a contest to see who can, by adding some substance found around the house, make water freeze at the lowest temperature. If they need a suggestion, ask them what you add to the ice when you make home-made ice cream to lower the temperature in the ice-cream freezer? [Salt]

1. To make the competition fair, everyone must use 100 g of water.
2. The lowering of the freezing point must be checked with a Celsius thermometer inserted into the water as it is freezing.
3. What is the best liquid substance that can be found; what is the best solid substance that can be found. What other strategies can be used to lower the freezing point below 0°C ?

E. Making Ice-Cream in a Tin-Can

1. Ingredients

a.	1 c milk	b.	1/2 tsp. vanilla extract
c.	1 c whipping cream	d.	nuts or fruit as desired
e.	1/2 c sugar	f.	1 egg (optional)
g.	1 c rock salt	h.	1 lb. coffee can & plastic lid
i.	spatula	j.	2 lb. coffee can & plastic lid

2. Place all ingredients in a 1 lb. coffee can and place tight-fitting plastic lid on can.
3. Place the 1 lb. can inside a 2 lb. coffee can
4. Pack crushed ice in the 2 lb. can around the 1 lb. can.

5. Pour at least 3/4 cup of rock salt evenly over ice. Place lid on can.
6. Gently roll the can back and forth on a table or floor for 10 minutes.
7. Open 2 lb. can. Remove 1 lb. can.
8. Open 1 lb. can and use a rubber spatula to stir mixture scraping sides of can. Replace the lid.
9. Drain ice water from 2 lb. can.
10. Roll back and forth for five more minutes.
11. Enjoy. Makes about three cups of ice-cream.

F. Ziploc® Bag Ice Cream

1. Ingredients
    a. 2 sandwich Ziploc® bags
    b. 2 1-gallon-size Ziploc® bags
    c. 1/2 c cream or half-and-half
    d. 1/4 c milk
    e. 2 Tbs. sugar
    f. 1/8 tsp. vanilla
    g. 1 beaten egg (optional)
    h. 3 c crushed ice
    i. 1/2 c rock salt
    j. mixing bowl
2. Make sure everything is cold, including the mixing bowl.
3. Mix the cream, milk, sugar, vanilla, and egg in the mixing bowl
4. Pour this mix into the double sandwich-size Ziploc® bag. The bags need to be double thickness to prevent any leaks. It goes without saying that the bags should be sealed tightly.
5. Pour the crushed ice and rock salt into the double gallon sized Ziploc bag.
6. Place the small bag of ice cream mix inside the large bag of ice and salt. Once again, make sure everything is sealed tightly.
7. Watch what happens while you gently rock the bag for abut five minutes (don't rock too hard, or you'll end up with salty ice cream!)
8. When the ice cream looks frozen enough, remove the small bag and rinse it in cold water to remove any salt on the outside.
9. This makes about one big scoop of ice cream. If you prefer, it can be put into the freezer to let it get even harder.

GAS LAWS

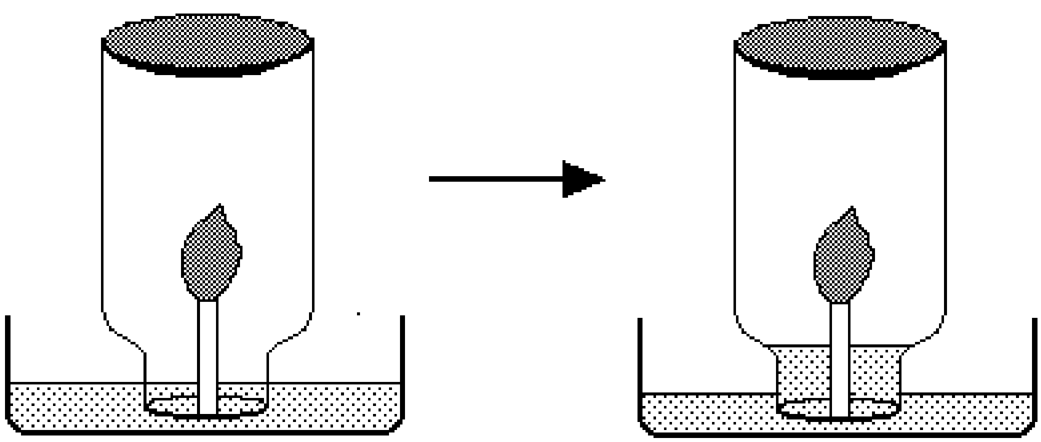
PROBLEM PRESENTATION / EXPLORATION

A. The Collapsing Soft Drink Can

1. The materials needed for this demonstration include:
   a.) 2 empty soft drink cans (Diet Coke® and Classic Coke®)
   b.) a plastic dish pan filled with ice water
   c.) tongs
   d.) hot plate
2. Fill the pan half full with ice water.
3. Before the students enter the class pour 5 mL of water into an empty Classic Coke® can; do not put any water into the Diet Coke® can.
4. Place both cans on the hot plate and heat them for about 10 minutes.
5. Using tongs, quickly invert the Classic Coke® can into the pan of ice water.
6. Observe what happens.
7. Now invert the Diet Coke® can into the pan of ice water.
8. Have the students try and explain what happened. [When the Classic Coke® can is inverted and placed into the ice water the can immediately is crushed. When the Diet Coke® can is inverted and placed into the ice water very little collapsing takes place.]

B. Rising Tide

1. The materials needed for each student station in this activity include:
   a.) birthday candles (a different number at each station)
   b.) 1 dish (the bottom of a large petri dish or pie plate works well)
   c.) 1 quart jar
   d.) food coloring
   e.) water
   f.) matches
2. Secure the candle to the bottom of the dish or pie pan using hot wax or clay.
3. Half fill the dish with colored water.
4. Light the candle.
5. Invert the jar and place over the candle.
6. Record observations.



CLASS RESPONSE / CONCEPT INVENTION

A. Why did the Classic Coke® can collapse but the Diet Coke® can did not? In the Classic Coke® can the water was changed to vapor and filled the can with water vapor. When the temperature was lowered the water vapor changed back into liquid water.

This takes up only about 1/70 of the volume that the vapor occupied. (Remember, the molecules are much closer together in the liquid state than in the gaseous state.) The air pressure on the outside of the can is now so much larger than the tiny pressure on the inside of the can that it collapses. In the Diet Coke® can the original air was heated up by being heated on the hot plate. But when this can was inverted and lowered into the ice water there was no drastic change in volume because the volume that the hot air took up was only reduced a small amount by being cooled down. (There was no change of state in this case.) Thus, even though the pressure on the inside of the Diet Coke® can was a little lower than on the outside, it wasn't different enough to cause the collapsing that we saw in the Classic Coke® can. You will probably see a little collapsing of the Diet Coke® can. Make note of it since this can be used to reinforce the example of Charles' Law that will be taken up later. (Charles' Law says that volume and temperature are directly proportional to each other. In other words, as the temperature of the air decreased, the volume of the air also decreased.)

B. Why did the water rise inside the jar as the candles went out?

1. In many science books an erroneous explanation has been advanced for this demonstration. It has, in the past, been used to show that the air is composed of 20% oxygen because when the candle goes out (due to there not being enough oxygen to support combustion) about 20% of the volume of the bottle fills with water. However, **this is wrong !** The amount of water entering the jar depends on a number of factors and will not rise 20% of the volume every time. Some of these factors are the number of candles, the temperature of the water, and how fast the jar is placed over the candle.
2. The first major thing wrong with this explanation is that there is just about as much carbon dioxide produced in the burning of the candle as there was oxygen used up. Therefore, the overall volume of the gas should not change much at all if this explanation were correct.
3. The second major thing wrong with this explanation is that the oxygen is not actually all used up when the candle goes out. There is a classic film loop from the old ESS curriculum that shows this by putting a mouse in the bottle in which the candle is burning. The mouse has no trouble breathing after the candle goes out since there is quite a bit of oxygen remaining.

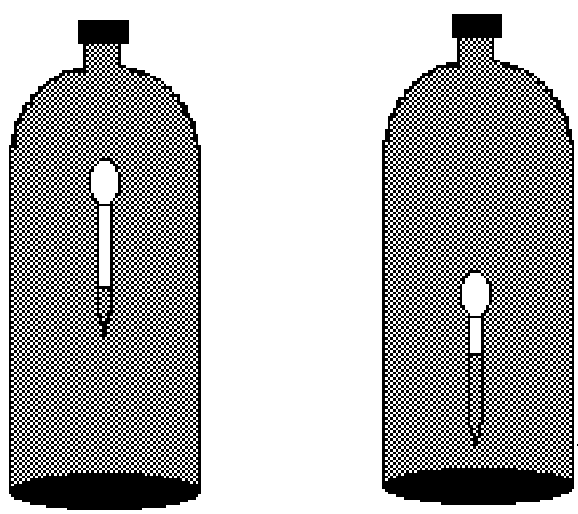
C. Why then did the water come up?

1. The foundation for explaining this can be provided by doing the following that will require these materials: a balloon, a ruler, an oven, and a freezer (This activity can be completed as a homework assignment if necessary.)
2. Inflate a balloon and tie it off. Allow enough room for the balloon to expand.
3. Using the ruler, or better yet using large calipers, measure and record the diameter of the balloon. If calipers are not available place the balloon between two shoe boxes on a table. Measure the span between the two boxes and this will be the diameter.

4. Place the balloon in an oven for 15 minutes at not more than 150°F (65°C). Remove the balloon and immediately measure and record the diameter.
5. Now, place the balloon in the freezer for 15 minutes. Remove and immediately measure and record the diameter.
6. What happened to the balloon in each case. What appears to be the relationship between volume and temperature?
7. It appears that as temperature goes up, volume goes up; and as temperature goes down, volume goes down. This is know as **Charles' Law: Temperature is directly proportional to volume, assuming that all other variables remain constant**.
8. A more correct reason why the water comes up into the bottle when the candle goes out can be seen in light of Charles' Law. While the candle was burning it heated up the air in the bottle. This caused the air to expand , pushing some of it out the bottom of the bottle as it was lowered over the candle. When the candle went out this now smaller mass of air cooled. As we have seen from above, when the air is cooled, the volume decreases. When this happens, the water rushes in to take up the space formerly occupied by the warmer air.
9. As has been mentioned above, there are other factors that contribute to the rising water. We will not investigate them at this time.

D. Boyle's Law - Cartesian Diver

1. The materials needed for each station in this activity include: a 2-L soft-drink bottle, a medicine dropper, and water
2. Remove the label from the soft-drink bottle and fill the bottle with water leaving no air in the bottle.
3. Add enough water to the dropper to cause the dropper to remain at the top of the bottle but completely submerged when placed into the 2L bottle.
4. Again make sure the bottle is filled to the top and screw the cap on the bottle and tighten.
5. Apply pressure to the sides of the bottle; release the pressure; what happens to the dropper?
6. How do you explained what happened? What is the relationship between pressure and volume of air trapped in the dropper?



BEFORE SQUEEZING **AFTER SQUEEZING**

7. Examine closely the air trapped in the medicine dropper. What happens to the amount of air when you press the sides of the bottle? What happens to

the amount of the air when you release the pressure? (According to Boyle's Law, increasing the pressure on a gas will decrease its volume. Applying pressure to the sides of the bottle increases the pressure on the water, forcing it into the dropper and reducing the volume of air in the dropper. The dropper becomes heavier and sinks. Releasing the pressure allows the volume to increase, forcing out some of the water. Since the medicine dropper now weighs less it will once again float.) Do you think the dropper would act the same way if the 2L bottle was only about two thirds full of water, in other words, the top third of the bottle was air? [You might have to squeeze a little harder, but it still works.]

8. The fancy way of stating **Boyle's Law is: The volume of a gas is inversely proportional to its pressure if all other variables are held constant.**
9. This set up is referred to as a Cartesian diver. Can you think of anything outside the laboratory that works on this principle? [Submarine]

E. If you have a vacuum pump, there are many activities that can show the relationship of volume and pressure. A vacuum pump simply pumps out air from an enclosed system. Since there are fewer molecules now present, the air pressure is lowered. When air is allowed to reenter the container the pressure will then increase.

1. Put a partially inflated balloon that has been tied off under a bell jar.
2. Connect the vacuum pump to the bell jar. What will happen when the vacuum pump is turned on?
3. Before the pump is turned on there is equal pressure felt on both the inside of the balloon and on the outside of the balloon.
4. When the pump is turned on, air on the outside of the balloon is being pumped out and the pressure under the bell jar is suddenly less than the pressure on the inside of the balloon. Consequently the balloon expands. It is trying to get back to the condition where the pressure on the inside and on the outside are once again the same. Until this happens the volume of the balloon will expand.
5. When the pump is turned off, the volume stops expanding. The resulting pressure on both the inside and outside of the balloon is equal but lower than at the beginning. Note with this lower pressure, there is larger volume.
6. What will happen when air is let back into the bell jar? Since the outside pressure is now going up, the volume of the balloon is collapsing so that the pressure inside the balloon can also increase. When the pump is stopped again, the volume will also stop changing. As the pressure went up, the volume went down.
7. What do you think would happen if you dispensed some shaving cream into a beaker and put it under the bell jar? Try it. (Remember, there is gas trapped in the soap inside the can. This gas is the propellant that forces the shaving cream out when you press the button.)
8. Try putting marshmallows under the bell jar.
9. What other interesting things might you put into the bell jar to try to show the relationship between pressure and volume of a gas?

CONCEPT EXTENSION

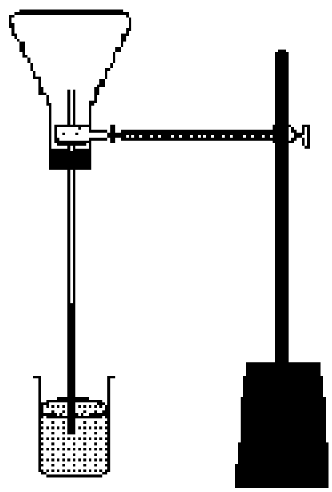
A. Will the Cartesian Diver work with liquids other than water? [In most liquids, the answer is yes]

1. Try a liquid less dense than water and one that is more dense than water.
2. Because alcohol is less dense than water it is a good choice to test. You might want to use a 1L bottle or even one smaller such as a clear plastic dish washing soap bottle so that you don't have to use so much alcohol to fill it up. Rubbing alcohol is probably the cheapest alcohol. If you are careful, the alcohol will not be harmed by simply putting a dropper into it and can be used for other experiments.
3. Because the density of the alcohol is lower than water's density you might need a longer dropper to get it to work.

4. Another liquid that could be used that is less dense than water is cooking oil. The dropper could be added right to the plastic bottle that many brands of cooking oil are packaged.
5. Many liquids that are more dense than water are not probably real safe to use. However, a 10% solution of salt is safe, cheap, and easy to make. (You need 10 grams of salt for every 90 grams of water.)
6. Another liquid that is more dense than water is 7-Up® because of all the sugar dissolved in the water. Ask the students if they think this will work? Let them try it. It won't work. Why? Let them figure this problem out. The carbon dioxide gas coming out of solution prohibits the Cartesian Diver from working properly. Once they have decided the bubbles are causing the problem, have them try and explain why they are interfering. Is there any way that 7-Up® could be made to work? Someone is bound to come up with the idea of heating the 7-Up® until all the carbon dioxide has been expelled and then using the "degassed" 7-Up®. Now it will work.

B. Since there appears to be a relationship between the volume of a gas and the temperature of the gas, could we make a thermometer made out of gas instead of alcohol or mercury?

1.



2. Constructing an "air thermometer"
   a. An "air thermometer" can be made by obtaining a Pyrex® flask with a one-holed rubber stopper fitted with a long piece of glass tubing (40-50 cm).
   b. Invert the flask so that the end of the glass tubing is well below a beaker of colored water, then clamp it to a ring stand.
   c. Heat the flask with a Bunsen burner. Note that the molecules of air inside the flask will expand and bubbles will be seen coming out of the end of the tube into the colored water.
   d. Now, place on the top of the flask a wet towel. The air will cool and contract allowing the colored water to move up the tube.
   e. When the system has equilibrated the tube can be calibrated. Mark on the tube with a grease pencil or other marking device the height of the water. From a mercury thermometer note the temperature of air in the room an assign this temperature to the mark just made.
   f. Continue to calibrate the "air thermometer" by changing the conditions to which the flask of air is subjected. Under each condition the mercury thermometer must be placed under the same conditions so that the "known" temperature can be assigned to the corresponding height of the colored water in the tube.
   g. Intermediary marks can be made between the known temperatures

by proportionally drawing lines on the tube that correspond to the difference in degrees of temperature between the known temperature marks.

3. This is a very sensitive thermometer as long as the glass tube is never allowed to stick out above the level of the colored water. If this happens it needs to be recalibrated.

ACTIVITY SERIES

PROBLEM PRESENTATION / EXPLORATION

A. Some metals react with dilute hydrochloric acid (HCl) to form hydrogen gas bubbles, while others do not. The reaction may be very slow or extremely fast, and the rate of this reaction is one way of determining the activity of a metal.

B. Let us first look at the reaction of a metal with acid (TEACHER DEMO):

$$Ca + 2\,HCl \rightarrow H_2 + Ca^{++} + 2\,Cl^{-}$$

Notice that the H_2 bubbles are released very fast, meaning that Ca is an active metal.

CAUTION: There must be no flames in the lab while this experiment is being conducted.

C. The Determination of the Relative Activity of Mg, Cu, Zn Through Hydrogen Displacement

1. Remember, if the metal does react with the acid, it is **more** active than hydrogen; if it doesn't react with the acid, it is **less** reactive than hydrogen.
2. Before each part of the experiment clean each metal briefly with sand paper.
3. Place about 3 mL of 3M hydrochloric acid in three different test tubes. Carefully drop the metal into the acid to see if it displaces the hydrogen.

Mg + HCl	Cu + HCl	Zn + HCl

4. Try to compare the rate of formation of the bubbles of hydrogen so that you can rank them according to their activity.

Mini Activity Series

Highest

Lowest

CLASS RESPONSE / CONCEPT INVENTION

A. In addition to displacement of hydrogen from acids by metals, other reactions can happen when a metal is placed in a solution of a salt of another metal. Sometimes a reaction happens, and the metals seem to switch places. The more active metal displaces the less active one.

B. Now let's look at the reaction of a metal reacting with the salt of another metal. Sometimes a reaction will happen and sometimes it won't (TEACHER DEMO).

Example: $Pb + FeSO_4 \rightarrow$ No Reaction

$Fe + PbSO_4 \rightarrow Pb + Fe^{++} + SO_4^{=}$

RULE I **If a metal, A, reacts with a solution of metal B's salt, then A is**

more active than B.

RULE II **If A doesn't react with a solution of B's salt, then A is less active than B**.

C. The Determination of the Relative Reactivity of Mg, Cu, Zn Through Displacement of Each Others' Salts

1. Place 3 mL of Mg salt solution in each of two test tubes. Place 3 mL of Cu salt solution in each of two test tubes. Place 3 mL of Zn salt solution in each of two test tubes. You should have six test tubes of solutions.
2. Carefully add a piece of Cu to the first tube, and a piece of Zn to the second tube. Observe any changes in the metal, the color of the solutions, or the change in temperature of the tubes.
3. Carefully add a piece of Mg to the third tube, and a piece of Zn to the fourth tube. Observe any changes in the metal, the color of the solutions, or the change in temperature of the tubes.
4. Carefully add a piece of Mg to the fifth tube, and a piece of Cu to the sixth tube. Observe any changes in the metal, the color of the solutions, or the change in temperature of the tubes.
5. On the basis of your observations, what is the ranking of the three metals according to their activity? Remember when using metal A and the salt of metal B, or metal B and the salt of metal A, if one reaction works the "opposite" one can't work!

	Mg^{++}	Cu^{++}	Zn^{++}
Mg			
Cu			
Zn			

Mini Activity Series

Highest

Lowest

6. If you were going to do this experiment over again, what would be the fewest number of tests that you could do (instead of doing all 6 of them) to decide the ranking? [Three]

CONCEPT EXTENSION

A. Construction of a Six Metal Activity Series

1. You will be given six metals (Mg, Zn, Fe, Sn, Cu, and Al) and asked to build an activity series.
2. The object of this experiment is to build the activity series with doing the fewest number of experiments that you can.
3. Before starting any experimentation, write out your plan, thinking how you

can build the series using the fewest steps.

4. Obviously, filling in the table below would allow you to do the job, but it can be done with less than the thirty experiments needed to fill in the table.

	Mg^{++}	Zn^{++}	Fe^{++}	Sn^{++++}	Cu^{++}	Al^{+++}
Mg						
Zn						
Fe						
Sn						
Cu						
Al						

Activity Series

Highest

Lowest

B. Determination of an Unknown Metal in the Activity Series

1. Use the unknown metal given to you by the instructor and figure out where it belongs in the activity series you have just built.
2. Describe your procedure for determining its position.

C. Any common metals and their salts may be used as unknowns. Ni or Co would probably be two good choices if you have access to them.

FACTORS AFFECTING RATE OF REACTIONS

PROBLEM PRESENTATION / EXPLORATION

A. Provide for each group the following:
   1. A bowl of ice water
   2. A beaker of hot (at least 60˚C) water
   3. A balloon large enough to fit over a one-holed rubber stopper that has been inserted into a 125 mL Erlenmeyer flask
   4. A 125 mL Erlenmeyer flask
   5. A No. 5 one-holed rubber stopper
   6. Alka-Seltzer® tablets
   7. Mortar and pestle
   8. Graduate cylinder

B. The contest is to see which group can make the Alka-Seltzer® react the fastest.
   1. Everyone must use 50 mL of water in their Erlenmeyer flask
   2. The timing will begin from the time the Alka-Seltzer® enters the flask and last for exactly two minutes.
   3. At the end of the two minutes the balloon must be pinched off and tied. (A representative from another group should be an observer so people don't blow into their balloon to increase their volume.)
   4. The winner will be the group that has made their reaction go the fastest over the two minute interval.
   5. If there is any doubt about who has won, the class must devise a way to measure the volume of each balloon.
   6. The group having the balloon with the largest volume wins.

CLASS RESPONSE / CONCEPT INVENTION

A. What were the factors considered by the groups in deciding how to make the reaction take place faster? Have the groups express their thoughts.
   1. Temperature of the water
   2. Number of tablets
   3. Surface area of the tablets (grinding them up creates more surface area)
   4. Agitation

B. How could we find out which of these factors is the most important? Once again this is a perfect opportunity for the students to practice separation and control of variables. Have them design ways to test for only one variable while holding all the others constant.

C. Temperature
   1. Place only one tablet that has not been ground up in 50 mL of water in the Erlenmeyer flask. Do not agitate the contents. Place the flask/balloon apparatus in the ice cold water and wait for two minutes. Tie off the balloon at the end of the two minutes.
   2. Place only one tablet that has not been ground up in 50 mL of water in the Erlenmeyer flask. Do not agitate the contents. Place the flask/balloon apparatus in the warm water and wait for two minutes. Tie off the balloon at the end of the two minutes.
   3. Measure the volume of the gas generated in each reaction by submerging the balloon in water and measuring the volume of the water displaced.

D. Concentration
   1. Place two tablets that have not been ground up along with 50 mL of water. Do not agitate the contents. Place the flask/balloon apparatus in the ice water and wait for two minutes. Tie off the balloon at the end of the two minutes.
   2. Measure the volume of the gas generated by submerging the balloon in water and measuring the volume of the water displaced. Compare with C1.

E. Surface Area
   1. Grind up one tablet with the mortar and pestle and transfer it to the first flask along with 50 mL of water. Do not agitate the contents. Place the

flask/balloon apparatus in the ice water and wait for two minutes. Tie off the balloon at the end of the two minutes. (Compare with C1)

2. Grind up two tablets with the mortar and pestle and transfer it to the second flask along with 50 mL of water. Do not agitate the contents. Place the flask/balloon apparatus in the ice water and wait for two minutes. Tie off the balloon at the end of the two minutes. (Compare with D2)
3. Measure the volume of the gas generated in each reaction by submerging the balloon in water and measuring the volume of the water displaced.

F. Agitation

1. Place one tablet that has not been ground up along with 50 mL of water. Place the flask/balloon apparatus in the ice water and constantly swirl for the entire two minutes. Tie off the balloon at the end of the two minutes.
2. Measure the volume of the gas generated by submerging the balloon in water and measuring the volume of the water displaced. Compare with C1.

G. Which of the factors tested were important in determining the rate of the chemical reaction? From the class observation which set of conditions would result in the very fastest reaction?

1. Determining which single factor was most important will probably be difficult because the volume of CO_2 will not be sufficiently different to give a clear answer.
2. It should be clear, however, that the reaction is speeded up if the reaction is carried out at increased temperatures, if the concentration of the Alka Seltzer® is greater, if the surface is large (powder form), and if the reaction mixture is continually agitated.
3. A very elementary explanation for this is that in order for the chemicals to react they must "bump into" each other. The greater the number of collisions, the greater the rate of reaction. By increasing the temperature the molecules move faster and have more collisions. By putting more Alka Seltzer® in the water there are more molecules to run into each other. By powdering the tablets there is more surface area for collision with the water. Likewise, the agitation brings more of the reacting molecules in contact with each other. In these ways we can account for the reaction rate being faster.

H. There is another factor that affects the rate of some reactions. To introduce this factor you will need some 3% hydrogen peroxide. This is the same hydrogen peroxide that you buy at the drug store. Also you will need some steel wool and some sand.

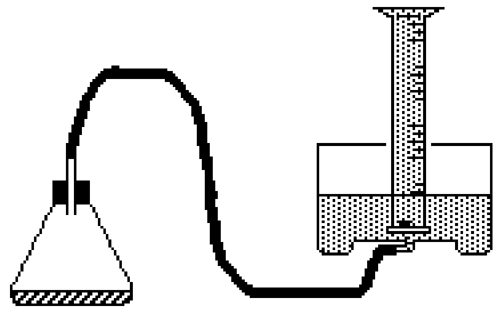
1. Place about 20-25 mL of hydrogen peroxide in each of the three beakers. Observe for a couple of minutes and note any activity.
2. Add a small piece of clean steel wool to the second beaker, and a small amount of sand to the third beaker.
3. Compare the rate of formation of bubbles of oxygen in each of the three beakers for a few minutes.
4. After 10 or 15 minutes more pour the liquid from each beaker down the sink. Flush it with a lot of water. Examine the steel wool and the sand. Are there any changes in appearance?
5. What happened to the rate of the reaction upon adding the steel wool? (It speeded up.) Did the steel wool get used up? (No).
6. What we have seen is an example of a CATALYST. A substance that changes the speed of a reaction but is not used up is called a catalyst. The steel wool was a catalyst, while the sand was not.

I. It was obvious that the steel wool and sand didn't get used up in the above reaction. The same reaction can be carried out using a catalyst that dissolves in the hydrogen peroxide and will not be seen after the reaction but is still there. If the liquid would be evaporated off it would be the same as with what we started.

1. In the sink or in a bucket submerge 50 mL graduated cylinder. Push one end of a rubber hose up into the submerged graduated cylinder.
2. Attach to the other end of the hose to the glass part of an eye dropper from which the rubber bulb has been removed.
3. Insert the other end of the dropper into a one holed rubber stopper that fits

into a 125 mL Erlenmeyer flask.

4. Place about 10 mL of 3% hydrogen peroxide in the flask. Add 15 ml distilled water. With tweezers drop in one crystal of potassium iodide and quickly put the stopper into the flask.



5. Measure the volume of gas generated as the gas pushes the water out of the cylinder.
6. Repeat this same procedure with new hydrogen peroxide but leave out the crystal of potassium iodide. [It will take place at a slower rate]
7. Compare the rate of generation of oxygen gas with and without a catalyst. [Faster rate with the catalyst.]

J. There are many biological catalysts inside our bodies that speed up or slow down reactions. Many of these are proteins that participate in reactions at the cell level. These proteins are called enzymes. The enzymes that slow down reactions are normally called inhibitors, and in the food industry they are called preservatives since they slow down the decay of food and preserve it for long periods of time. A listing of ingredients on many different types of food indicated the presence of these preservatives. Two of the major types of preservatives are "antimicrobials" (prevent spoilage by bacteria, molds, fungi, and yeasts) and "antioxidants" (prevent changes in color or flavor because of oxidation.)

1. Antimicrobials
    - a.) ascorbic acid (vitamin C)
    - b.) benzoic acid
    - c.) sodium benzoate
    - d.) citric acid
    - e.) lactic acid
    - f.) calcium lactate
    - g.) butylparaben
    - h.) methypparaben
    - i.) propylparaben
    - j.) propionic acid
    - k.) calcium propionate
    - l.) potassium propionate
    - m.) sodium propionate
    - n.) sodium diacetate
    - o.) sodium erythorbate
    - p.) sodium nitrate
    - q.) sodium nitrite
    - r.) sorbic acid
    - s.) calcium sorbate
    - t. potassium sorbate
2. Antioxidants
    - a.) ascorbic acid (vitamin C)
    - b.) BHA (butylated hydroxyanisole)
    - c.) BHT (butylated hydroxytoluene)
    - d.) citric acid
    - e.) EDTA (ethylenediaminetetraacetic acid)
    - f.) propyl gallate
    - g.) TBHQ (tertiary-butylhydroquinone)
3. Have students check twenty foods at home to see which seem to be the most widely used antimicrobials and antioxidants.
4. Have students discuss whether it is better to buy foods that have no artificial preservatives.
5. There has been a large controversy about the use of using sodium nitrate and sodium nitrite in foods in the past few years. Have students research the pros and cons of this type of use.

CONCEPT EXTENSION

A. Preparation for the Formaldehyde Clock Reaction
   1. In preparation for this reaction the following solutions must be made:
   2. Phenolphthalein Solution - Place 1.0 gram of phenolphthalein solid in a flask. Add 50 mL ethyl alcohol and 50 mL distilled water. Mix thoroughly. (If you do not have access to phenolphthalein, grind up an Exlax® tablet (not the chocolate kind) and dissolve it in rubbing alcohol. Filter off the solid particles that don't go into solution. You can use this without adding any more water.)
   3. Formaldehyde Solution (SOLUTION A) - Put 23 mL of formaldehyde (37-40% aqueous solution) in a 1.0 liter flask. Add 15 mL of the phenolphthalein indicator solution. Now add 962 mL of water and thoroughly mix.
   4. SOLUTION B is made in two parts B1 and B2 which are then equally mixed to make SOLUTION B.
   5. Solution B1 - Add enough water to 20.8 g of sodium bisulfate ($NaHSO_3$) to make 1.0 L of solution
   6. Solution B2 - Add enough water to 6.30 g of sodium sulfite (Na_2SO_3) to make 1.0 L of solution.
   7. Now combine B1 and B2 to make SOLUTION B.
   8. The solutions may be prepared a day or two in advance, but they will decompose if stored longer than one week.

B. The Formaldehyde Clock Reaction
   1. Measure out 10 mL of SOLUTION A into a graduated cylinder and pour it into a clean beaker.
   2. Measure out 10 mL of SOLUTION B into a different graduated cylinder and pour it into a different clean beaker.
   3. A third clean beaker, larger than the other two, will serve as the reaction vessel. Both solutions from the small beakers should be poured at the same time into the larger beaker. Swirl the larger beaker for about five seconds and set it on top of a piece of white paper on the table.
   4. Start measuring the time from when the two solutions were poured into the larger beaker. Record how long it took for the color to form.
   5. Repeat the reaction with clean cylinders and beakers with one difference. Before adding SOLUTION A and SOLUTION B together, cool the solutions by letting them sit in their small beakers in ice water for about five minutes.
   6. What do you predict will happen to the reaction time for this reaction compared with the one conducted at room temperature?
   7. Predict what would happen if you only used 5 mL of SOLUTION A + 5 mL of water instead of 10 mL of SOLUTION A as before? Would it take longer or shorter for the color to appear?

C. Meat tenderizers contain an enzyme called papain. Have students find out what papain does by doing some research. To give them an example of what happens carry out the following demonstration.
   1. Prepare some gelatin according to the directions on the package.
   2. Divide the gelatin into two portions. To the first portion sprinkle some meat tenderizer containing the papain. To the second portion add nothing.
   3. Set the two portions of gelatin out on the table at room conditions. Note the changes after a few minutes.

D. One of the most important factors affecting the rate of reactions is temperature. Although almost any chemical system could demonstrate this, there is a neat, simple, and quick system that you may never have thought about. It is the light stick that is so prominent around Halloween time. Technically you want to get a Cyalume® light stick from the American Cyanamid Company.
   1. Light sticks feature chemiluminescent reactions that give off light (glow) in the dark.
   2. Chemiluminescence is a phenomenon wherein chemical molecules produced in a chemical reaction are produced in a chemically excited state that releases light energy. In most reactions where energy is released at room temperature, heat rather than visible light is emitted. The normal place

where we see this phenomenon is in fireflies. Light sticks are based upon the same sorts of chemical reactions as take place in fireflies.

3. In one of the formulations for a light stick, hydrogen peroxide is stored in a thin glass ampoule. When the ampoule is broken by manipulation of the external plastic tube, the hydrogen peroxide reacts with another chemical called phenyl oxalate. The energy released is transferred to a dye. The dye fluoresces, and this is the light that we see when our light stick glows. By using a different dye, the color of the chemiluminescent light can be changed. [Normally, there are white, green, blue, and red light sticks available at Halloween. If you wait until after Halloween, you can pick them up at about half what they go for prior to Halloween. It is very difficult to find the light stick at times other than Halloween.]
4. Have students investigate ways to study how temperature affects the rate of reaction of a light stick.
    a. Prepare a hot water bath, an ice bath, and a room temperature bath.
    b. Activate three light sticks following the manufacturer's instructions. Place one light stick in each bath.
    c. Darken the room. Note the relative intensity of light emitted from each stick.
    d. Develop a method for determining how long a light stick will continue to give out light. Compare the length of time for a light stick that had remained in the freezer overnight before being activated with one that had been heated in boiling water for ten minutes before being activated with one that had been activated at room temperature.
    e. Activate a light stick at room temperature. Now place it in the freezer overnight. What will happen as the temperature is increased to room temperature. Will the light stick continue to give off light after the temperature was raised?
    f. As long as the plastic outer liner has not been punctured, the used light stick can be disposed of in the trash can.

MEASUREMENT OF pH

PROBLEM PRESENTATION / EXPLORATION

A. A couple of days before this experiment begins indicate to the students that we will be working with simulated stomach acid. To impress upon them that it is harmful and care must be used when working with it, drop a little piece of raw hamburger into a flask containing about 100 mL of 0.10 M HCl. Put a small tuft of steel wool in another portion of the 0.10 M HCl. Tell the students that the will be studying the substance in the stomach fluid that causes this type of chemical reaction.

B. Provide 100 mL portions of 0.10 M HCl to each group. Add to it a few mL of red cabbage extract. (Directions for obtaining this are given in the **CLASS RESPONSE / INVENTION** section of this activity.)

1. Ask the students what happens when they take Rolaids®, Tums®, or Digel® for an upset stomach?
2. Provide a couple tablets of Rolaids® and a means for grinding them up (mortar and pestle, or small hammer).
3. Tell them to add small portions of their Rolaids® to the "stomach acid" and observe what happens after each addition.
4. Ask them if they have any idea what is happening to the stomach acid when the antacid substance is being added.

CLASS RESPONSE / CONCEPT INVENTION

A. The thing that acids have in common is the presence of hydrogen ions, H^+. It is the excess of this ingredient that causes acid indigestion in our stomachs. The chemical substance in Rolaids® can use up or destroy these H^+ ions. When we lower the amount of H^+ ions by taking the Rolaids® we get the concentration of H^+ ions low enough so that our stomach doesn't feel bad any more.

B. How can we find out how many H^+ ions are in various acid solutions? A convenient way is to know the pH of the solution. The pH scale simply tells us how abundant the H^+ ions are in a solution. Even though this seems backwards, **the lower the pH, the more H^+ ions in the solution**.

1. The pH of stomach fluid is 1
2. If you would stick an eye dropper into this fluid and draw some out, it would be able to "eat up" a piece of steel wool.
3. What if you took the container of stomach fluid and added 1000 mL of water to it and then removed an eye dropperfull? Would this solution now be able to eat up the steel wool? No, because there aren't as many H^+ per dropperfull. Maybe a better example is the difference in tasting some frozen orange juice concentrate and tasting it after four cans of water have been added to it. In which tastefull did you get the most orange flavor?
4. Lets start with 10 mL of stomach acid. (Remember that there are enough H^+ ions per mL in this acid to have a pH = 1.)
5. Add to this 10 mL of stomach acid 90 mL of water. Now if we took 10 mL of this solution, would it have as many H^+ ion in it as the first 10 mL? No, it would only have 1/10 as many. If your stomach had this mixture, you wouldn't be as sick as if it contained the first mixture. We are going to assign the pH of this new solution to be 2. (Remember, it only has 1/10 as many H^+ as the acid which had pH = 1.)
6. Take 10 mL of solution #2 and add 90 mL of water to it. If you would take 10 mL of this solution would it have more or less H^+ ions than the second solution? Since it has only 1/10 as many as the second solution we are going to give it a pH of 3. (Remember, the smaller amount of H^+ ions, the bigger the pH.)

7. Take 10 mL of solution #3 and add 90 mL of water. What will be the pH of this solution? [4]
8. Take 10 mL of solution #4 and add 90 mL of water. What will be the pH of this solution? [5]
9. Take 10 mL of solution #5 and add 90 mL of water. What will be the pH of this solution? [6]
10. Which solution has the greater amount of H^+ ions, the one with the pH = 4 or the one with pH = 2? [There are how many times more H^+ in the solution with pH = 2 than in the solution with pH = 4? 100 times.]
11. Save these solutions for the next part of the experiment. Make sure each one of the six solutions is labeled with its pH. You should have 90 mL of the solutions having pH = 1, 2, 3, 4, 5, and 100 mL of the solution having pH = 6.

C. Each group should take about 100 g of red cabbage and place it in a large beaker. Add to it about 200 mL of water. Heat it until the liquid comes to a boil. Let it boil for about 5 minutes. After cooling for a few minutes, pour off the cabbage juice into another container.
1. Add two dropperfulls to each of the diluted stomach acid solutions that you prepared earlier in steps 5-9 above.
2. Just as a reference, add to a few mL of a known acid (such as vinegar) 2 dropperfulls of the cabbage juice. Likewise, add to a few mL of a known base (such as ammonia water) 2 dropperfulls of the cabbage juice. Note the color of cabbage juice in the presence of an acid and in the presence of a base. [It is red in the presence of an acid; it is green in the presence of a base.]
3. The cabbage juice is a type of substance that we call an INDICATOR. By its color it indicates to us the approximate pH of the solution into which it is placed. Note that it doesn't tell us exactly what the pH is, but it does give us a general idea of the pH.
4. If you have pH Hydrion® paper, introduce it at this point to show that the indicator which these papers has been soaked is able to indicate much closer pH values.
5. A very simple form of indicator is litmus paper. Show the students that below a pH of 7 the litmus paper is red and that if placed in a solution with a pH above seven the litmus paper is blue.
6. Soak some filter paper in the cabbage juice and set it out to dry. After the paper has dried, cut it up into strips. These "cabbage-paper" strips can now be used to test for the general pH of different substances around the house. If the paper turns red the solution being tested is acid, and if it turns green the solution is basic. (Just like the acid and base in #2 above.)
7. If you have access to a pH meter show the class that there are very precise ways to measure the pH by using an electronic device called a pH meter.

D. The pH for a number of common substances can be found in the table below.

SUBSTANCE	pH	SUBSTANCE	pH
Battery Acid	.8	Blood	7.4
Gastric Juice	1.0	Milk of Magnesia	10.6
Lemon Juice	2.2	Windex with Ammonia	11.5
Classic Coke	2.5	Lye	13.0
Vinegar	3.0		
Coffee	5.0		
Cow's Milk	6.5		

CONCEPT EXTENSION

A. It turns out that there are many substances around us that can be used as acid/base indicators.
1. Try some grape juice (not grape drink or grape soda) in the vinegar and

ammonia water solutions.

2. Grind up some blackberries and soak them in water to make blackberry juice. Try this in the vinegar and ammonia water solutions.
3. Try different colors of construction paper to see if they act as indicators. Put a strip in vinegar (acid) and in ammonia water (base).
4. The dye in one particular color of ditto paper is especially good for demonstrating the acid/base character of substances. Wasau Papers Astrobright Galaxy Gold (WAAB57A) is the official name of the goldenrod paper.
   a. Investigate the color of the paper when it is soaked in a base and in an acid. [Bright red in base; it will remain orange in acid.]
   b. By using a moistened bar of hand soap (the base) as a crayon the goldenrod paper will magically produce a red message on an orange background.
   c. Strips of the paper can be soaked in aqueous baking soda and dried. They will turn a deep red. Then these strips, along with strips of untreated orange paper, can be dipped into various solutions to test them for acidity or basicity in a similar fashion to using the cabbage paper strips.

B. Extract a substance called phenolphthalein from Exlax® tablets.
   1. Have each group grind up three Exlax® tablets (not the chocolate kind)..
   2. Add to this powder about 50 mL of alcohol and heat it gently over a hot plate. (Don't heat with a flame since alcohol is flammable.) Stir frequently.
   3. Place a Mr. Coffee® filter in a jar and pour the solution through the filter paper. Allow the solution to cool. Throw away the solid material caught in the filter paper.
   4. Add some of the cooled solution to vinegar and the ammonia water. [It should be colorless in the vinegar solution and pink in the ammonia water solution.]

C. Have students find out what indicator is used in testing the water in an aquarium or at the local swimming pool.

MAGNETISM

PROBLEM PRESENTATION / EXPLORATION

A. What is Attracted to a Magnet?

1. According to legend the discovery of magnetism occurred about 3000 years ago in an ancient Middle Eastern country called Magnesia (it is a part of modern day Turkey). Here special rocks known as lodestones were found to be naturally attracted to certain other objects. Since that time we have found ways to alter substances that do not naturally possess this property, so that they too can exhibit the same mysterious ability found in the ancient lodestone.
2. Assemble a collection of objects including samples of wood, metals, liquids, rubber, cloth, plastics, and any samples of elements (iron, gold, silver, aluminum, etc.). Also include a penny, nickel, and dime. Make sure that for some groups of students you put out an American 5¢ piece and other stations put out a Canadian 5¢ piece. Test each with a lodestone or with a magnet. Which substances were affected by the magnet?
3. Where on the magnet did the attraction seem to occur? Investigate other magnets with different shapes. Determine which portions of each magnet exhibit the attractive properties.

B. What Materials Will Magnetism Pass Through?

1. Tie some string to a powerful horseshoe magnet and suspend it from a ring attached to a ring stand.
2. Tie some thread to a paper clip. Adjust the length of the thread so that when it is taped to the table top it will extend to a length so that the paper clip will be attracted to the magnet. It will appear to be floating in mid air. There should be about 3 cm between the top of the paper clip and the bottom of the magnet.
3. Use this set up to reinforce the idea that there is an invisible force acting on the paper clip coming from the magnet. Ask the class what would happen if the string were cut. Will another invisible force called gravity be stronger than the magnetic force? Just so that everybody is sure, go ahead and cut it.
4. Obviously magnetism passes through air as illustrated by the floating paper clip. But through what other substances will it pass? Before testing any substance, force the students to predict what they think will happen.
   a. Start with putting a piece of paper between the magnet and the paper clip. Does the paper clip still float? Does this mean that the magnetic force can pass through one sheet of paper? [Yes]
   b. Try a piece of cardboard.
   c. Try a piece of glass.
   d. Try a piece of plastic (overhead transparency is good, or one of those plastic covers than comes on a can of coffee).
   e. Try a piece of aluminum foil.
   f. Try a piece of thin wood.
   g. Try a thicker piece of wood.
   h. Try water. (A good way to do this would be to put some water in the plastic coffee lid.)
   i. The strength of your magnet will ultimately determine how many of these substances allow the magnetic force to pass through.

C. Can You See Magnetism?

1. We have said that the magnetic attraction that magnets have for objects containing iron, cobalt, or nickel is thought of in terms of a magnetic force. So far we have only seen the results of this force. How can we see how this force is oriented around the magnet?
2. Sprinkle iron filings on a plate of glass, a piece of cardboard, or on a paper plate. Place this over various shaped magnets. It works better if the glass is very close to the magnet but not resting on it. One way to accomplish this

would be to put a rubber stopper at each corner of the piece of glass. The stoppers serve as legs to keep the glass up off the magnet.

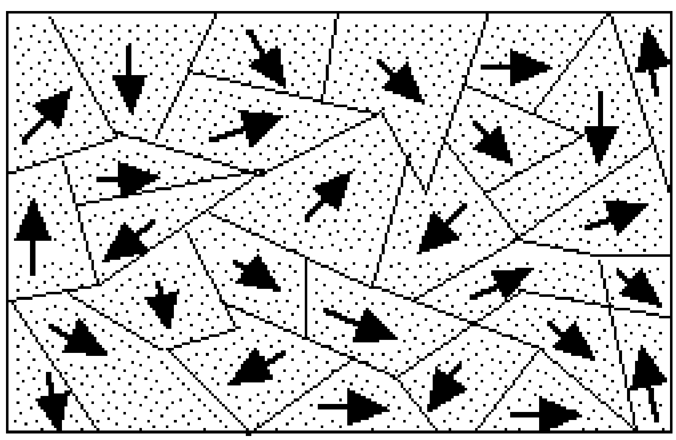
3. Tap the glass gently so that the filings are evenly distributed and so that they can align themselves along the lines of magnetic force. In this way we can "see" the magnetic force around each magnet.
4. Compare what this reveals with what you found out concerning the sections of a magnet that seems to attract metal objects. [The greater the concentration of the magnetic force lines, the greater the attractive power of the magnet.]
5. Place under the glass two magnets. First arrange them so that unlike poles are near each other, then arrange them so that like poles are near each other. How do the patterns of iron filings differ?
6. Lest students think that magnetic lines of force only operate in the plane of the glass plate, a three dimensional version of this exercise can be conducted.
    a. Get a bottle of cooking oil. A cylindrical bottle works best. Add directly to the bottle a handful of iron filings. Replace the cap, if it is metallic, with a plastic one, or put a rubber stopper into the mouth.
    b. With the bottle tightly capped shake the iron filings and oil. Place a bar magnet next to the bottle. Wait at least two minutes for the alignment to take place. Try putting the magnet perpendicular to the long axis of the bottle. Then try aligning the long axis of the magnet with the long axis of the bottle. You will be able to see that the lines of force go out in all directions, not just in one plane.
    c. Fix two bottles with iron filings. Place them side by side. Suspend the bar magnet between the two bottles. This will allow a full set of magnetic force lines to develop.

CLASS RESPONSE / CONCEPT INVENTION

A. How Can Magnets Be Made?
1. Temporary magnets (needle)
    a. Hold a needle by its eye end and rub its entire length on one end of a strong magnet about 30 times, from the eye to the point only.
    b. Set a bowl far from any iron or steel objects. Pour in some water and float on it a piece of aluminum foil as large as a quarter.
    c. Lay the magnetized needle on the foil. What does it do? If it is spun around, does it return to the same position each time? [Yes]
    d. The end of the needle that is pointing toward north is called the north-seeking pole. (It actually is the south pole of the needle.) Mark this end of the needle with some red finger nail polish.
    e. Put someone else's floating needle in your bowl. What happens when the two north-seeking poles come close together? What happens when the two south-seeking poles come close together? What happens when opposite poles come together?
2. Temporary magnets (crowbar)
    a. If we tried to rub a crowbar in the same manner as the needle, it would not work very well. A very powerful magnet would be required as well as a lot of rubbing. But there is an easy way to magnetize a crowbar.
    b. Start by facing north and point the crowbar downward at about a 25° angle.
    c. With a hammer, gently tap the end of the crowbar which is nearer to you. Tap for about one minute.
    d. Try to pick up some paper clips with the end of the crowbar which is farther from you.
    e. Now turn and face east and hit the crowbar with the hammer for about a minute
    f. Again try to pick up some paper clips. What has happened? [The crowbar should no longer act as a magnet.]

B. Why Do Magnets Work?

1. Only a small number of substances can be used to make magnets. Iron, cobalt, and nickel are the best materials with which to make a magnet.
2. Apparently, stroking these materials with a permanent magnet somehow rearranges the particles of matter in some way to cause the magnetic property to appear.
3. Clumps of iron atoms in the needle called **domains** are themselves little magnets. They have a north pole and a south pole. However these domains are not arranged in such a way as to make the needle magnetic until the permanent magnet acts on them. The permanent magnet aligns them so that all the north poles are facing the same direction (all the south poles would have to be pointing in the opposite direction.) This aligning is what causes the overall effect by having each tiny little magnetic field add together to produce the new magnetized needle. When the domains were randomly arranged they tended to cancel one another out and the metal did not behave like a magnet. This outside influence of the permanent magnet is called induction, similar to what we saw happen when we charged an electroscope by induction in the Static Electricity lesson. The larger question is why can some materials be magnetized while others can not. The reason that the individual domains and the even smaller atoms of which they are made up have a north and south pole can be traced to the motion of the electrons in the atoms. Specifically, it is the spin of the electrons that is responsible. In most elements the electrons occur in pairs in the individual atoms. Each electron is spinning in the opposite direction of its paired electron. This spinning of the negatively charged electron creates a magnetic field. Because of the opposite spins the magnetic fields are canceled out. Some metals, however, contain atoms with unpaired electrons. Since these weak magnetic fields have not been canceled out by the electrons being paired, each atom has a weak magnetic field. The individual magnetic fields extend in many different directions in an unmagnetized substance. Not until a strong magnet comes close to the metal will these randomly dispersed magnetic domains arrange themselves in the same direction to form a temporary magnet.



4. Why does a paper clip attracted to a permanent magnet attract another paper clip to it? [Temporarily the permanent magnet induces, or lines up the domains in the first paper clip, so that it acts as a very temporary magnet. When the first paper clip is removed from the permanent magnet it loses its ability to attract other paper clips. The domains in the first paper clip move back into their random orientation when the permanent magnet is removed.]
5. How con we explain the magnetizing and demagnetizing of the crowbar? [Hitting the crowbar as it was aligned with the biggest magnet known (the

earth) moves the domains in the crowbar to line up with the magnetic forces lines coming out of the north pole of the planet. Pointing the crowbar east and west and hitting it with the hammer disrupts the domains and the crowbar loses it magnetic properties.

6. Heat the magnetized needle in a Bunsen burner flame for a minute. After allowing it to cool test out its magnetic properties. Why does it no longer act as a magnet? [The heat disrupts the alignment of the domains.]
7. The temperature at which the iron loses its magnetic property is know as the Curie point. Pierre Curie discovered in 1895 that the temperature at which the domains are disrupted varies for different metals. The Curie point for iron is 768°C, for cobalt 1100°C, and for nickel 375°C.
8. Experimentally determine the Curie point for a Canadian nickel minted before 1982.
   a. Unknown to the students mix in at least one Canadian nickel minted before 1982 with other US nickels. Ask the students what will happen when a magnet is put into the pile of nickels.
   b. Probably they will respond that nickels aren't attracted to magnets. This is true for US nickels since they are only 25% nickel. But for the Canadian nickel minted before 1982, there is enough nickel metal that it will be attracted to the magnet.
   c. With a magnet adhering to the Canadian nickel move it into the flame of a candle. Note what happens after the nickel has been sufficiently heated (>375°C). [The nickel will fall off the magnet since the Curie point has been exceeded and the nickel is no longer magnetic.]
9. What is the biggest magnet you have ever seen?
   a. Probably planet Earth is the correct answer to this question, but what is the largest magnet that you can see in its entirety?
   b. To almost everyone's surprise it is found inside the house. Not every house contains one. The older the house, the better chance that it will contain this magnet. Give up?? It is in the bathroom. That's right, it is the bathtub. As mentioned above not every house has one. None of the modern day bathtubs work because they are made out of fiber glass. Even if your house has a metal bathtub it might not qualify for being a magnet.
   c. In old, old houses where the bathtubs were made out of cast iron you will find your magnets. Because it has been in the same location and orientation to the magnetic field of the earth, for a long period of time, many of these old bathtubs have undergone alignment and are magnetic. If the tub is in a north-south direction in the room, one end will be north and the other south when a compass is brought near. This applies to the Southern states. In states farther north, the north and south points are likely to be at the top and bottom of the tub.

CONCEPT EXTENSION

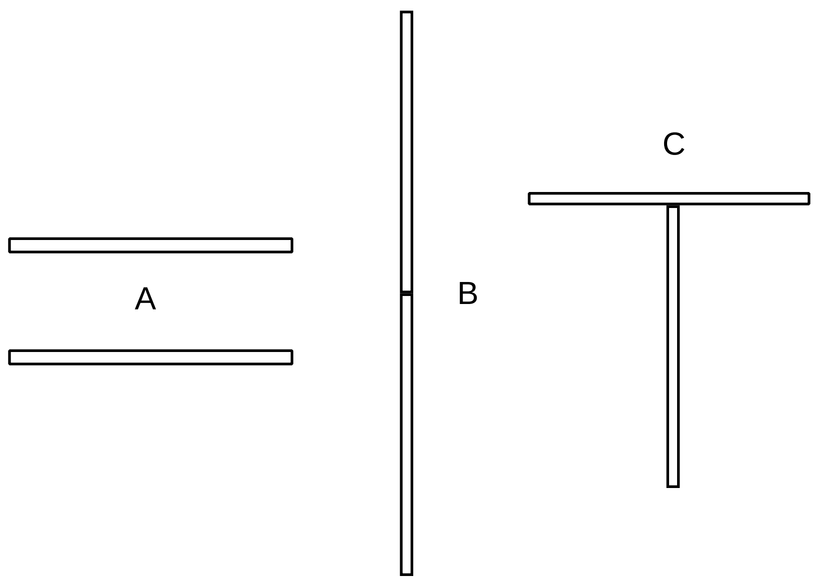
A. Cutting Up a Magnet
   1. What would happen to a bar magnet if you cut it into three equal pieces with a hacksaw?
   2. It turns out that unless you have a very good hacksaw or a very lousy bar magnet that it is very hard to saw the magnet into three pieces. An acceptable substitute for this exercise is to magnetize a needle. The needle can be divided into three equal pieces much easier.
   3. Predict what will happen when you put the three pieces back together in the same order as they were before cutting. [All three pieces will attract each other.]

4. Pull the two ends away from the middle. Turn them around so that what were the north and south poles of the unsawed magnet are now pointing inward toward the center piece. Move them toward the center piece. Predict what will happen. [The center piece repels each end piece.]

5. Separate each of the three pieces of the magnet and test each end with a paper clip. [Each end of each magnet should attract the paper clip.]
6. Using all these observations explain what happens to a magnet when it is cut or broken. [When the magnet is cut the cut end becomes the opposite pole to the that of the other end of this piece. This would account for the two end pieces. The middle piece in turn will have a north end (the end that was originally attached to the top piece) and a south end (the end that was originally attached to the bottom piece.)
7. A magnet that is cut in two does retain its magnetic power, but the vibrating experienced when it was sawed apart weakens it considerably.
8. What would you predict if the magnet was cut in half along its long axis? How would the two pieces react to each other and to a paper clip? [The left half would be repelled from the right half. Both halves would still act as magnets. The top half of the left side would repel the top half of the right side. It would be very difficult to glue the two halves back together.

B. Which Bar is the Magnet?

1. Two identical steel bars are needed for this problem. One should be a bar magnet while the other should be unmagnetized.
2. Propose to the students the following problem: One of these bars is a magnet and one isn't. Without using any other materials how can we tell which one is the magnet." Encourage them to apply the ideas learned in the other parts of this lesson.
3. If they run out of ideas, suggest placing the bars in the following positions, A, B, and C and have them evaluate what happens. Only in position C will they be able to deduce which bar is the magnet.



4. In A the two bars will be attracted to each other but we will not be able to tell which one is doing the attracting and which one is being attracted. In B the two bars will also be attracted to each other, but again we will not know which one is the bar doing the attracting.
5. Why will setup C allow us to figure out which bar is the magnet? Thinking back to what we learned about the magnetic field about a single bar magnet we know that the field is weakest at the center of the bar. If the horizontal bar is the magnet, there will be no attraction. If the horizontal bar is not the magnet, there will be attraction because the pole of the magnet will be attracted all up and down the unmagnetized bar.

C. The Compass in Your Nose

1. "All humans have a trace amount of iron in their noses, a rudimentary compass found in the ethmoid bone (between the eyes) to help in directional finding relative to the earth's magnetic field.

   Studies show that many people have the ability to use these magnetic deposits to orient themselves--even when blindfolded and removed from such external clues as sunlight--to within a few degrees of the North Pole, exactly as a compass does.

   A researcher from England's Manchester University found that when a magnet is placed on the right side of the head, the directional accuracy of test subjects falls 90 degrees to the right. When a magnet is placed on the left side, the error falls 90 degrees to the left, proving conclusively that humans are profoundly affected by magnetic fields.

   Though no one knows how this 'sixth' sense is processed by the brain, more than two dozen animals, including the dolphin, tuna, salmon, salamander, pigeon, and honeybee, have been found to have similar magnetic deposits in their brains to help them in navigation and migration." {McCutcheon, M, (1989). *The Compass in Your Nose and Other Astonishing Facts About Humans*, Jeremy P. Tarcher, Inc., Los Angeles, pp. 96,97.}
2. Have the class organize an experiment using their own members to see if there is anything to this ability to orient ourselves with respect to magnetic north without a traditional compass. There are a number of things that must be controlled to make any conclusions valid.

STATIC ELECTRICITY

PROBLEM PRESENTATION / EXPLORATION

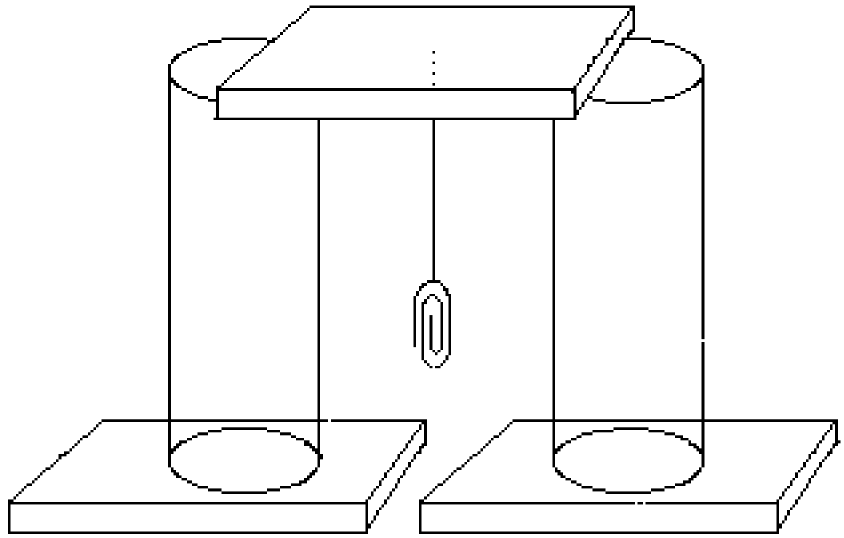
A. Balloons
   1. Blow up and tie off a number of balloons. Prepare some of them by rubbing them against a sweater or other article of clothing. Do not charge the others. Have students come up to the board and try to stick them in a horizontal row. Obviously, some will stick to the board while others won't.
   2. Solicit reasons from the class. As soon as someone suggests that you must rub the balloon before attempting to stick it to the board, ask them to predict against which kind of substances a balloon should be rubbed to make it stick. (Most substances will successfully charge the balloon. Wool, cotton, and hair are the most common materials used to charge balloons.)
   3. Possibly before you finish this investigation some of the balloons that originally stuck to the board will fall to the floor. Ask the students to offer explanations for this behavior. [Over a period of time electrons will transfer from the balloon to the board and the induced positive charge on the board will be neutralized resulting in the balloon falling down

B. More Balloons
   1. Blow up four identical balloons and tie a thread to each. Hold two of the balloons together by the two threads and show that the balloons will hang down against each other. (Do not rub the balloons beforehand.)
   2. Take two balloons and rub them with a wool cloth. Ask students to predict what will happen when they are brought side by side. [They will repel each other so that they can not touch. Both balloons were charged by friction.]
   3. Take the other two balloons and rub only one of them with the wool. Ask students to predict what will happen when they are brought side by side. [They will be attracted to each other. One of the balloons was charged by friction and the other by induction.]

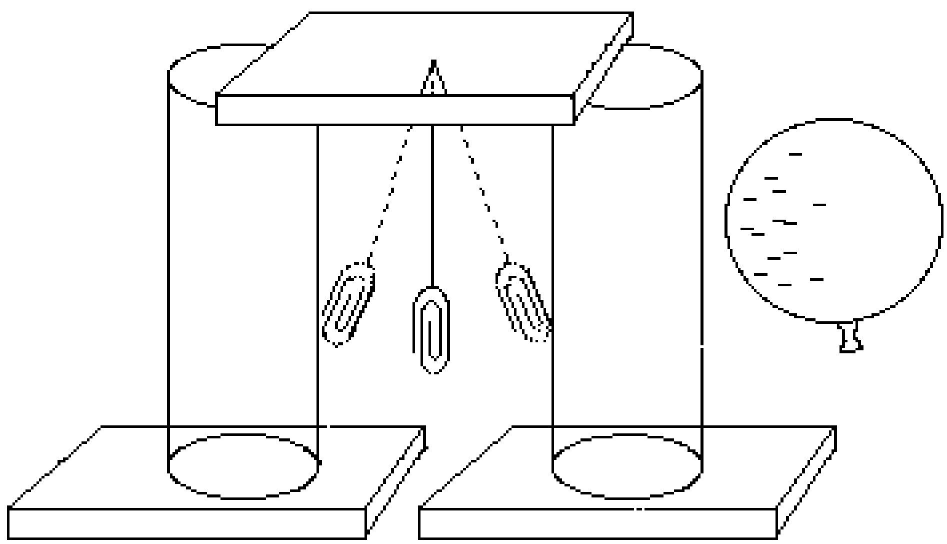
C. The "Magnetic" Ruler
   1. Place on a flat table a hollow cardboard roll that toilet paper comes on.
   2. Take a plastic ruler and rub it vigorously with a handkerchief for 30 seconds.
   3. Approach the roll slowly with the ruler until the roll begins to move, then move the ruler away from the roll in the same direction that the roll started to move. In other words, it will look like the ruler is pulling the roll across the table.
   4. [The ruler has been charged negatively by friction (rubbing) and as it approaches the roll it induces a positive charge on the leading edge of the roll. This in turn is attracted to the ruler. As long as the ruler and the roll are not allowed to touch, the ruler can pull the roll along.]
   5. Students will probably be puzzled about how this works. This should all be cleared up in the Concept Invention phase of the lesson.

D. The "Magnetic" Meter Stick
   1. Place a watchglass on a table.
   2. Balance the flat edge of a meter stick on the watchglass so that it may rotate in a plane parallel to the table..
   3. Charge up a glass or hard rubber rod by rubbing it with silk (glass rod), wool flannel (rubber rod).
   4. Bring the rod close to the end of the meter stick but not touching it.
   5. Advance the rod in front of the meter stick. It should interact with the meter stick and make it slowly twirl.

E. The Electrostatic Pendulum
   1. For this exercise you will need two tall tin cans, three pieces of paraffin wax, thread, a paper clip, a rubber balloon, and wool cloth.
   2. Set each can on one of the blocks of paraffin. Balance the third block of paraffin on the open ends of the two cans. Suspend from this block the paper clip by means of the thread in such a way that the paper clip hangs down in between the two cans.



3. Rub the balloon with the wool cloth and bring it close to one of the cans. Observe. [The clip will move back and forth between the cans.]



4. The negatively charged balloon when brought close to one of the cans repelled the electrons to the other side of the can (the side closer to the paper clip). The neutral charged paper clip is then attracted to this charged can and moves to make contact with it. In making contact the clip receives electrons making it the same charge as the can and then moves away since like charges repel. The paper clip now negatively charged induces a positive charge in the second can and is attracted to it. Upon making contact it gives up its charge to the second can and is attracted again to the first. The back and forth motion is repeated a number of times.
5. It is very important that the paraffin be used. It serves as an insulating agent so that electrons can not be drained off too readily. **This, as most of the electrostatic demonstrations, works better on a cold, dry day in the middle of the winter.**

F. The Confused Pithball

1. If pithballs are unavailable, they can be made from a Styrofoam® ball covered

with pencil lead or aluminum spray paint. Suspend the pithball from a thread attached to a support.

2. Rub the comb with the wool cloth and approach the pithball. Ask students whether they think it will be repelled or attracted. [It will be attracted.]
3. After showing that the comb will attract the pithball, bring the comb close enough to touch the pithball. Immediately the pithball will be repelled from the comb.
4. After the pithball has settled down approach it with your finger. [It will be attracted to your finger.] Finally, touch it with your finger. [As soon as the pithball is touched by the finger the charges are neutralized and there is neither repulsion nor attraction by the finger.]
5. Each of these observations should become understandable in the next section of this lesson.

CLASS RESPONSE / INVENTION

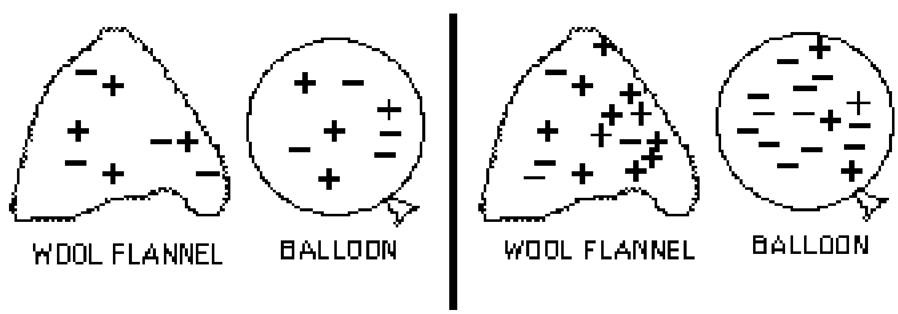
A. Matter Is Made Up of Charged Particles

1. Matter is made up of particles having positive charges and negative charges. The negative particles are called electrons. Matter is neutrally charged when there are just as many positive charges as there are negative charges.
2. Neutral matter can become charged by removing or adding electrons. All of the phenomena experienced in the PROBLEM PRESENTATION / INVENTION section above can be explained in terms of matter being charged and the interactions it had when coming in contact with other neutral or charged matter.

B. Charging by Friction

1. Many objects can be charged by rubbing them with another substance. Friction between unlike materials causes electrons to move from one to the other substance.
2. Rubbing a balloon with wool causes electrons to leave the wool and move onto the balloon which makes the balloon negative. Even though the balloon has both positive and negative charges, the overall charge is negative. This would mean that the resulting charge on the wool would be positive since electrons were removed from the originally neutral wool.

BEFORE RUBBING **AFTER RUBBING**



3. Rub a balloon with some wool. Tie some thread to the balloon and hang it from a support. Bring the wool close to the balloon. What will happen? [The balloon and wool will be attracted to each other due to their opposite charges.]
4. Rub two balloons with wool. Hang them from a support. Since both balloons are negative in charge, it should not be surprising that the balloons will be repelled from each other.
5. Next, rub a hard rubber rod (a hard plastic comb works well if you don't have rubber rods) with some wool flannel. (What charge will the wool have? [+] What charge will the comb have? [-]) Bring the charged comb close to the charged balloon. Did it act the same way that the two balloons did? [Yes])

6. Take a piece of glass rod and rub it a few times with a piece of silk. What charge will develop on the glass rod? What charge will develop on the silk? How could you find out? [Bring the silk close to the charged balloon. Did it repel or attract? It should have repelled. Bring the glass rod close to the balloon that has been charged. It should attract. These observations should allow us to conclude that the glass rod becomes (+) when rubbed with silk, and the silk becomes (-) when rubbed with the glass rod.]
7. Knowing the charges developed on the comb and glass rod or the wool and the silk the students should be able to find out what the charges are on different substances that have been rubbed together. If they are repelled by the charged comb or the charged balloon, they are (-). If they are repelled by the charged glass rod, they are (+). They never will be repelled by both rods.
8. The charge on the rubber rod or comb works much better than the charge on the glass rod. The glass rod does not hold a charge very well unless the experiment is done in a very dry, non-humid room, conditions that are more probable in the winter.

C. Charging by Induction

1. Cut up tiny bits of paper and scatter them out on the table. Rub a hard rubber comb through your hair a few times or rub it vigorously with some wool flannel. Bring the charged comb near the bits of paper. What happens? [They are attracted to the negatively charged comb.]
2. Rub a piece of glass rod with silk. Bring the charged glass rod near the bits of paper. Will they be attracted to the charged glass rod? Students may guess that they won't since the paper was attracted to the negative rod or comb in #1. It probably would seem logical that the positive rod would repel the paper instead of attracting it. However, the bits of paper are also attracted to the positively charged glass rod. [Remember, if you can't get the glass rod to work, just use the wool that you used to charge the rubber rod or comb. Because the comb became negative, the wool has to be positive.]
3. The paper is neutral meaning that it is made up of an equal number of positive and negative charges. When the negatively charged comb is brought near the paper the electrons in the paper are free to move away from the comb (like charges repel) but they remain in the paper. The part of the paper closest to the comb must be positively charged. (The only charged particles that move are electrons; the positive charges can not move.) The part of the paper farthest away from the comb was then negative.
4. The negatively charged comb is now attracted to the side of the paper next to it which is positive. When the comb is taken away the electrons in the paper will spread out through the paper just as they were before coming close to the negatively charged comb.
5. If the positively charged glass rod comes close to the paper the electrons in the paper move to the part of the paper closest to the comb (unlike charges attract.) The part of the paper farthest away from the glass rod is then positive. The positively charged comb is now attracted to the side of the paper next to it which is negative.
6. The paper is attracted to either a negative or positive rod. The reason, as we have seen, is because the charged rod temporarily influenced the charge distribution in the neutral substance. This is known as creating a charge by **Induction**. Induced charges are ones that result from an object being near another strongly charged object.
7. Making a Condiment Copier
   a.) Place some pepper into a petri dish. Place the lid on it. Cut a circle of paper to fit the lid of the petri dish. Cut out a design in the middle of the paper.
   b.) Hold the paper against the top of the dish and rub the open area with a wool cloth for at least 30 seconds.
   c.) Remove the paper stencil and invert the dish for a couple of seconds. Upon turning the dish over what happens?

d.) Only the area where the wool rubbed the dish became charged (-). When the pepper came in contact with the negatively charged area it became charged by induction. The side in contact with the dish was positive which allowed the pepper to adhere to the charged part of the dish which made the design when the dish was turned over.

e.) This principle is central to electrostatic photocopying as well as other industrially important processes.

8. "Magnetic" Water?

a.) Open the tap and allow a small stream of water to run into the sink. Charge a hard rubber comb by running it through your hair a few times or rubbing it with some wool. (This will be negatively charged.)

b.) Hold the back of the comb about 2 cm from the stream of water. Predict what will happen. [The stream of water is bent toward the comb.]

c.) Charge a glass rod by rubbing it with silk or use the wool that was used to charge the comb (this will be positively charged).

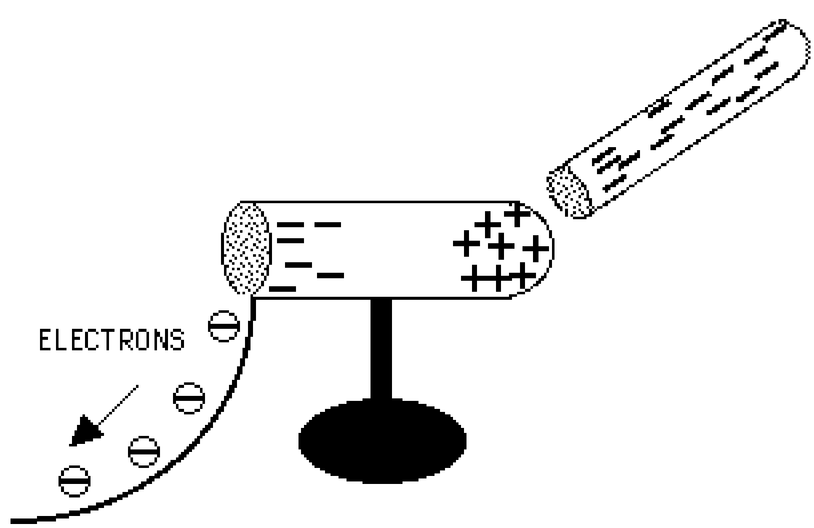
d.) Hold the glass rod about 2 cm from the stream of water. Predict what will happen. [The stream of water will bend toward the glass rod just like it did when the charged comb was used.]

e.) Both the negative comb and the positive glass rod were capable of inducing the water molecules so that they lined up in a manner that the charge on the comb or rod was opposite to the molecules being attracted to the comb or rod. Water molecules have the advantage of having both a slightly positive and slightly negative end. When the negative comb came close the molecules turned so that their positive ends were facing the charged comb and the water stream bent. When the positive glass rod came close the molecules turned so that their negative ends were facing the charged rod and once again the water stream bent.

9. Grounding

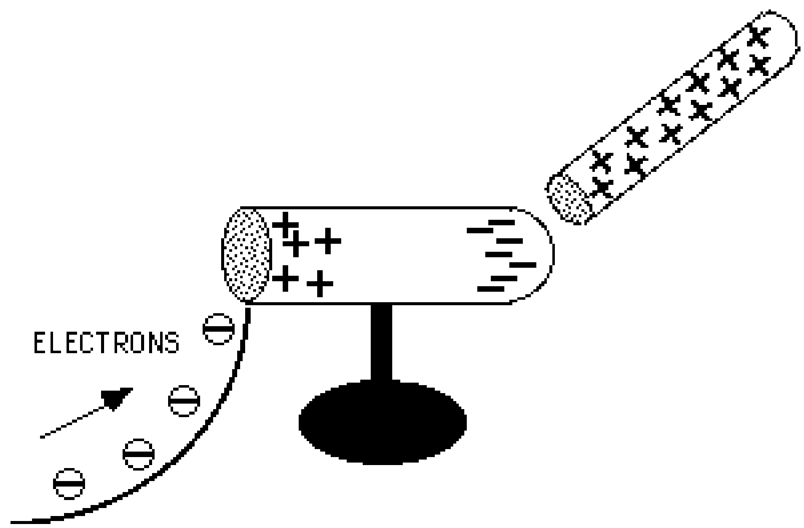
a.) A conductor such as a piece of metal can be permanently charged by induction. The examples of the bits of paper, the particles of pepper, and the water molecules all experienced an induced charge but this charge was temporary. Upon the removal of the originally charged object the electrons making up the particle returned to their normal distribution.

b.) A piece of metal can be induced by bringing a negatively charged rod or comb close to it in the same way the bits of paper were induced.



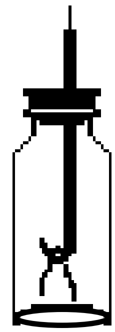
The electrons move away from the end close to the rod. However, if while still under the influence of the charged rod a new conductor is touched to the metal, electrons can flow out of the metal. No longer does the metal have equal numbers of negative and positive charges. Now upon removing the charged rod (remember, it never came in touch with the metal) the metal has developed an overall positive charge. Bringing the rod near to the metal results in attraction rather than repulsion. [Metal is (+) and the rod is (-)] The conductor which was briefly attached to the piece of metal that allowed excess electrons to leave (or enter as we will see in the case below) is called a **ground** because the conductor is often attached to the earth or ground.

c.) What would happen if a positively charged glass rod was substituted for the negatively charged comb? This time the end of the metal close to the glass rod would be negatively charged as the electrons would have migrated in this direction. If while still under the influence of the charged glass rod a new conductor is touched to the metal, electrons will flow from the conductor to the positive side of the metal. No longer will the metal have equal numbers of negative and positive charges. Now upon removing the charged glass rod the metal will have an overall negative charge. Bringing the glass rod near to the metal results in attraction rather than repulsion. [Metal is (-) and rod is (+)]



D. Electroscope

1. If you have a commercial electroscope, use if; but if you don't, you can build one.
2. Make a J-like hook out of the uninsulated end of a piece of electrical wire. From both ends of the wire remove the insulation
3. Obtain some Christmas tree icicle material. This material is made of aluminized Mylar® film. A strip of the icicle material should be placed, aluminizied side down, on the hook so that the two leaves can hang straight down.
4. Lower the hook with icicle into a jar with a narrow neck (a 12 oz glass soft drink bottle works find). The wire should project out of the jar about 5 cm. Seal the neck of the jar with an appropriate rubber stopper or by carefully packing piece of clay or Play Doh® around the wire.



5. During the use of the electroscope students should be instructed to never open the bottle in an effort to adjust the position of the leaves. NEVER touch the leaves.
6. Test the electroscope by rubbing a comb through your hair or rubbing it with some wool and slowly bringing it near the uninsulated wire at the top of the electroscope. Do not touch the wire with the comb. The leaves (pieces of icicle) should spread apart. Upon removing the comb the leaves should move back together.
7. Predict and explain the following:
    - a.) What happens when the comb comes close to the exposed wire and actually touches it? [The leaves spread apart and stay apart. The charge on the leaves is the same as the charge on the comb or glass rod used to charge them.]
    - b.) What will happen when you touch the exposed wire with your finger? [The electroscope will discharge since your finger is acting as a ground.]
    - c.) How could you put a negative charge on the electroscope so that the leaves remain spread apart <u>without touching the wire with the charged object (charged comb)</u>? [Bring the charged comb up to but not touching the wire and touch the wire with your finger. Without moving the comb away remove your finger. Then move the comb away. The negatively charged comb forces the electrons down into the leaves and causes them to spread apart but leaves the top of the wire positive. Touching the wire at this point draws electrons from your finger into the top of the wire. The electroscope has now picked up more electrons than it started with. When the charged comb is removed the leaves remain separated.]
    - d.) What would happen if you now touched the wire at the top of the charged electroscope with your finger? [This time your finger will drain off excess electrons and the leaves will drop back down to their neutral positions.]
    - e.) How could you put a positive charge on the electroscope so that the leaves remain spread apart <u>without touching the wire with the charged object (charged glass rod)</u>? [Bring the charged glass rod up to but not touching the wire and touch the wire with your finger. Without moving the glass rod away remove your finger. Then move the glass rod away. The positively charge glass rod draws electrons up from the leaves to the top of the wire leaving the lower portions of the leaves positively charge causing them to spread out. Touching the wire with your finger allows a path for the electrons to drain off. The electroscope now has fewer electrons than it started with. When the charged glass rod is removed the leaves remain separated.]
    - f.) What would happen if you now touched the wire at the top of the charged electroscope with your finger? [This time your finger will supply electrons and the leaves will drop back down to their neutral

positions.]

E. Why did the balloons stick to the board?
    1. Rubbing the balloons charged the balloons with a negative charge. As these balloons approached the neutrally charged board the electrons on the surface of the board were repelled. This left a positive charge at the surface of the board. The negatively charged balloon was then attracted to the positively charged surface of the board.
    2. Over a period of time electrons will transfer from the balloon to the board and the induced positive charge on the board will be neutralized resulting in the balloon falling down.

F. Why did the balloons repel?
    1. The first two balloons from the EXPLORATION phase of this lesson were charged by friction. By rubbing them with wool electrons were transferred to the surface of the balloons. This gave both of the first two balloons a negative charge. When the two balloons were put side by side they repelled because like charges repel.
    2. The neutral balloon and the negatively charged balloon illustrate an important principle. This is a good way to demonstrate induction. It is effective because students may think that a neutral object can't be attracted by a charged object. The evidence of the charged balloon inducing a charge on the neutral balloon without ever touching it is extremely important for students to understand.

G. The magnetic ruler can be explained in the same way as the neutral balloon being attracted to the negatively charged balloon in that a charge was induced on the paper roll by the negatively charged ruler. This allowed a close ranged attraction to occur so that the ruler can pull the roll along.

H. The electrostatic pendulum is a good exercise to allow the students to analyze the charges developing on both the cans and on the paper clip during the oscillations between the two cans. This involves charging by friction (the original balloon), by contact (when the paper clip touches the can electrons flow because both the can and the paper clip are metal conductors), and by induction (both the balloon and the paper clip induce charges on the cans).

I. The confused pithball can be explained in much the same way as the electrostatic pendulum.
    1. When the comb first attracts the pithball it is due to induction.
    2. When the comb actually touches the pithball the pithball is charged by contact and obtains a negative charge. Immediately the two negatively charged objects (comb and pithball) repel each other.
    3. The pithball induces a charge on your finger when it is brought near to the pithball. The negatively charged pithball is attracted to your finger which has a positive charge on its surface.
    4. Touching the pithball allows electrons to drain away off the pithball returning it to a neutral charge. At this point the attraction ceases and the pithball will hang down in its starting position.

CONCEPT EXTENSION

A. Making an Electrophorus
    1. Have you ever noticed during the winter that after shuffling your feet on the carpet and upon approaching a metal doorknob that sparks travel between your finger and the doorknob? We want to build an instrument that can store up some electricity even better than you shuffling your feet across the carpet. It is called an **electrophorus**.
    2. Glue a small block of wood or paraffin to the inside center of the pie pan. This will be your handle for picking up the pie pan without discharging it.
    3. Cut out a rubber circle from an old inner tube with the same diameter as the pie plate. Lay it flat on the table. Rub it vigorously with wool or fur for at least 30 seconds.
    4. Lift the pie pan by the wooden handle, keeping your fingers away from the

metal, and hold it close to the charged rubber sheet.

5. While it is in this position, touch the pan briefly with the tip of your little finger. What do you hear?
6. Charge the aluminum pan again. Try discharging it again in a darkened room. What do you think will happen?
7. Prepare a **dead** fluorescent tube by putting it on a table. Allow the one end to touch a large metal object such as a locker, radiator, or a pipe. After charging the pie pan again bring it close to the other end of the florescent a tube. When it touches the end of the tube what happens? [It really lights up!]
8. The explanation for the action of the pie-pan generator (electrophorus) is straightforward. First, what charge did the rubber inner tube receive when rubbed with the wool? [The wool became (+) and the rubber sheet became (-).] When the pie pan was held near the rubber sheet and you touched the metal, the negative charge on the rubber sheet caused the electrons in the metal to be repelled from the pan to your finger which made the spark. [Now, what charge must the pie pan have? Remember, electrons have been discharged in the spark. The pan is now (+). Finally, when you touch the pan to the fluorescent tube electrons jump back from the fluorescent tube to the pie pan. When the charge moved from one end of the fluorescent tube to the end touching the pie pan the electrons were moving and the tube lit up for a short time.]

B. Lightning

1. In many ways the discharge we saw from the fluorescent tube to the pie pan is the same thing that happens when lightning occurs.
2. Lightning is a rapid discharge of electrons through the air that can release as much as 3,750,000,000 kilowatts of power. The interaction of the electrons with the air causes the glowing spark we call lightning. The temperature of the air can rise 30,000 degrees. This tremendous change in temperature causes the air to expand rapidly resulting in what we call thunder.
3. Although lightning is not fully understood, some things are clear. During a thunderstorm the charge distribution in clouds is arranged so that the bottoms of clouds become negatively charged. They in turn induce a positive charge on the surface of the earth below. When the difference in charge is great enough the air becomes a conductor. The kind of discharge with which we are most familiar is that between the clouds and the oppositely charged ground below. But the more frequent type of discharge is between oppositely charged parts of different clouds.

C. Can you explain the following?

1. What makes plastic wrap such as Saran Wrap stick to food storage containers? Is it due to static electricity? How would you go about testing to see if this is plausible? [Electric charges on the plastic wrap attract the sides of bowls causing it to cling. The charge was probably put on the plastic wrap when it was pulled off the roll quickly. One way to check the probability of this explanation would be to lay a piece of plastic wrap on the table and rub it with wool and then try to determine whether the cling was more intense. To check which substances the plastic wrap more readily clings to could possibly be investigated in terms of whether the bowl is a conductor or insulator. The bowls that are conductors will be more easily induced and form a stronger attraction. Aluminum, glass, plastic, and wooden bowls could be used.]
2. What causes clothes in a clothes dryer to get all mixed up and stick together when you take them out of the dryer? [By the clothes tumbling over and over and coming in contact with each other there is a lot of transfer of electrons due to friction. When the dryer stops different parts of the clothing have opposite charges and tend to cling to each other.] A good research project would be to have students find out how anti-static-cling products that we put in our dryer work.
3. Picture the following. Boy and girl are on opposite sides of the front seat of the car. After awhile he scoots across the plastic seat cover towards the

center. She also scoots toward the middle. Still more time goes by, he scoots, she scoots. Slowly their lips are approaching each other, and SNAP, CRACKLE, POP they undergo an electric experience. What happened?? [As they scooted across the plastic seat cover they both were being charged due to friction. When their lips made contact there was a sudden discharge creating the electric experience.]

CURRENT ELECTRICITY

PROBLEM PRESENTATION / EXPLORATION

A. Homemade Batteries

1. Lemon/coin battery
    a. Obtain a lemon and roll it a few times on the counter.
    b. Make two parallel slits very close together in the lemon
    c. Insert a copper penny (minted before 1982) in one slit and a nickel in the other slit. the coins can be very close but must not touch each other.
    d. Touch both coins with your tongue at the same time. What happens? [They will feel a small electric shock.] The lemon juice kills the bacteria on the coins. (I still think that it would be a good idea to clean the coins with soap and water and a brush before performing this activity.)
    e. A larger version of the lemon battery can be made by using larger strips of zinc and copper stuck into a lemon. About 1 volt can be produced with this type of battery. Because only a small amount of current is flowing, only a very small bulb may be made to light up. If you change the zinc to magnesium a small clock that runs on batteries can be operated. Just remove the alkaline battery and attach the magnesium strip to one side of the clamp that holds the battery. Attach the copper strip to the other side of the clamp. Allow the two metals to hang in a glass of orange juice. The clock will keep excellent time for quite a few hours. There is a commercial product called the Two Potato Clock® which is composed of zinc and copper electrodes that will run a digital clock for weeks. The electrodes can be stuck into potatoes, oranges, apples, Coke®, and many other substances. This clock will accurately provide time for months before the potatoes must be replaced. They can be ordered from Arbor Scientific Co. as well as from various toy stores.
2. An 11¢ battery
    a. Clean a number of pennies (minted before 1982) and a number of dimes with soap and water and a brush.
    b. Soak pieces of filter paper (paper towel will do) in salt water.
    c. Arrange pennies and dimes in alternating layers separated by a piece of filter paper that has been soaked in salt water. Start on the bottom with a penny.
    d. Attach to the bottom penny with an alligator clip a wire hooked to one side of a galvanometer. Attach to the top dime with an alligator clip a wire hooked to the other side of the galvanometer. Note the reading. How large was the deflection? In which direction was the deflection. (If you don't have alligator clips you may hold the wires to the coins with your fingers. The magnitude of the current is so small that it will not harm you.)
    e. Reverse the leads from the coin battery to the galvanometer. Note the magnitude of the meter. Note the direction of the deflection. Were there any differences this time? [The magnitude remained the same. The deflection was in the opposite direction.]
    f. Based on your observations from which end of your coin battery did the electrons come out and go into the galvanometer? [Came out of the penny which is the negative end.]
    g. Change the number of dimes and pennies used to make the battery. Note the magnitude of the deflection as these changes are made. [No change in direction but the magnitude is larger when more coins are used. Each of the cells is in series with the other cells.]
3. Wet cell battery (the Gerber Cell)

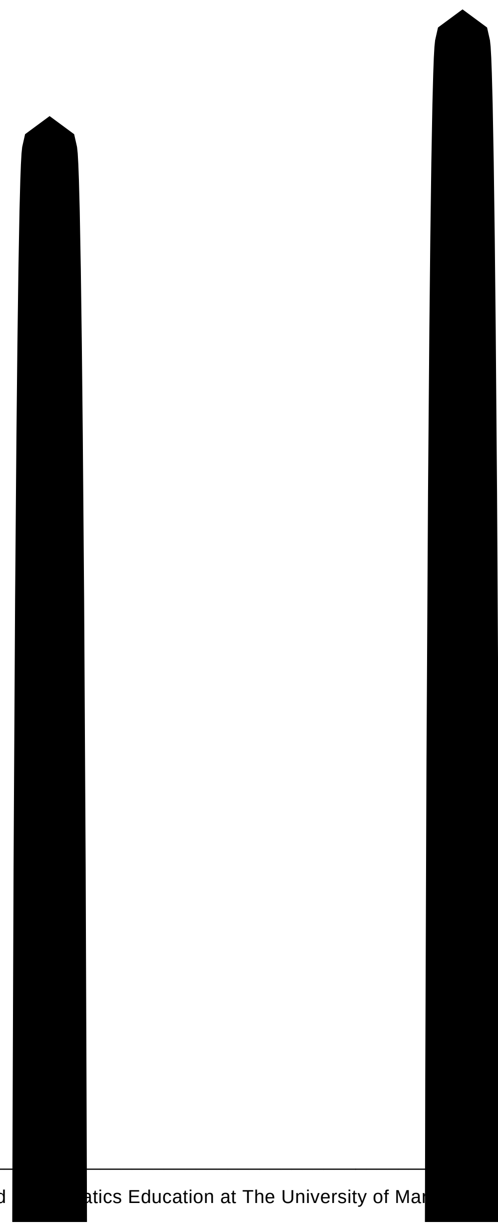
a. Obtain strips of two different metals. Copper and magnesium make good ones.
b. Sand the strips of metal with a fine coarse sandpaper. (The copper metal could be cleaned by dipping it in a dilute nitric acid solution for a few seconds. The magnesium strip could be cleaned by dipping it quickly into a 1 M hydrochloric acid solution.)
c. Fill a Gerber® baby food jar with sodium sulfate solution. Place the magnesium strip in the jar.
d. Cut a 15 cm strip of dialysis tubing and hold it under water until it becomes flexible. Tie a knot in one end to make a bag. Put the copper strip in the bag and fill the bag with copper sulfate solution. Place the bag with its contents into the Gerber® jar.
e. Insert a rubber stopper so that the magnesium strip and the copper strip in the bag are held in place above the jar.
f. Attach a volt meter to the two strips. Note the voltage produced in this "wet cell" battery.
g. Attach two wires to a flash cube or a flash bulb. When these wires are touched to the magnesium and copper strips in the Gerber cell the flash bulb should be set off.

B. Batteries and Bulbs

1. Although students can define a circuit after studying a textbook, they need concrete experiences with a battery, bulb, and wire to really understand the concept of a circuit.
2. Challenge: How many ways can you get a bulb to light using a battery, a bulb, and one wire?
3. Eventually one or two students will get the bulb to light. (You will be surprised how many students will have trouble doing this.) The other students will copy the arrangement to get their bulbs to light. Ask the class what special places on the battery and bulb must be touched to get the bulb to light.
    a. Note that the dry cell battery has two special places. The top of the battery is the positive terminal, and the bottom of the battery is the negative terminal. Electrons flow from the negative pole to the positive pole of the battery through an external circuit.
    b. The bulb has two special places that must be connected to the dry cell to light the bulb. The silver tip on the bottom of the bulb and the gold threads on the side of the bulb are the two special places that must be connected by a conductor to the two poles of the battery.
4. Urge the students to find other ways to light the bulb. Only after a variety of ways has been discovered should you give them the prediction sheet and ask them to predict which of the drawings represent a hookup where the bulb would light up. Let them build it and check their prediction.

Batteries and Bulbs Prediction Sheet

Draw a circle around each of the following that would light the bulb as depicted. Build any of those that you are not sure of and see if they do light the bulb.



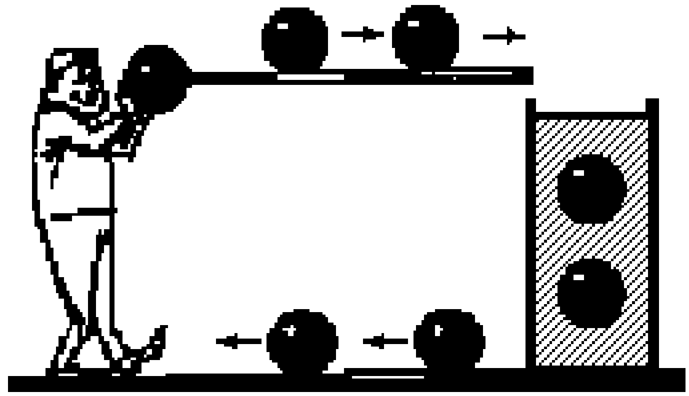
CLASS RESPONSE / CONCEPT INVENTION

A. Teacher Background

From the lessons on static electricity we have seen that electrons can be build up on a substance by physically rubbing two substances together in a way so that electrons are rubbed off (work done) one substance and transferred to the other. Work was required to separate the negative from the positive charge to create the static charge. Furthermore, we saw that a charged object (the electroscope) could be discharged. This was demonstrated by the sensation of being shocked as well as lighting up the dead fluorescent bulb. This movement of charges is called electric current. Normally we only call it current if it continues to move for more than a fraction of a second. If a path can be provided so that charge can continually move we have an electric circuit. The most important component of the circuit is the device capable of continually separating negative from positive charge. In doing this it imparts to the electrons stored energy that can be used to continue the flow of charge. This component is normally thought of as a battery. Traditionally the energy supplied to separate the charge is chemical energy due to the chemical reactions going on in the battery. Electric current always results at the expense of some other energy required to separate the negative from positive charges. Two other forms of energy that can be tapped are heat which produces a thermocouple and a solar cell which depends on energy supplied directly from the sun. In the next lesson (Electromagnetism) we will see that charge separation between terminals can be maintained by the application of mechanical energy to an electric generator.

The electric current in a circuit is due to the regular motion of the electrons past a given point. Current is defined as the rate of movement of charge past a definite cross section. In other words current equals the charge passing a certain cross section divided by the time taken for the charge to pass that point. The charge on 6.26×10^{18} electrons comprise a negative charge known as one **coulomb**. When one coulomb of charge passes a given point in one second the electric current is said to be one **ampere**.

The motion of electrons in a circuit can be described by comparing an electric circuit to an imaginary bowling ball circuit. Here a man lifts the balls from the floor to a shelf. The balls roll along the shelf into a cylinder of heavy oil. They fall through the oil at constant speed and are removed from the bottom by a trapdoor mechanism. The balls roll along the floor to be picked up by the man to repeat the process. As the man raises each ball from the floor to the shelf he transfers to the ball a certain amount of energy. On the shelf the ball has more gravitational potential energy than it had on the floor. If the ball fell off the shelf through the air its potential energy would be transformed to kinetic energy. But in falling at constant speed through the oil the potential energy lost by the ball is transferred to the molecules of the oil, raising its temperature. The bowling balls are agents by which the work the man does is transferred to heat in the oil. The process can continue as long as the man has enough energy to lift the bowling balls.

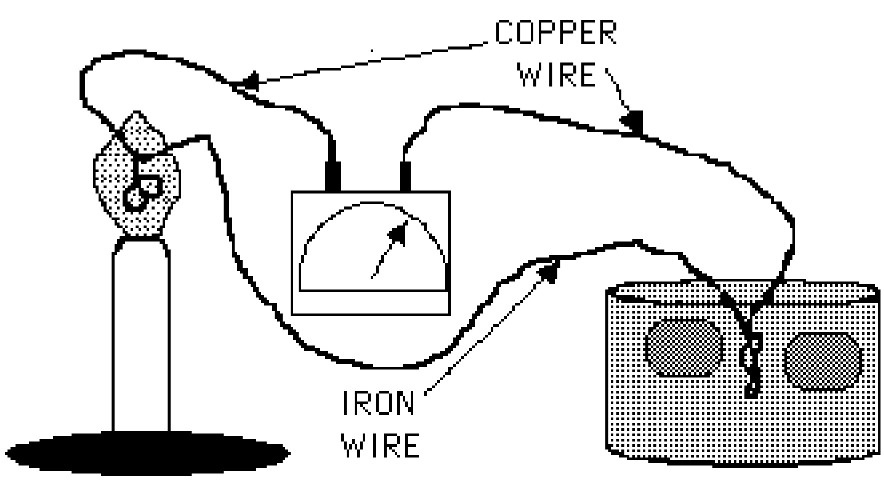


Similar terms can be used to describe the motion of electrons in the electrical circuit. The dry cell transforms its chemical potential energy to the potential energy of electrons as it "raises" them from the positive terminal of the battery to the negative terminal (chemical reaction provides the energy). The electrons drift through the circuit to a lamp. As the electrons "fall" through the lamp filament their potential energy is transferred to the ions of the filament, raising its temperature. The chemical energy of the cell is transformed to electrical potential energy which is transformed to heat in the lamp filament.

In the same way that the man supplies each bowling ball with gravitational potential energy, the dry cell supplies each electron with electrical potential energy. Thus there is an electrical potential energy difference per electron between the positive and negative terminals. The quantity of energy per charge is called **electrical potential**. If an amount of energy is supplied to an amount of charge as it moves between the terminals, there is an electrical potential difference between the two points. If a battery supplies 1.0 joules of potential energy for each coulomb of charge, there is an electrical potential difference of one **volt**. Often the term voltage is used in place of electrical potential. If the oil provided more resistance to the movement of the bowling balls, fewer of them would travel through the oil in a given amount of time. Thus, for the same amount of voltage a smaller amount of current would flow when there is greater resistance.

B. Thermocouple

1. Obtain three lengths of wire, two copper wires and one iron wire.
2. Join the iron wire and one of the copper wires together by twisting them to make a junction. Twist the other end of the iron wire to the other copper wire to make a second junction. Attach the remaining ends of the two copper wires to an ammeter.



3. Place the first junction in a beaker with ice and water (cold junction). Place the other junction in a candle flame (hot junction). Note what the ammeter is indicating.
4. Heat energy is being used to liberate the electrons which then can flow through the ammeter on their way to the cold junction.
5. Replace the candle with a Bunsen burner flame. What change is indicated? [The greater the temperature between the junctions, the greater the current.]
6. The current reading could be used to measure how great a temperature difference there is between the two junctions.

C. Conductivity tester

1. Connect one side of a bulb holder to one end of a dry cell battery. Connect a copper wire to the other side of the bulb holder. Attach an alligator clip to the free end of this wire.
2. Connect another copper wire to the other end of the dry cell battery. To this free end also attach an alligator clip.
3. Place a small bulb in the bulb holder and touch the two alligator clips together to see if the bulb will light. If it does the circuit is complete and ready to be used as a conductivity tester.
4. Test a number of objects by touching the two alligator clips to them. If the light bulb lights up they are conductors, if it doesn't they are non conductors.
5. From the selection of objects which cause the bulb to be brightest? Which allowed it to only barely light up?
6. Obtain a long pencil. Cut the wood of the pencil away to expose the graphite center. Scrape the wood off so that at least a 10 cm portion of the graphite is exposed.

7. Attach one of the alligator clips from the conductivity tester to the pencil point at the end of the pencil. Touch the second alligator clip to the graphite exposed closest to the pencil point. Note the bulb.
8. Slide this second alligator clip along the graphite toward the eraser end. What happened to the brightness of the light in the bulb?
9. What could account for the smaller amount of current passing through the bulb as the alligator clip was moved from contact at about 4 cm from the other clip to about 10 cm from the other clip? [There was greater resistance due to the longer length of graphite the electrons had to travel. With the same pushing power provided by the battery, more friction and collisions with the carbon atoms in the graphite caused less charge per second to pass through the circuit. Consequently, the bulb didn't have as much current passing through it and it didn't light up as much.
10. Repeat step nine with only one change. Get one of those big fat pencils that first graders use or a carpenter's pencil that has big thick lead. Compare the brightness at the 4 cm mark and the 10 cm again. But also compare the brightness at the 4 cm mark for an ordinary pencil and the 4 cm mark for the fat lead pencil. In which case did there seem to be less current flowing (as deduced by the brightness of the bulb) ? In which case was there the most resistance to the flow of the current?
11. This leads us to the important relationship that as resistance increases, the amount of current decreases. More specifically it says that **if the voltage is held constant, current flow is inversely proportional to resistance**.
12. Use the first stripped pencil for the following investigation. Attach the first alligator clip at the pencil point. Attach the second one at the 4 cm point. Now replace the dry cell battery, first using a 1.5 volt, then a 6 volt, and finally a nine volt battery. Compare the brightness of the bulb under each new voltage.
13. **With the resistance being held constant the voltage is directly**

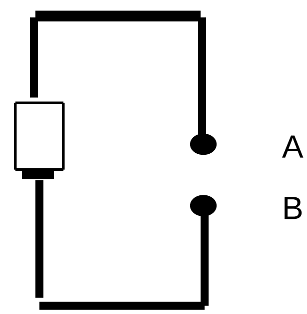
proportional to the current flow. (The more voltage, the more current flowed which made the bulb brighter.)

14. For the third investigation we will need both of the scrapped pencil setups. The first one will feature the regular pencil with the 1.5 volt dry cell. The alligator clips will be attached at the pencil point and at the 4 cm mark. The second set up will use the fat pencil and the 6 volt dry cell. One alligator clip will be at the pencil point. Move the second alligator clip so that the brightness of the bulb will be the same as in the first set up.
15. We know that the thick lead offers more resistance that the thin lead. So if we start by putting the second alligator clip at the 4 cm mark in the fat pencil we know that there is more resistance being experienced than in the first set up. Because we have to move the clip toward the eraser end before the brightness is similar to the first set up, we know that for the same amount of current to be flowing (same brightness) there must be more resistance for more voltage. In other words, **with the current remaining constant, the voltage is directly proportional to the resistance**.
16. These three investigations have all been combined to give us what is commonly referred to as **Ohm's Law**. Using the following symbols, **I** for current, **V** for voltage, and **R** for resistance, Ohm's Law is expressed as:

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{R}}$$

D. "DRAW" a Circuit

1. With a very soft "lead" (graphite) pencil draw a simple circuit such as the following containing a battery and some "wires." The circuit is open because of the gap at A and B.



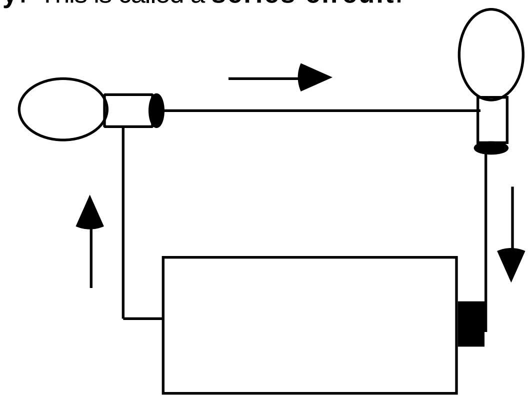
2. Place the leads of a VTVM (Vacuum Tube Voltmeter) on the dots at A and B. If the graphite lines are thick and no gaps occur, the meter should indicate that a current is actually flowing through the lines drawn. A tight connection must be made from the battery. Copper wires coming from the + and - ends of the battery should be taped securely to the graphite lines where the battery is indicated in the circuit.
3. Erase part of one line showing that without a complete circuit the current will cease to flow. Redraw the line and the current should start to flow again.
4. Lengthen the lines of the circuit to see if the meter changes.

CONCEPT EXTENSION

A. Challenge: How can you make two bulbs, a battery, and two wires light both bulbs?

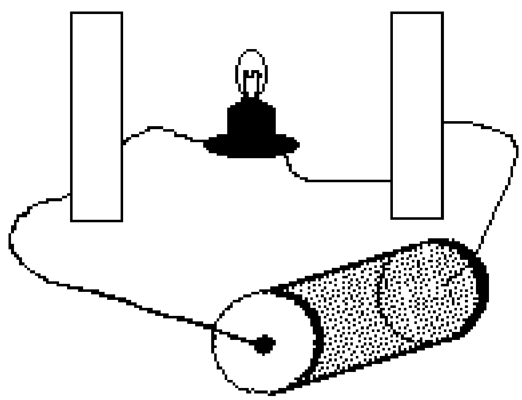
1. As before, give the supplies to the students so they can explore rather than you telling them how to do it. If they have grasped the concept of a complete circuit and that the special places that must be attached on both the battery and the bulbs, they should figure this out in a short period of time.
2. The biggest problem they will probably have is keeping all the connections together. Provide some tape so that they don't get frustrated with the connections coming loose and lose sight of the idea of the light bulbs being hooked together in series.
3. Point out that in all of their successful circuits that **there is only one path**

that the electrons can take when they leave the negative end of the battery and follow before returning to the other end of the battery. This is called a **series circuit**.

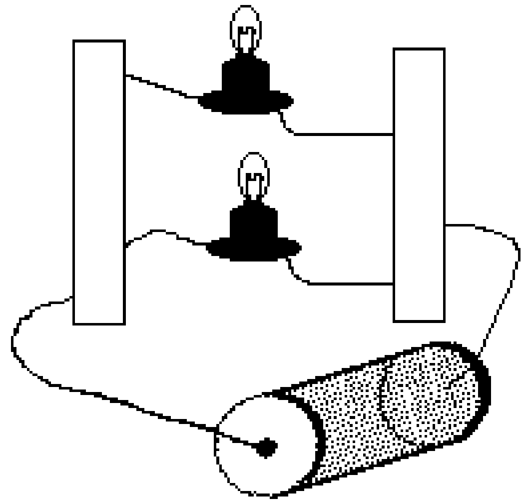


B. Parallel Circuits

1. Obtain two strips of aluminum foil about 15 cm long and 1 cm wide. Place them on the table parallel to each other with about 10 cm between them. Prepare two copper wires each with an alligator clip on one end. The other end of each should be securely attached to the poles of the dry cell battery. Screw in a bulb to a bulb holder and attach a copper wire to each post. Each of these wires should also have an alligator clip on one end.
2. Now, attach one of the alligator clips from one end of the battery to one of the alligator clips coming form the bulb holder. Before hooking the alligator clip from the wire attached to the other end of the battery to the second wire coming from the bulb holder, ask the class what will happen, if anything, when the connection is made. If they are following what you have done, they will see that this is nothing more than a simple complete circuit. When all the connections are made the bulb comes on.



3. Obtain a second bulb and bulb holder equipped with two wires having alligator clips on one end that are hooked to the holder exactly like the first one. Before proceeding, disconnect the clip coming from the battery to the second aluminum strip. Leave the first bulb hooked up as in #2 above.
4. Ask students what would happen if the second bulb and bulb holder were also connected to the two aluminum foil strips in the same fashion as the first one. In other words, the two aluminum strips are like two legs of a ladder and the first bulb/holder forms the first rung while the second bulb/holder forms a second rung. See diagram below.



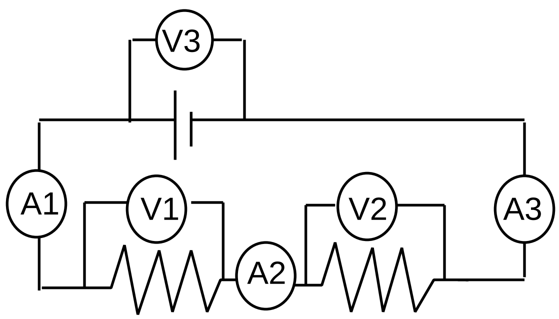
5. Hook the second bulb in but don't complete the circuit until some discussion has transpired. Have the students try and trace the path the electrons would follow to get from one end of the battery back to the other end. Hopefully it will be seen that there is now **more than one path for the electrons to follow**. When the connection is completed, some electrons will travel one path while some will travel the other path. Consequently, both bulbs will light up? We call this type of circuit a **parallel circuit**.
6. Now give each student one battery, two bulbs, and four wires. Ask them to make a parallel circuit that will light up both bulbs.
7. After some experimentation time direct the students attention back to the aluminum strips and the two bulbs hooked together in parallel. Ask them what would happen if you unscrewed the top bulb so that it is not making connection. [Obviously the lower bulb should not go out because of the way we put the system together in steps. Indicate to them that this is the neat thing about parallel circuits, that if one bulb goes out the other can still stay lit.]
8. Find someone in the class that has the two bulbs wired in parallel and someone else who has them wired in series. Start first with the parallel one and say to the class, "What would happen if we unhook one of the bulbs, would the other one stay lit?" [When you do it, it stays lit.]
9. Repeat the question for the series circuit. [When one of the bulbs here is removed there is no longer any complete path for the electrons to follow and the other bulb goes out.]
10. Let them work some more with trying to set up parallel circuits.

C. How Bright is the Light?

1. Four identical bulbs and two identical batteries are needed for this exercise.
2. First hook up a single bulb to a battery and note its brightness. Then hook another one in series. How does the brightness compare in the two cases. [Even though they were exposed to the same total voltage the amount of current flowing in the first case caused a brighter light. When the resistance was doubled in the second case the brightness was less. [As the resistance went up, the current went down; Ohm's Law.]
3. Unscrew one of the bulbs. What happens? [Since there is only one path for the electrons to follow, breaking the path prevents either bulb from staying lit.
4. Now hook two of the bulbs in parallel to an identical battery. Compare the brightness of the bulbs hooked up in series and those hooked up in parallel. [The bulbs in series will be dim while the bulbs in parallel will be brighter.]
5. Unscrew one of the bulbs. What happens? [The second bulb continues to burn. Since there are two paths for the electrons to follow on their way back to the other terminal of the battery, the second bulb continues to burn.]
6. Compare the brightness of the two bulbs in parallel with each other. What happens to the brightness when one of the bulbs is unscrewed? [The

brightness is the same in each bulb. The brightness does not change with one bulb is unscrewed.]

7. If you have access to ammeters and volt meters, you might want to investigate quantitatively what they have qualitatively seen. The schematic below is that of two resistors (light bulbs) hooked to a battery in series. Below that is the schematic with the meters attached.



8. Meters A1, A2, and A3 will all read the same. The sum of V1 and V2 should equal V3. From this it appears that the current is the same throughout the whole circuit (only true for series circuits). It also appears that the sum of the voltage drops across the two bulbs equals the total voltage (also only true for series circuits).

9. Make the same measurements with the parallel circuit.

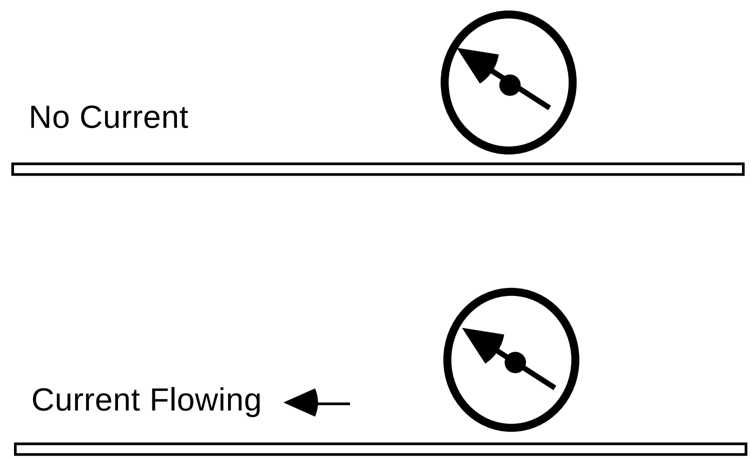
10. Meters V1, V2, and V3 will all read the same (only true for parallel circuits). The sum of A1 and A2 will equal A3 (also true only for parallel circuits). From this it seems that the voltage remains constant throughout the entire circuit. It also appears that the sum of the individual branch currents equals the total current in the cell.

ELECTROMAGNETISM

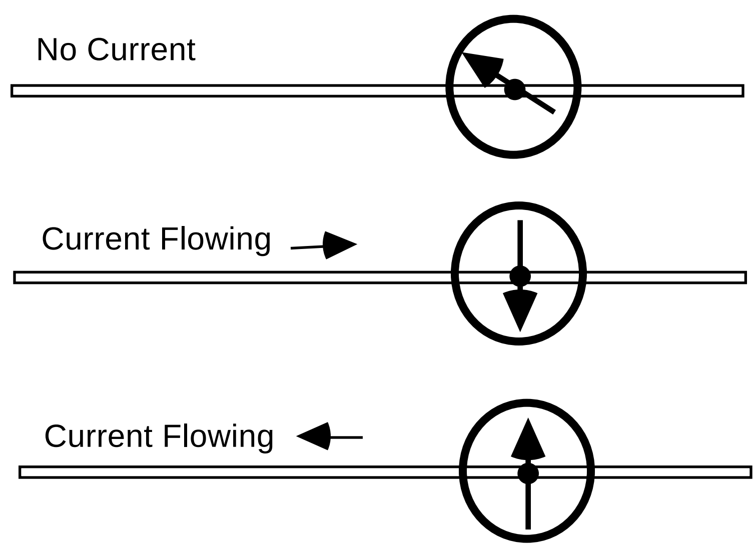
PROBLEM PRESENTATION / EXPLORATION

A. Oersted's Discovery (*Magnetism can be produced from electricity*)

1. Place a loop of copper wire flat on the table. With the wire remaining flat on the table attach the two ends to the terminals of a dry cell battery. Place a small compass next to the wire. Observe the compass. Do not leave the wire hooked to the battery for more than a few seconds. It will get hot. [There should not be any motion of the compass needle.]



3. One day in 1820 Oersted was lecturing a physics class when he noticed a wire lying **above** a compass. When the current flowed through the wire the compass needle was deflected. This chance observation led him to a powerful discovery.
   a. Hook up the wire to the battery again. This time hold the wire above the wire that is resting flat on the table. Note what the needle on the compass does. [It deflects at an angle perpendicular to the wire.]

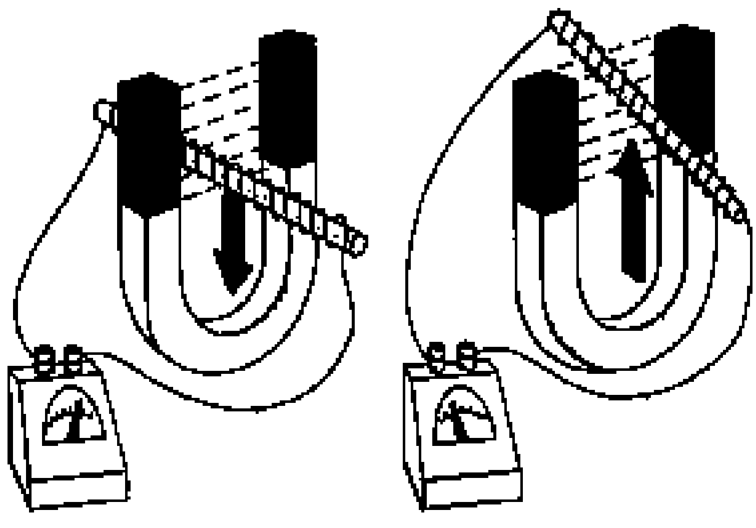


   b. Once again hold the compass above the wire that is resting flat on the table but reverse the connections of the wires to the terminals of the battery. Note what the needle on the compass does. [This time it deflects the other direction but still perpendicular to the wire.]

4. From these experiments we see that **an electric current flowing through a wire gives rise to a magnetic field whose direction depends upon the direction of the current**.

B. Henry and Faraday's Discovery (*Electricity can be produced from magnetism*)

1. In 1831 Faraday (England) and Henry (USA) reasoned that if magnetism can be produced from electricity, electricity should be able to be produced from magnetism.
2. A galvanometer is a sensitive device that will register the direction that electrons are flowing through it. Hook a piece of copper wire to the two terminals of the galvanometer. Move a horseshoe magnet up and down so that the wire can cut the magnetic lines of force between the poles of the magnet. Note the reading of the galvanometer. [When the magnet is moving downward the deflection will be one way; when the magnet is moving upward the deflection will be the other way. If the magnet is not very strong, a deflection may not appear to occur. In the Concept Invention portion of this lesson this will be remedied by using a wire with many loops so that more lines of force will be cut.]
3. Set the horseshoe magnet on the table so that the legs are pointing upward. Move the same wire and galvanometer back and forth cutting the magnetic force line between the poles of the magnet. Note the reading of the galvanometer. When the wire is moving downward the deflection will be one way; when the wire is moving upward the deflection will be the other way.]



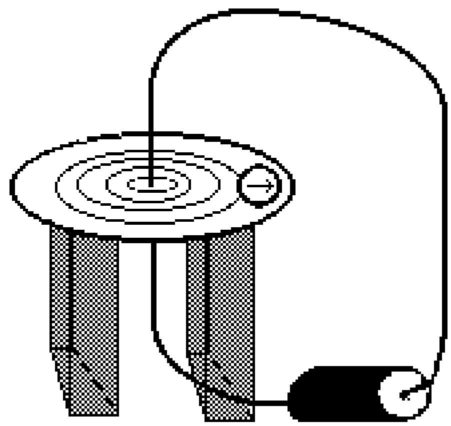
4. In neither case was any source of voltage needed to cause electrons to flow. The production of voltage and current depends only on the relative motion between the conductor and the magnetic field. **Voltage is induced and electrons flow whether the magnetic field of the magnet moves past a stationary conductor, or the conductor moves through a stationary magnetic field**.

CLASS RESPONSE / CONCEPT INVENTION

A. Electromagnetism

1. Set two books on end side by side about 20 cm apart. Use the point of a pencil to poke a tiny hole in the middle of a paper plate and place it on top of the books.

2. Thread a strip of insulated copper wire through the hole so that the wire passing through the plate is perpendicular to the plate. Loop the wire back down passing by the outside of the plate. The two ends of the wire should be hanging below the plate
3. Sprinkle some iron filings on the plate. Place a small compass on the edge of the plate.
4. Attach the ends of the wire to a dry cell battery on the table. The end coming from under the plate should be attached to the negative terminal.
5. Set a small compass on the inside edge of the plate. Observe the compass needle. Tap the plate gently and observe the filings. As in the first section of this lesson don't leave the wire hooked to the battery more than a few seconds at a time. [The compass deflected so that it was perpendicular to the wire. The iron filings moved to arrange themselves in concentric circles around the wire.]

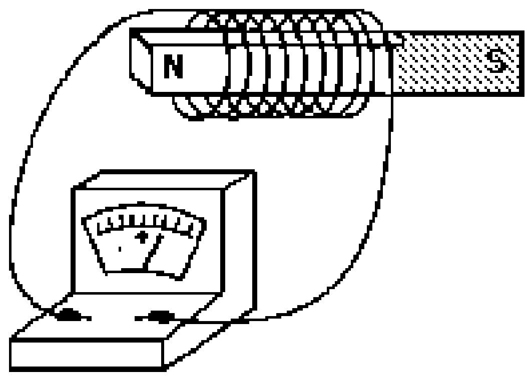


6. Reverse the attachment off the wire ends to the battery. Observe the compass and the iron filings. [The filings stay the same but the compass reversed its deflection.]
7. Would the magnetic field created around the wire be able to pick up a paper clip? [Upon trying it, the chances are very good that it will not.]
8. It occurred to Oersted that if this single loop would produce a magnetic field that looping the wire more times should produce a stronger field.
    a. Loop some wire around a pencil. Make about thirty loops. Attach the ends of the wire to the dry cell battery. Try to pick a paper clip. [This should work better.]
    b. Provide a nail long enough that it will fit in the coil and extend beyond it on either end by 1 cm. Have them try again to pick up a paper clip. [This time it will pick up a number of paper clips.]
    c. Challenge the students to a contest to build an electromagnet that can pick up more paper clips than anyone else in the classroom. Provide for them extra batteries, wire, different things (aluminum rods, paper rods, wood, plastic, crayons, chalk, glass, etc.) that they can put into the coil to take the place of the nail. Give them time to experiment before you have your contest.
    d. The winning electromagnet will probably optimize a number of factors; using more than one battery will help, the more turns in the coil will help, an iron core will help, and the often overlooked factor is that both ends of the core will pick up paper clips. Sometimes students only try to use one end.

B. Electromagnetic Induction
1. As we saw in the first section of this lesson, when a conductor cuts the magnetic lines of force, electrons flow. As we saw in #8 above looping the wire seemed to improve the field; would using a coil and magnet produce a

greater amount of electron flow?

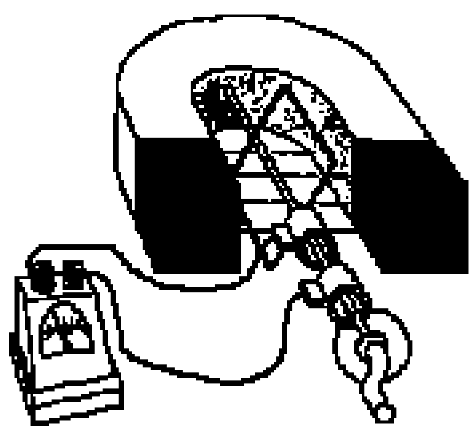
2. In place of the single loop used in A2 of the first section use a coil of wire to cut the lines of force between the poles of the horseshoe magnet. Did you see greater deflection in the galvanometer? [Yes]
3. Wrap about 4 m of insulated copper wire around a cardboard tube from a roll of paper towels. Attach the ends to a galvanometer
4. Insert a bar magnet into the cardboard tube. Move it back and forth. At first slowly, then rapidly. [Slow movement will not produce much deflection. Rapid movement produces a larger deflection. Moving in produces deflection in one direction; moving out produces deflection in the other direction.]



5. Hold the magnet still an rapidly move the coil back and forth. Was there any difference in the galvanometer readings when the tube was moving and when the magnet was moving? [No]
6. The process by which a current is produced by the relative motion of a conductor in a magnetic field is called **electromagnetic induction**.

C. Generator

1. An important application of electromagnetic induction is the operation of a generator. The movement of either the conductor or the magnet in B4 and B5 above required kinetic energy. A system that uses kinetic energy to produce electrical energy is called a **generator**.



2. In a simple hand crank generator the magnet is fixed and the coil of wire moves. Because the coil rotates, the direction of the magnetic field changes in relation to the coil. This changing direction of the magnetic field causes the current that flows in the coil to change direction as well. Thus, the current produced is alternating current.
3. Investigate a bicycle generator that operates the light. A knob on the

generator is moved so that it touches the wheel. As you pedal the bike, the moving wheel provides the kinetic energy which turns the knob which turns a shaft inside the generator. The shaft rotates a coil of wire through the magnetic lines of force of a stationary magnet. This causes current to flow which lights the headlight.

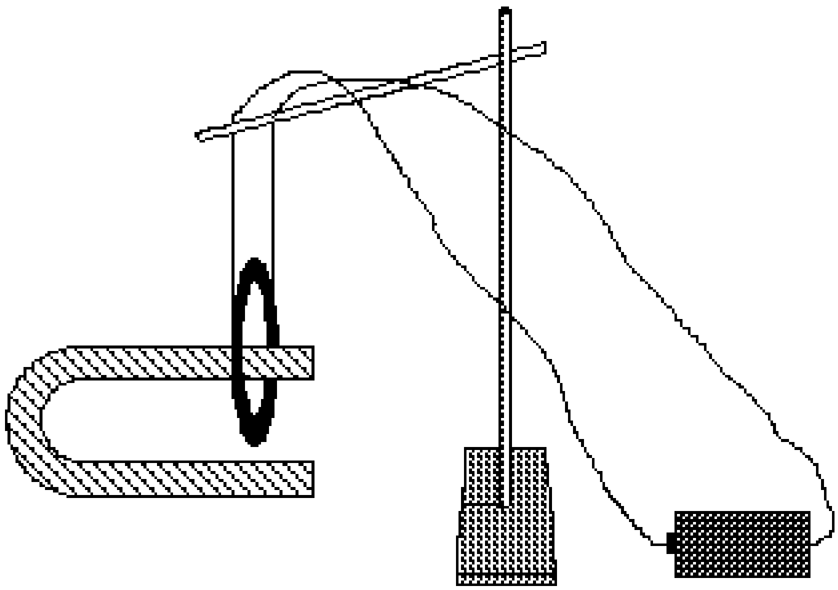
D. Motor
1. The opposite of a generator is a motor. Here, electrical energy is converted to kinetic energy. Both the generator and the motor are examples of electromagnetic induction.
2. A motor consists of an electromagnet that rotates on an axle. It rotates continuously between the two poles of a fixed permanent magnet.
3. The continuous switching of the current causes the electromagnet to be continuously repelled by the fixed magnet. It spins around and around. This kinetic energy (energy of motion) which, through electromagnetic induction, can be used to do work.

CONCEPT EXTENSION

A. Jump Rope Generator
1. How could you use an extension cord to produce electricity? The obvious answer is to plug it into the wall outlet. But this challenge is a little more difficult than that.
2. Challenge: Use only a 50 ft extension cord hooked to a galvanometer and produce electron flow.
3. After students puzzle over this for a little while suggest to them that if magnetic force lines are cut with a conductor electrons should flow. Remind them that the largest magnet in the world **is** the entire planet. Remind them that there are magnetic lines of force going around the world from pole to pole.
4. If no one has still come up with an idea, suggest to them to use the extension cord as a jump rope. As they twirl the cord they will be cutting the magnetic lines of force around the earth.
5. Details that must be attended to are:
   a. The cord must make a loop with both ends hooked to the galvanometer. Do this by attaching an alligator clip to the ground prong of the cord and via a short piece of copper wire to one terminal of the galvanometer.
   b. Jam another alligator clip into the ground receptacle on the other end of the extension cord, and attach this, via a short piece of copper wire, to the other terminal of the galvanometer.
   c. Align the extension cord in the east/west direction. Why? [When the cord is turned we want it to perpendicularly cut the lines of force that are going north/south.]
   d. Leave both ends of the extension cord on the ground and pick up the middle half and twirl it like a jump rope (you will need two twirlers.)
   e. What effect does the rotational speed of the cord have on the deflection of the galvanometer? [The faster the turning the greater the deflection of the galvanometer.]

B. Building a Primitive Motor
1. Wrap 4 m of lacquered wire around a paper towel roll to make a coil. It should have at least 30 turns. Wrap some masking tape around the coil so it doesn't fall apart. Leave 40 cm of uncoiled wire at each end.
2. Attach a horizontal rod to a ring stand. From the rod wrap the two lengths of wire from the coil so that the coil hangs 20 cm below the rod. Leave 10 cm of wire free at each end. Tape the wires to the rod.
3. With books, or bricks mount a horseshoe magnet parallel to the table so that the north pole of the magnet sticks out. Adjust the height of the magnet so that the coil hangs freely around the magnet but does not touch it.
4. Attach one of the free wires to one end of a D cell battery and briefly touch

the other wire to the other terminal of the battery. Notice what happens to the coil. [It moves in one direction.]



5. Reverse the ends of the battery that the wires are attached to. Notice what happens to the coil this time. [It moves in the opposite direction.]
6. Notice that we had to manually reverse the current through the coil. If alternating current was used as it is in a motor motion can be sustained.

RADIOACTIVITY (Half-Life)

PROBLEM PRESENTATION / EXPLORATION

A. Most of you like to spend money. Lets investigate how long it would take to spend a million dollars. You probably think that this would not be much of a problem, right? There is only one rule we will follow in this exercise. **On each day you can only spend half of what you start the day with.** So on the first day you get to spend a half million dollars.

1. Question: "If on January 1 you start with one million dollars, on what day will you end up with only one dollar or less?
2. Estimate how long you think it will take to spend the million dollars: two days? a week? a month? a year? ten years?
3. The following table may help in figuring out how long it would take.

Date	Starting Amount	Ending Amount
Jan. 1	1000000.00	500000.00
Jan. 2	500000.00	250000.00
Jan. 3	250000.00	125000.00
Jan. 4	125000.00	62500.00
Jan. 5	62500.00	31250.00
Jan. 6	31250.00	15625.00
Jan. 7	15625.00	7812.50
Jan. 8	7812.50	3406.25
Jan. 9	3406.25	1703.12
Jan. 10	1703.12	851.56
Jan. 11	851.56	425.78
Jan. 12	425.78	212.89
Jan. 13	212.89	106.44
Jan. 14	106.44	53.22
Jan. 15	53.22	26.61
Jan. 16	26.61	13.30
Jan. 17	13.30	6.65
Jan. 18	6.65	3.32
Jan. 19	3.32	1.66
Jan. 20	1.66	.83

4. According to the above table, on Jan. 20 you would end up with less than one dollar.
5. How long do you think it would take you to spend one hundred dollars following the same rule?

Date	Starting Amount	Ending Amount
Jan. 1	100.00	50.00
Jan. 2	50.00	25.00
Jan. 3	25.00	12.50
Jan. 4	12.50	6.25
Jan. 5	6.25	3.12
Jan. 6	3.12	1.56
Jan. 7	1.56	.78

6. In both of these cases we would say that the time it took to spend half of what remained was one day. We might call this the "half-life."

CLASS RESPONSE / CONCEPT INVENTION

A. In the exploration activity above, the time to use up half of the money was imposed on you for the exercise (one day). We would now like to determine what this "half-life" for some other activity is experimentally.

B. Isotopes of various atoms undergo a totally random phenomenon known as radioactive decay. One can not predict when any single atom will undergo decay, however, for a large number of atoms the "half-life" can be determined. **The "half-life" is the amount of time that it would take for half of the atoms we start with to undergo their random decay**.

C. We want to experimentally determine how long it would take for an imaginary isotope to have half of its atoms decay. We will simulate atoms by using partially colored sugar cubes.

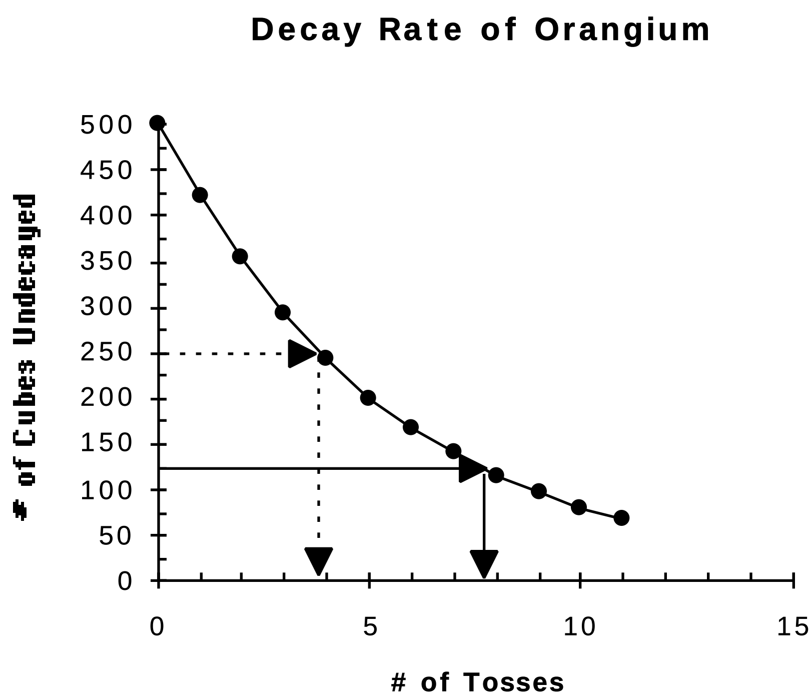
D. Preparation of "ORANGIUM", "GREENIUM," and "BLUIUM".
   1. Obtain approximately 1500 sugar cubes.
   2. With an orange magic marker color one face of each of 500 sugar cubes orange.
   3. With a green magic marker color two faces of each of another 500 sugar cubes green.
   4. With a blue magic marker color three faces of each of another 500 sugar cubes blue.
   5. Place all the "ORANGIUM" "GREENIUM", and "BLUIUM" isotopes into three separate large Ziploc bags. (If the sugar cubes are stored in a sealed Ziploc bag, they can be used for many years. If left open to the air, the sugar will absorb moisture from the air and become sticky.)

E. Directions
   1. Have a group of students toss from the bag all of the orange sugar cubes onto the table. Insure that they are lying flat on the surface of the table.
   2. Separate into two piles those that landed with an orange face up and those that landed with a white face up.
   3. Record the number of each in the table below. Each cube that lands with an orange face up represents an atom that has decayed.
   4. Set aside all the cubes that landed with an orange face up. Gather up all those that landed with a white face up and put them back in the bag. In your second toss use only these atoms in the bag.
   5. Repeat this process for a total of eleven tosses. Mythical data are plotted below.

Toss #	# White Cubes After Toss	# Orange Cubes After Toss	Cumulative # of Orange Cubes
0	500	0	0
1	422	78	78
2	354	68	146
3	294	60	206
4	243	51	257
5	200	43	300
6	167	33	333
7	140	27	360
8	115	25	385
9	96	19	404
10	80	16	420
11	67	13	433

Total # of Cubes 500

   6. Plot the data from the experiment on a piece of graph paper. Label the vertical axis # Cubes Undecayed (white cubes), and label the horizontal axis # of Tosses.



7. Read from the graph the "half-life" of "ORANGIUM" (the number of tosses it took for half of the total cubes to come up with an orange face.)
[If the total # of cubes was 500, then how many tosses did it require for 250 of them to come up with an orange face? On the y-axis find 250; draw a line horizontal to the x-axis (the dotted line) starting at 250 and stopping when it reaches the curve. Now starting at this point on the curve, draw a line parallel to the y-axis (dotted line) until it crosses the x-axis. Read how many tosses it says it took to have 250 cubes come up with an orange face. Does this match up with how many throws it took? Check your data table. According to our mythical data the graph would indicate that about 3.8 tosses would be required to have 250 of the cubes come up with an orange face. If we look at the table we see that after three tosses 206 of them had come up orange. After four tosses 257 had come up orange. Roughly this corresponds to about 3.8 tosses being required to use up half of the cubes.]
8. If it takes 3.8 tosses to use up 250 of the cubes, one-half of what started out with, how long would it take to use up half of the 250? (This is asking the same thing as in part G below, except that we have the data on the graph to check it. Notice that another line parallel to the x-axis has been drawn from 125 on the y-axis and where this crosses the curve another line parallel to the y-axis has been dropped. This line crosses at about 7.7. The difference between 7.7 and 3.8 is about 3.9. This means that it took about 3.9 tosses to reduce the 250 cubes down to 125. In other words the half life (about 3.8 or 3.9 tosses) remains the same. Therefore it would take about 3.8 or 3.9 more tosses to reduce the 125 cubes down to 63 cubes. If you have time, do it with the cubes to check it out.

F. Carry out the determination of the "half-life" for "GREENIUM" and "BLUIUM" in a similar manner. Do all three isotopes have the same "half-life"? [No.]

G. What would the "half-life" be if you used 2000 "atoms" of "ORANGIUM"? Have students predict. Would it be four times as long, since you started with four times as many "atoms"? Would it be one fourth as long? [The "half-life" will not change. It is not dependent upon the number of atoms you start with. We saw that to some extent in number 8 above.]

H. Hopefully the students can draw the conclusion that the half-life is not dependent on the initial quantity. This is not to be confused with the Exploration Activity where the "half-life" was imposed on the exercise.

I. Many naturally occurring processes in this universe other than radioactive decay proceed in a manner similar to that illustrated by the sugar cube isotopes. A very common example of this is water draining out of a buret. Just as the rate of sugar cubes coming up with a colored face was directly proportional to the number of cubes left, the rate of water draining out of the buret is directly proportional to the volume of water left in the buret. [The more water in the buret, the faster it drains; the lesser amount in the buret, the slower it drains.]

J. Can we find the "half-life" of the water draining from a buret in an analogous way to our determination of the "half-life" of the sugar cube isotopes?

1. Fill a buret with water. Let it drain through the tip until all the air is forced out. Allow it to drain down to the 50.0 mL mark [The stopcock must be wide open when the water is draining out.]
2. Place a 10 mL graduated cylinder beneath the tip of the buret and allow all the water below the 50.0 mark to drain out into the graduated cylinder. RECORD THIS VOLUME. It is important that all the water beneath the 50 mL mark be measured. You might have to apply some positive pressure on the mouth of the buret to blow the water out.
3. Refill the buret with water and drain through the tip until all the air is forced out. Add more water if needed so that the water level can be drained down to the 0.0 mL mark.
4. Open the stopcock all the way to start the water flowing. Measure the time needed for the water to drain to the 10 mL, 20 mL, 30 mL, 40 mL, and 50 mL marks. The best results probably occur when one person watches the falling level and calls out to the second person who is watching the clock and recording the times.
5. Repeat step #4 to check on the times to hit each of the marks. Average the two times and enter these times in the average time column.
6. When filling in the table, note that the "Vol Remaining" equals TOT VOL - Buret Reading. (TOT VOL = 50.0 mL + Volume you found in step #2)
7. Plot the data from the experiment on a piece of graph paper. Label the vertical axis Vol Remaining [This is just like the sugar cube graph.] Label the horizontal axis Time.

SOUND

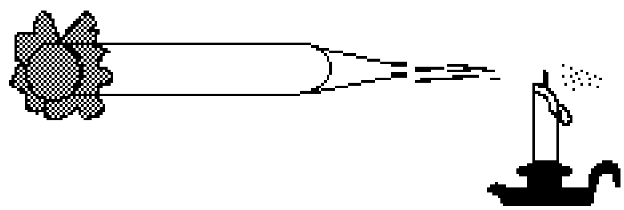
PROBLEM PRESENTATION / EXPLORATION

A. Can You "See" Sound?

1. If you were deaf, how could you see sound? You have all seen receivers in a stereo system that have meters that indicate the various sounds that are being produced by the speakers. In this case as the tape, record, or CD is activated, a current is sent to the meters at the same time it is sent to the speakers. In this way you can "see" the sound as well as hear it.
2. Lets build a non-electronic device to observe sound. You will need an oatmeal box or coffee can. Remove both the top and bottom of the box or can. Stretch a balloon or rubber sheet over one end of the box/can and secure with a rubber band or string. Be sure the balloon is stretched tight.
3. Attach a small mirror to the center of the surface of the balloon with some glue. Place the device on its side on a flat on a table. After darkening the room shine a flashlight at about a 45° with the flat surface of the balloon. Direct the reflection at a white wall or movie projection screen.
4. Have a student yell into the open end of the tube and watch the reflection. Can you explain what you see? Try different degrees of loudness.

B. Can You Put Out a Fire With Sound?

1. Obtain a mailing tube or large cardboard tube having a diameter of seven to ten centimeters. Both ends should be open. To one end stretch a balloon or rubber sheet and secure it with a rubber band or string.
2. Make a paper cone and fasten it to the other end of the mailing tube. The hole at the bottom of the cone should be between 0.5 and 1 cm in diameter.



3.. Light a candle and place it in front of the mailing tube/cone device. Secure the candle so that it will not tip over. Now clap your hands near the stretched balloon. Notice what happens Whistle or play a small radio near the stretched balloon. Finally flick your finger at the balloon surface. The flame should go out. Explain what happened in each of these cases.

C. Can You Hear a Bell in a Bottle?

1. Obtain a large Florence flask and equip it with a solid rubber stopper. Find a small hand bell (jingle bell) that will fit through the mouth of the flask. Push a thumbtack into the bottom of the rubber stopper. Finally, attach the bell by means of a short piece of iron wire to the thumbtack so that when the rubber stopper is lowered into the flask it will hang at about the center of the flask.
2. Shake the flask. Can you hear the bell? [Yes]
3. After removing the stopper pour about 20 mL of water into the flask and heat it to boiling. Let it boil for at least one minute.
4. Immediately insert the stopper with the bell into the flask. (Use a towel or other protection from the steam and hot glass.)
5. After letting the flask cool off for a minute shake it again. Can you hear the bell now? [Not very well.]

D. How Fast Does Sound Travel?

1. Take the class outside and face a large vertical brick wall.
2. Starting about 10 meters in front of the wall bang two sticks together and slowly walk backwards away from the wall.
3. As soon as an echo of the banging sticks can be heard by someone, move forward or backward A step at a time until the whole class can hear the echo.
4. Measure the perpendicular distance from the position where the echo was

heard to the wall.

5. The minimum time interval that the human ear can detect between two claps of the stick is 0.1 second. When this interval between the clap and the echo is shorter than 0.1 second, no echo is heard. This is why no echo was heard when standing only 10 meters in front of the wall. The time it took the echo to come back at this distance must be 0.1 second.
6. Can you find out from the information collected how fast the sound was traveling through the air? [The echo should be heard at about 17 m in front of the wall. This would mean that the sound traveled to the wall and back (2 x 17m) in 0.1 second. This means that the speed of sound is about 34m/0.1 second or about 340 m/second.]

CLASS RESPONSE / CONCEPT INVENTION

A. What Causes Sound?

1. Every sound starts with energy being imparted to an object. This sets up a vibration in the object. Vibrating your vocal chords when you speak, or beating on a drum, or blowing into a trumpet are examples. The first EXPLORATION activity illustrates the idea of vibration. The energy was supplied by clapping your hands which caused the air molecules to vibrate which in turn caused the balloon to vibrate which caused the mirror to move back and forth so that you could visibly see the sound.
2. Notice how important the air was in this process. Could the energy disturbance (the hand clapping) have reached the balloon without the air providing a means of transferring the energy disturbance? [No] In addition to having an energy disturbance there must be a medium through which the disturbance can travel.
3. Notice what happened in the bell in the flask case. Shaking the bell was the energy disturbance. This then caused the air in the flask to vibrate and was transmitted to the glass, to the air on the outside of the flask, and to our ears. But in the case where the water was boiled, the air was forced out of the flask and replaced by water vapor. Upon the cooling of the water vapor the water molecules suddenly condensed into liquid water leaving most of the volume void of molecules. Shaking the bell now produced only a faint sound. The same energy disturbance occurred, but there was very little medium through which it could be transmitted to reach our ears. If a perfect vacuum could be produced, no sound would be heard.

B. How Would the Nature of the Medium Affect Sound?

1. Does sound travel better through gases, liquids, or solids?
2. Have you ever put your ear down to a railroad track and heard the train coming from miles down the track? Have you ever been swimming under water and heard somebody hit two rocks together? How does that compare with sticking your head out of the water and having the two rocks banged together above the water?
3. Position an ordinary coat hanger upside down (hook end pointing down). Tie a piece of string to each end (the curved parts making up the corners of the hanger "triangle.") Wind the string two or three times around the end of your first finger on each hand. Now stick these fingers in your ears. Either swing the hanger into a stationary, solid object or have someone else hit the coat hanger with a pencil. How does the sound you hear differ from hitting a normal coat hanger with a pencil?
4. The original vibration was set up by hitting the hanger with the pencil. This caused the hanger to vibrate which caused the string to vibrate, which was transmitted through your fingers to your ears. The resulting sound was a gong-like one, much richer and louder than the vibrations that normally travel through the air to your ears.
5. The idea of sound being a disturbance from one molecule to another can be illustrated by the following demonstration. Line up four students side by side and shoulder to shoulder. Place a chalkboard eraser on the head of the last

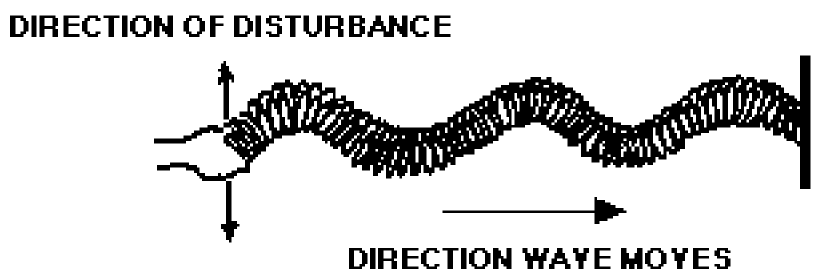
student. Each student should gently push against his or her neighbor, thereby showing the transmission of the movement along the line. The eraser falling from the head of the end student is evidence that the disturbance that began on the opposite end of the line has reached the one wearing the eraser. Did the first student push on the end student wearing the eraser? No. This is a very simple analogy of how an energy disturbance is transmitted through a medium.

C. How Would the Speed of Sound Be Affected Through Different Media?

1. We will investigate this more experimentally later, but a simple analogy might be helpful to start with. (See the lesson on Dominoes, average speed, p. 43.)
2. Line up dominoes at evenly spaced intervals (approximately 2 cm apart stretching out over a 100 cm length. Push over the first one and watch this disturbance transmitted to the next domino, and to the next, etc. Measure the amount of time it takes until the last domino topples. Lets say this setup represents sound being transmitted through a solid. Now line up the dominoes at evenly spaced intervals (approximately 4 cm apart.) stretching out over a 100 cm length Push the first domino and predict whether the time required for the last domino to topple will be greater or smaller than in the first case. [Longer] This might represent a liquid where the molecules are farther apart. Setting up both the solid and liquid situations and applying the disturbance at the same time may more graphically illustrate the comparison. Sound travels slower through substances where the particles making up the medium are farther apart. **The general rule is that the speed of sound is directly proportional to the density of the medium**.

D. Transverse and Longitudinal Waves

1. A wave can be classified by the direction in which it disturbs the medium. A bobber on the end of your fishing line will float calmly on the lake until a fish pulls it down. In response the bobber will bounce up and down vertically, but the water waves generated will move horizontally out from the original disturbance. A **Transverse Wave** is a disturbance that moves the medium at right angles to the direction in which the wave travels. As the disturbance moves horizontally outward the medium is disturbed for an instant in a vertical plane.



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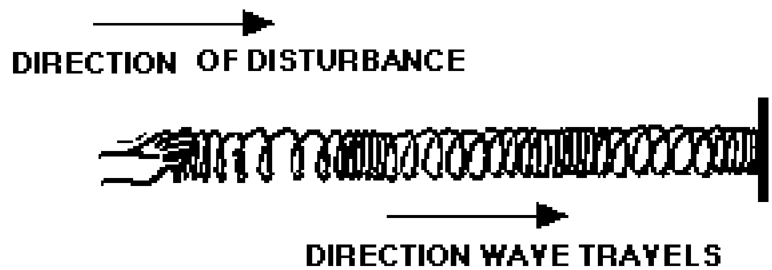
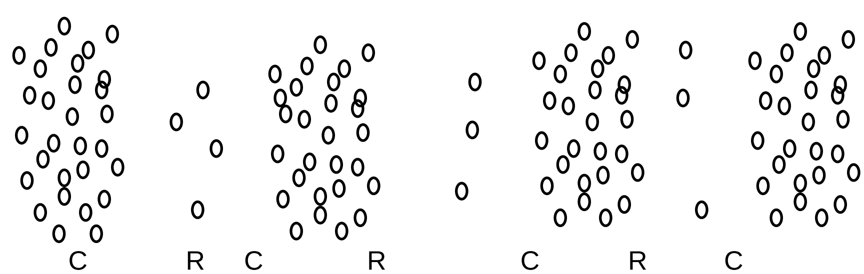
2. Place a large Slinky® on a smooth level surface. Have a partner hold the opposite end firmly. Stretch the spring until the coils are no more than 1 cm apart.
3. Suddenly move your end of the spring sideways about 20 cm, then quickly return it to its original position. A pulse should travel along it length and reach your partner. Compare the direction that the medium (Slinky®) moved compared to the direction of the pulse. This is an example of a transverse wave. If you rhythmically move your hand back and forth you will see a continual waveform traveling down the spring.
4. Bring the Slinky® back to its initial starting position. Reach a short distance down the spring and gather the coils toward you. Quickly release them. Observe the direction in which the pulse move and the direction in which the

coils of the medium move. Is this a transverse wave. [No]

5. In this case the spring did not move at right angles to the direction of the disturbance. It bunches up in some areas and spreads out in others. The spring moves back and forth rather than up and down. When the disturbance moves the medium back and forth parallel to the direction in which the wave travels we have a **Longitudinal Wave**. Sometimes these are called compressional waves.



6. By which type of waves does sound travel? [Longitudinal]
7. Sound is produced by the vibration (rapid back-and-fort motion) of an object which then pushes again and again on the surrounding medium. An example of a longitudinal wave traveling through air can be seen when you quickly push a door to your room inward. The door pushes against the air molecules next to the door, these molecules bump into other air molecules, etc. until the curtain hanging in your open window will swing out the window. Pulling the door shut will cause a rarefaction of the air next to where the door started and air molecules will rush into this near the door. The air molecules in the room will successively move toward the door and finally the curtains will be pulled toward the door.
8. Consider what happens when the tines of a tuning fork are struck with a rubber mallet. A series of compressions and rarefactions is set up and moves through the air. The air molecules move together and spread apart with respect to the frequency of the tines moving back and forth



E. Frequency, Wavelength, and Speed

1. The distance from one compression to the next compression in a sound wave is called its wavelength. Therefore, the diagram above shows a portion of the wave three wavelengths long.
2. If you stand at a fixed spot and count how many wavelengths of the sound reach you, you will determine the frequency of the sound.
3. If the wavelength above measures 4 cm and the portion of the wave pattern above represents a total of 1.0 seconds, the frequency would be 3 cycle/second. (When dealing with sound we use the term Hertz, so the frequency of this wave would be 3 Hertz.)
4. At what speed was this sound traveling through the air? Common sense tells you that the wave was traveling 12 cm/second. This involves using nothing more than the formula for finding average speed

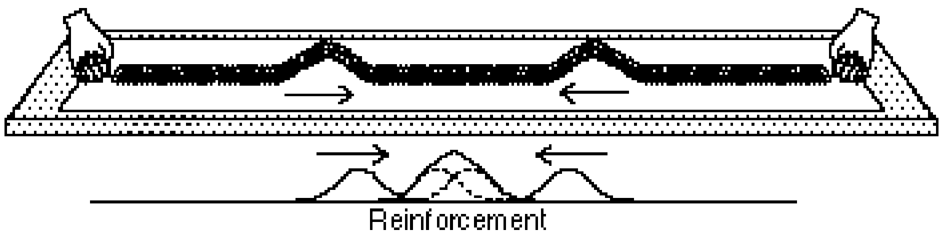
$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{12\text{ cm}}{1\text{ sec}} = 12\text{ cm/sec}$$

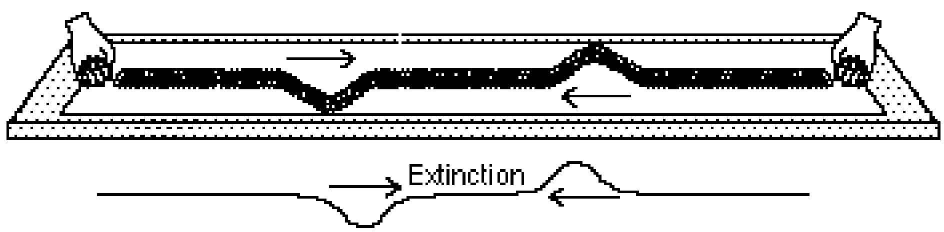
However, when dealing with wave movement we can use the following relationship: wave speed = wavelength x frequency, where we use **v** for wave speed, λ (lambda) for wavelength, and **f** for frequency.

wave speed = wavelength x frequency
v **=** λ **f** = (4 cm) x (3/sec) = 12 cm/sec

F. Constructive and Destructive Interference

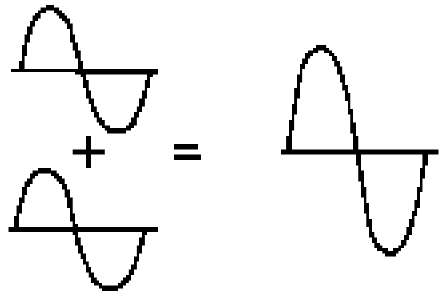
1. A very interesting demonstration can be done with either a rope or a Slinky®. Have two students hold the rope at opposite ends. Have student #1 start a pulse going down the rope in one direction and have student #2 start a pulse going in the other direction. What do you think will happen when they meet? This could be done with the Slinky® just as easily.





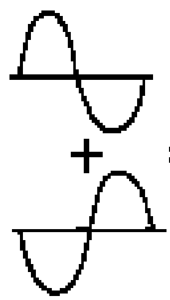
2. The answer is as can be seen above, "It depends." If the two waves hit at the same point "in phase" they will add together positively or reinforce the displacement. If they hit out of phase they will add together negatively and destroy the displacement. The positive reinforcement will make the wave pulse bigger (greater amplitude) and the negative reinforcement will completely level out the wave pulses. These two possibilities are examples of wave interference. In most cases when waves meet they are not perfectly in or out of phase and there is both positive and negative reinforcement

CONSTRUCTIVE INTERFERENCE



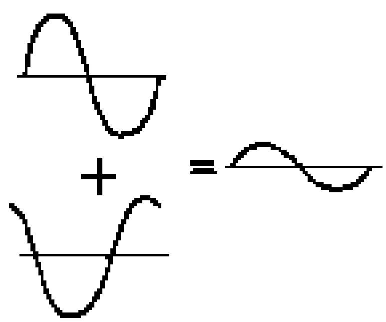
3. Total destructive interference can produce "dead" spots in which no sound can be heard. An example is in a large new concert hall. Dead spots are created due to the fact that sound coming from the stage radiates out in all directions. Some of the sound comes directly to your ears from the stage. Some of the sound, however, may hit a wall or ceiling and bounce off and then come to your ears. Now if the rarefactions from the direct sound arrive at your ears at the same time the compressions from the reflected sound, you will hear nothing. They cancel each other out, just like in the rope above. This is why there often are odd shaped panels hanging from the ceiling or panels affixed to the sides of the auditorium to keep the sound waves from being reflected in a manner that destructive interference occurs.

DESTRUCTIVE INTERFERENCE



4. If two instruments sound the same note and they arrive at your ear at the same time, you will not hear the separate tones they produced but instead you will hear the wave pattern produced due to the addition of the waves from the two instruments.

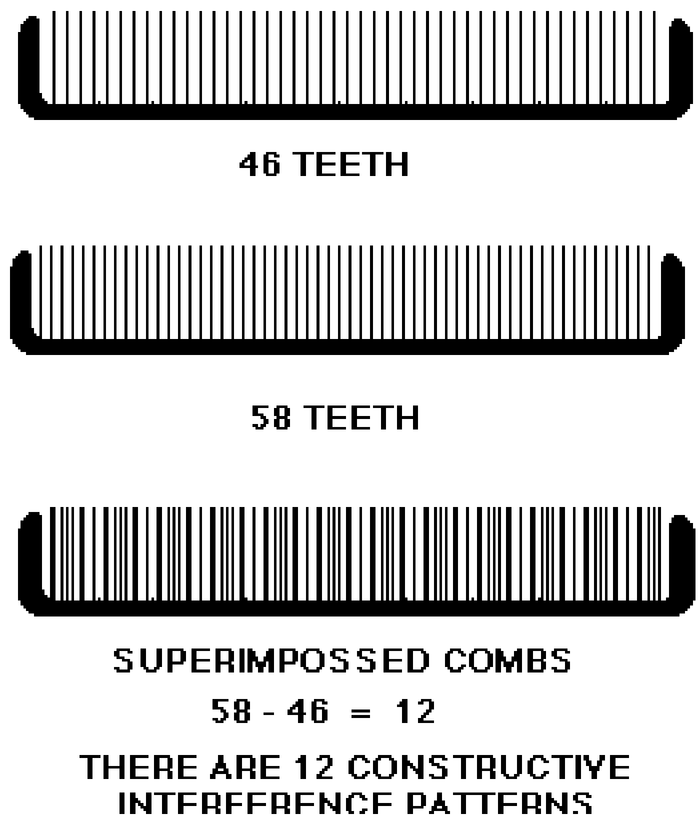
BOTH CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE



5. What would happen if two identical instruments played the same note, say middle C (512 Hertz) ? What would happen if one of the instruments was a little out of tune and it sounded 516 Hertz instead of 512 Hertz; what would you hear? Lets try it.
6. Get two tuning forks having the same frequency. Tie a rubber band around the one tine of one of the tuning forks. It now will not sound the same

frequency as the other tuning fork. Hit both of the tuning forks with a rubber mallet at the same time. What do you hear? [The loudness of the sound you hear will vary in a regular way. This is a feature of interference and is known as Beats. Beats are the result of compressions and rarefactions of two slightly different waves reaching your ears together. If the compressions come together they result in a greater compression. If a rarefaction from one instrument arrives at the same time as a compression from the other instrument there will be a partial cancellation and a smaller sound intensity results. This alternating loudness and softness is called beats. The frequency of these beats can be found by counting how many periods of loudness occur in a given time. It turns out that the difference in the frequencies of the two tuning forks is equal to the number of beats heard.

7. A very crude representation of beats can be illustrated by using two pocket combs having a different number of teeth for the same length of comb. If you overlap them you'll see a moiré pattern. The number of beats per length will equal the difference in the number of teeth per length for the two combs. Try it!



G. Resonance

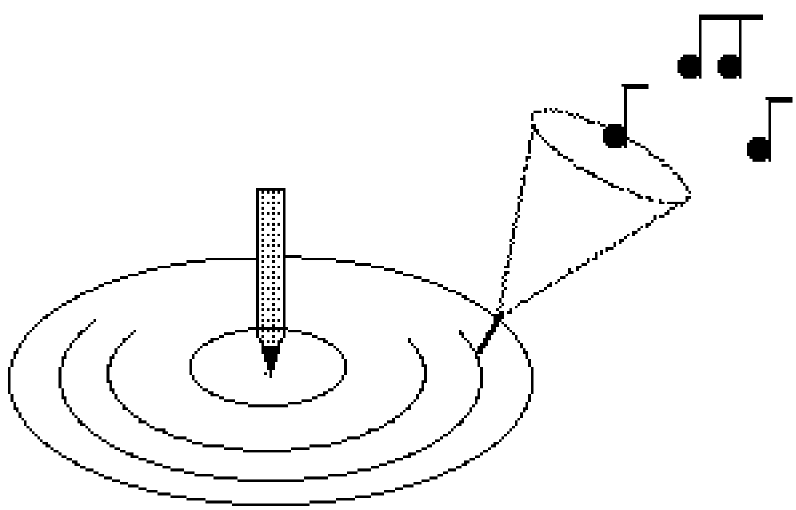
1. Get two identical pop bottles. Place one with its opening near your ear.
2. Have another student a few feet away blow across the other bottle to make a sound.
3. What do you hear every time he does this?
4. When two objects can vibrate at the same frequency, if one is set into vibration it will cause the other one to also start vibrating. This phenomenon is known as **Resonance**. It is the explanation for what happens in the famous commercial for Memorex where an opera singer can sound a note and cause a glass across the room to crack and break. The natural vibrational frequency of the glass is the same as the note sung. This causes the glass to vibrate so vigorously that it breaks.

5. Give two identical tuning forks to two students. Place them about 30 cm apart. Hit one of the tuning forks with a rubber mallet. Wait a couple of seconds and have the first student silence her tuning fork by putting her hand on it. What will happen to the other tuning fork? [It will be vibrating.] If tuning forks of different frequencies are used, the second one will not start to vibrate.
6. You are applying the principle of resonance every time you turn on your radio. Each radio station broadcasts at a specific frequency. When you turn the dial and tune in to a station, you are matching the frequency of your radio with the frequency of the broadcasting station.

CONCEPT EXTENSION

A. Homemade Phonograph

1. A simple phonograph can be made with materials from around the house. The first thing that is needed is an old 78 rpm or 33 rpm record, one with the little hole in the middle. Find a pencil that will fit in the little hole snugly. Insert the pointed end of the pencil to a depth of about one centimeter. You have essentially made a top so that if you spin the pencil with your fingers the whole record/pencil contraption will remind you of a spinning top.
2. A straight pin will serve as our needle. Our amplifier will be made out of a piece of paper. Roll the paper up into a cone. Tape the straight pin to the cone so that it is pointing down when the wide opening of the cone is pointing up.
3. To play your record, spin your "top." Then carefully move the "needle" so that it makes contact with spinning record. Lightly make contact with the record, and immediately you will hear what is recorded on the record.
4. What would happen if the paper amplifier cone was not attached to the straight pin? Would you hear the sound? What would happened if you used a larger sheet of paper to make a bigger cone, would the sound be louder? What other modifications could you make to improve the quality of your record phonograph?



5. To understand why this crude phonograph works, examine the record under a magnifying glass. You should see a continuous V-like groove cut in the plastic. When the record was cut the sounds caused a stylus to vibrate side to side with a frequency and amplitude determined by the pitch and loudness of the sound being recorded. As a result the walls of the groove wiggle from side to side. What happens when the needle runs into these groves. How does this create sound? [The process is reversed when the record is played. The needle follows these same wiggly paths causing the cone of paper to

vibrate with the same pitch and amplitude as the original sound. On a modern phonograph a minute electrical signal is generated in response to the wiggles. It is then amplified and sent through loudspeakers to reproduce the recorded sound. In the arm is a transducer that converts the groove undulations into the electrical signal by means of the stylus, a jewel-tipped needle.]

B. Tuning Forks, Pianos, and Pendula

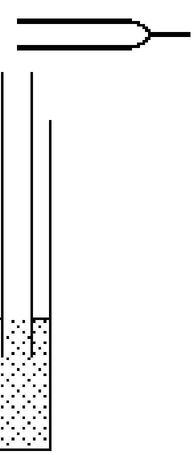
1. Strike a tuning fork with a rubber mallet and touch its stem to a piano. Wait a few seconds and kill the vibration of the tuning fork by grabbing it in your hand. What do you think will happen? [The string of the piano that is tuned to that same frequency will begin to vibrate all by itself. This is another example of resonance.]
2. Stretch a light string or thread about 50 cm long between two supports. The string should be stretched tight so that it is parallel to the table or floor.
3. Tie short lengths of string to seven washers and then hang them on the horizontal string. The lengths of string should be:

#1	#2	#3	#4	#5	#6	#7
20 cm	15 cm	20 cm	15 cm	5 cm	10 cm	15 cm

4. Before carrying out this next step, have the students predict what they think will happen. Start to swing washer #7 and observe the other washers. [The natural vibration rate of washers 7, 4, and 2 are the same and washers 2 and 4 will start to swing along with washer 7. The others should remain motionless. Any of the washers hung at the same height will start to resonate when a washer of its same vibrational frequency starts to swing.]

C. A Mini Pipe Organ and the Speed of Sound in Air

1. We have seen instances of strings, glasses, and tuning forks resonating. Gases can resonate as well. This is the principle of how flutes, clarinets, and the pipes in a pipe organ work.
2. Place some water in a tall cylinder of at least 50 cm. Cut in half a plastic golf club protector tube. These may be purchased at Wal Mart, K-Mart, etc. for under a dollar. Place the plastic tube in the cylinder holding the water.
3. Strike the tuning fork with a rubber mallet and hold it horizontally about 1 cm above the open end of the plastic tube. You should hear a sound made by the vibrating of the column of air. If you move the tube and tuning fork up and down, you will find a point where the air column gives the very loudest sound. (There will be more than one loud spot.) With a grease pencil mark on the plastic tube the level to which the water came when this point of loudest sound was found.



4. Measure the distance from the water level mark on the plastic tube to the top

of the tube. If a physics book is consulted, you will see that for a open-ended tube that the first resonance point comes at one fourth of the wavelength of the resonating column of air. The column of air is vibrating at the same frequency as the tuning fork.

5. With the information that has been gathered have the students figure out first the wavelength of the vibrating air column and the speed of sound in air. [The wavelength will depend on the frequency of the tuning fork used. It should roughly be 4 times the length determined in #4 above. The speed of sound can be calculated by using $\mathbf{v} = \lambda \mathbf{f}$. The accepted value for the speed of sound in air is 332 m/sec at 0°C. The speed of sound in air increases by 0.6 m/sec for each °C above zero. If room temperature is around 20°C, the speed of sound will be 344 m/sec. There will be some error in this method. If your students really want to determine a more accurate value, they will need to correct the length measured on the plastic tube. If they measure the diameter of the tube and multiply by .4 of this diameter and add this correction factor to the length determined, they will get a more accurate value for the wavelength and speed of sound.]

D. A Mini Pipe Organ and the Speed of Sound in a Gas Other Than Air

1. Based on our discussion about the speed of sound in different media, students should be able to predict what the speed of sound would be in something other than air. [The greater the density of the medium, the faster sound will travel through it.]
2. Set up the water resonance apparatus as in the last exercise (part C). Only one change will be made this time. Before sounding the tuning fork and measuring the water level and determining the wavelength, replace the air in the cylinder/tube with something other than air. One of the simplest (and safest) gases to generate is CO_2. Drop a few Alka-Seltzer® tablets into the water and allow the CO_2 to be generated. Wait a few minutes so that the cylinder and tube can fill with CO_2 . Because CO_2 is more dense that air it will have to fill the tube from the bottom and may take a while before enough CO_2 will have been generated to force the air out the top of the tube. Now sound the tuning fork and carry out the measurements.
3. Predict what will happen this time. Will the wavelength be longer, shorter, or the same as when the tube was filled with air? Will this cause the speed of sound to be greater, smaller, or the same as in air? Try to get the students to relate their predictions back to the model of how sound travels that we developed in the Concept Invention stage. [The speed of sound should be faster in CO_2.. The molecular weight of CO_2 is about 44 g/mole while the molecular weight of air is about 28 g/mole.
4. If you have gas jets in your classroom and if you are using methane to run your Bunsen burners from these gas jets, you can also test the other prediction of this theory. Since methane has a molecular weight of only about 16 g/mole, filling the cylinder and tube with it should make the speed of sound decrease. The easiest way to carry out this test would be to attach a rubber hose to the gas jet and stick it down to the bottom of the cylinder of water. Allow the gas to bubble up through the water and fill the cylinder and tube. Since it is lighter than air, it will easily rise out of the tube during the experiment. Allow it to keep bubbling throughout the whole experiment. As long a it is not bubbling too vigorously, it should not disturb the sound waves hitting the surface of the water and bouncing upward.

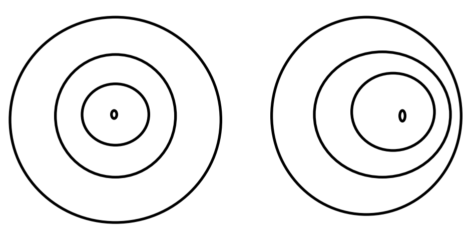
CAUTION: METHANE IS OBVIOUSLY FLAMMABLE. THERE SHOULD NOT BE ANY FLAMES IN THE CLASSROOM WHILE THIS DETERMINATION IS BEING MADE.

E. Using the Speed of Sound to Find the Frequency

1. Provide another tuning fork of unknown frequency and ask the students to find out its frequency by modifying the resonance experiment introduced in part C above. In other words use air in the tube rather than CO_2 or methane.
2. Obviously, all they must do is to use the speed of sound in air that they determined in part B and the wavelength that they determine in this setup to solve the equation $\mathbf{v} = \lambda \mathbf{f}$ for **f**.

F. Doppler Effect

1. We have all stood at a railroad crossing and heard the whistle of the approaching train. After the train passes you, you can still hear the whistle. How does what you heard when the train was approaching and when it was moving away differ? Would what you hear demonstrate beats? destructive interference? constructive interference? resonance?
2. Get a tape recorder and two students to make a tape for you. Have one student stand on the side walk with the tape recorder. Have the other student ride a bike toward the tape recorder. Attached to the bike should be a sound producing device that emits a constant frequency. Record the approaching sound. Continue to record as the bike and sound move away from the tape recorder. Finally, have the bike rider stop in front of the tape recorder and activate the constant frequency device. Tape a few seconds of this.
3. Bring the tape of the three situations to class and play it. Can the class determine when the sound was approaching the tape recorder, when it was receding from the tape recorder, and when it was not moving with respect to the tape recorder? What did their ears detect as being different about the three sounds?
4. In one case more sound waves were hitting the tape recorder per second than were produced by the sound generator per second. In another case fewer waves per second were hitting the tape recorder per second than were produced by the sound generator per second. And in the other case the same number of waves per second were hitting the tape recorder per second as were produced by the sound generator per second.
5. When the bike was approaching the tape recorder the waves were being all bunched together and pushed forward toward the recorder. When the bike was moving away from the tape recorder the waves get spread out. When the bike is standing still the tape recorder picks us the same frequency of waves hitting it as are produced by the sound generator.
6. A change in the frequency of a sound due to the motion of either the sound source or the observer is known as the **Doppler Effect**. Lets use a concrete example to illustrate this.
7. Get a large tub of water. Place a water bug in the center of the tub. If he moves up and down the water waves will radiate out from the center and hit the edge of the tub at the same frequency as he jumps up and down. What will happen to the frequency of waves hitting the side of the tub when he starts to move toward this side? [More waves will hit the side.] What will happen to the frequency of waves hitting the other side of the tube, the side he is moving away from? [Fewer waves will hit this side.]

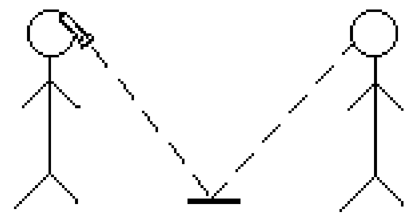


Light

PROBLEM PRESENTATION / EXPLORATION

A. Flashlight Geometry

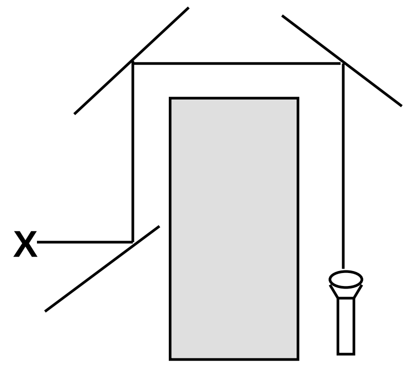
1. Needed for this exercise are two students of the same height, a flashlight, a flat mirror (15 cm x 15 cm), 2 meter sticks, and some masking tape.
2. Have two students stand facing one another 3-4 meters apart next to a blank wall. In between the students place a flat mirror (15 cm x 15 cm) on the floor.
3. With the lights dimmed have student #1 raise the flashlight to "nose-level" and aim it at the mirror. The flashlight bulb should be as close to his/her nose as possible.
4. Where will student #1 have to stand in order that he/she can aim it at the mirror on the floor and have the beam bounce up to student #2's nose?



5. Once this has successfully been done, measure how far each student is standing from the center of the mirror.
6. Repeat this activity with another student kneeling on his knees. Where would student #1 have to stand so that the flashlight beam hits student #3 in the nose?
7. Having studied the pattern involved in the first two cases, where would student #1 have to stand and where would the mirror have to be located to make the flashlight beam hit the intersection of the wall and ceiling? Is there more than one correct solution to this problem? [Yes}

B. **X** Marks the Spot

1. The CHALLENGE is to, with the help of three mirrors, shine a flashlight around an obstacle to hit the spot marked with an X.
2. The materials needed for this CHALLENGE are a penlight flashlight (obviously, if you have a laser, use it), three pocket mirrors (approximately 5 cm x 8 cm), clay or Play Doh®, a shoe box, and a card with a black X on it.
3. The rules are simple:
   a.) Have the students draw a diagram of where they think the mirrors should be placed before they are given the mirrors and other equipment.
   b.) Arrange the three mirrors (all three must be used) in such a way that by aiming the flashlight a beam of light can be bounced around so that it will finally focus on a card with the X in the center. It would probably help to dim the lights in the room.
   c.) The X must be placed on the card and located on the opposite side of the shoe box.
   d.) The beam must be parallel to the table or floor on which the box is placed.
   e.) The clay can be used to support the mirrors while they are being positioned.
   f.) Compare the final solution(s) with the predicted diagrams. One of many possible ways to set this up is sketched in the diagram at the top of the next page.



C. Convex Lens

1. Obtain a magnifying glass, a meter stick, a small candle, and a metal cap from a jar on which to set the candle so that the hot melted wax can be caught.
2. Place the candle, the magnifying lens, and your eye along the meter stick at different positions.
3. The CHALLENGE is to find the relative positions of your eye, the lens, and the candle so that you see:
   a.) an enlarged image of the candle rightside up
   b.) an enlarged image of the candle upside down
   c.) a reduced image of the candle upside down
   d.) an image of the candle having the same size but upside down
4. You have probably noticed that in moving the positions of the candle and the lens that there is a point where the image of the candle gets all blurry. Try to determine how far your eye is away from the lens when it seems the blurriest. Write this down for use later. (Concept Invention, F3)
5. Make sure to record the positions on the meter stick of the candle, the lens, and your eye for cases a, b, c, and d above. (You may require a measuring tape longer than one meter in one or more of the cases. This will depend on what type of lens you are using.)
6. Now, replace a white piece of poster board at the position your eye occupied. In which cases do you see an image projected there? If the image is not sharp, move the lens and/or the poster board to bring it into focus? Is there a case where you can not project the image onto the poster board?

D. Examples of plane (flat), concave and convex mirrors are required for this station. Possible sources of the curved mirrors are shaving or makeup mirrors (concave), circular rearview mirrors used on trucks (convex), some chromed hubcaps (convex), and spoons (concave and convex).

1. Have students look into the various mirrors and note their image.
2. In which mirror(s) can you make your image larger?
3. In which mirror(s) can you make your image smaller?
4. In which mirror)s) can you make your image remain the same size?
5. In which mirror(s) can you make your image appear rightside up?
6. In which mirror(s) can you make your image appear upside down?
7. is there any of these mirrors where you can make your image first be rightside up and then with some adjustment make it appear upside down?

CLASS RESPONSE / CONCEPT INVENTION

A. Intuitive Angles

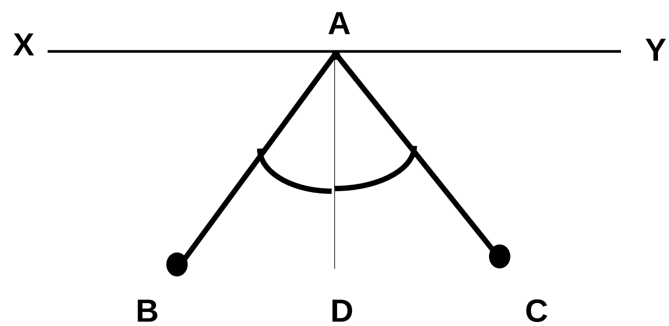
1. Find a volunteer who claims to be a good pool player for this demo.
2. On top of a lab table place a piece of wood approximately 5 cm by 10 cm by 100 cm. Arrange it so that the wide face is perpendicular to the table top.
3. In the middle of the board make a mark.
4. Place rubber ball approximately 100 cm from the mark and 65 cm from the

board (Position B).

5. Challenge the "pool player" to roll another rubber ball in such a manner that it first hits the mark on the wood (Position A) and subsequently bounces off and hits the first rubber ball.
6. What positional relationship is operating in this effort? Refer to the drawing below.

B. Angle of Incidence and Angle of Reflection

1.



2. The line AD is referred to as the Normal line. It is perpendicular to the line XY.
3. Very likely the "pool player" will be able to articulate that angle BAD must equal angle CAD for a ball thrown from C to hit a ball resting at B.
4. We want to call angle CAD the ANGLE OF INCIDENCE, in other words the angle initially made with the wall and the NORMAL. We want call angle BAD the ANGLE OF REFLECTION, or the angle made with the NORMAL when the ball reflected off the wall.
5. As the "pool player" intuitively knew, ***THE ANGLE OF INCIDENCE EQUALS THE ANGLE OF REFLECTION***.

C. Finding the Angle of Incidence and Angle of Reflection for Visible Light

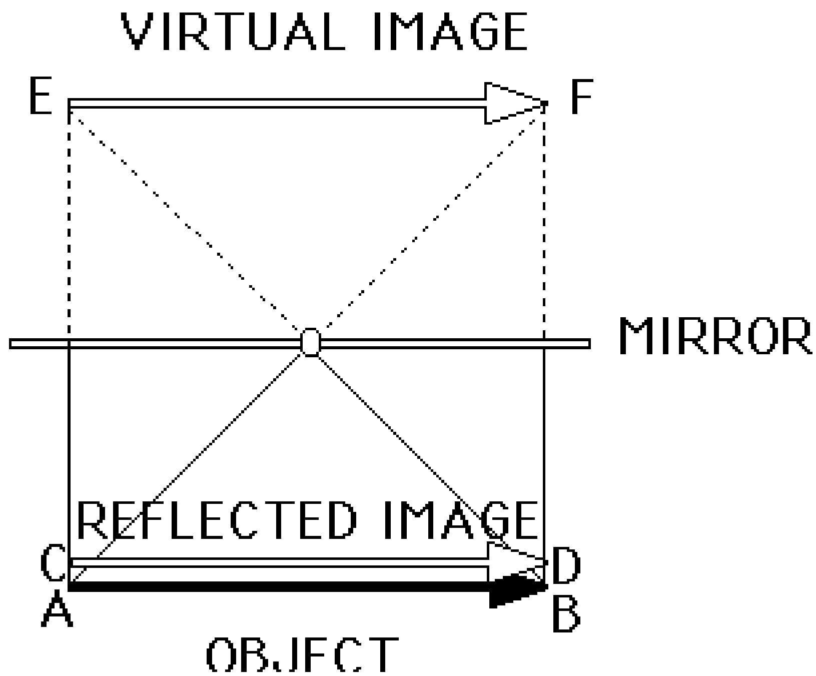
1. Place a sheet of paper with the long side facing you on the table. Draw a horizontal line across the page and label it XY.
2. Label the midpoint of XY A. Draw a dotted line perpendicular to XY through A. Label the other end of the dotted line D.
3. Draw a line from A to the left corner of the paper. Proceed down this line about 8 cm. from point A and mark a point B.
4. Place a mirror along line XY. Make sure that XY lines up with the back edge of the mirror. Make sure that the mirror remains perpendicular to the paper. You might use some blobs of clay to secure the mirror.
5. Take two pins, stick them on small pieces of clay, and place them on line AB. Make sure the pins remain vertical.
6. Lower your body to the level of the pins. Move your head left and right. Look at the pins toward the mirror, until the front pin covers the back pin and they look like one.
7. Place a pin to the right of the dotted line AD and move it around, until it looks as if it is lined up in the mirror and covers the other two pins. All pins should appear in a straight line. Keep your eyes near the level of the pins. After you line up the three pins, press the third pin down to mark the point. Label it C.
8. Draw a line from A going through point C.
9. Measure angles BAD and CAD. What positional relationship appears to be acting in this case? [The two angles are equal.]

D. Is Your Mirror Telling You the Truth?

1. Do you see the same thing in a mirror that others see when they look at you?
2. Stand in front of a plane mirror. The first thing that you notice is that your

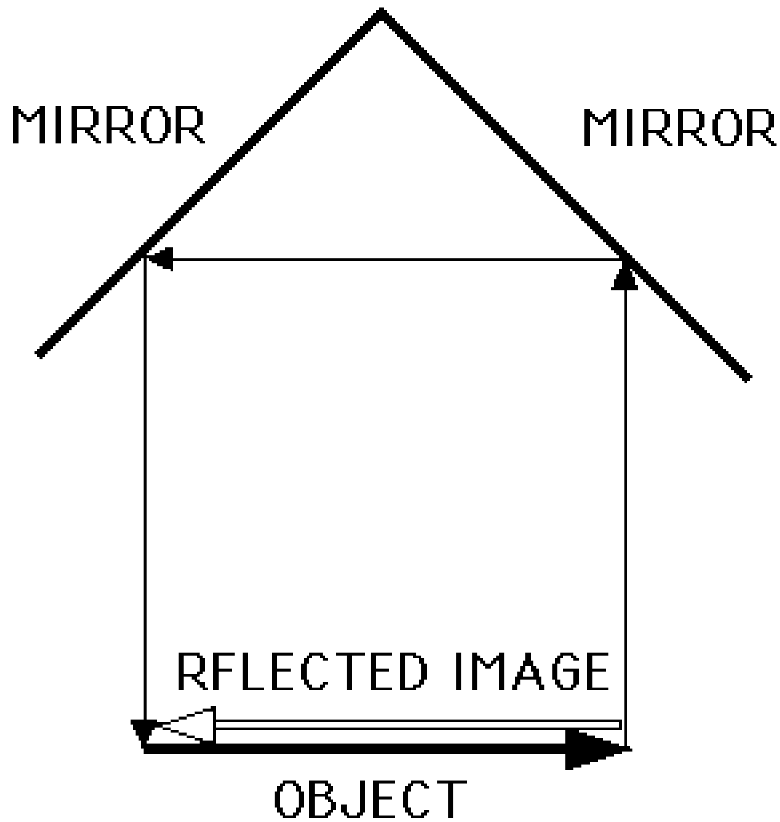
image seems to be coming from behind the mirror, even though you know that it isn't. Your image is the same size as you and is right side up, not inverted as in some other kinds of mirrors and lenses.

3. Find a student who parts his/her hair right down the middle. Make a black X with a magic marker on a piece of tape and put it on his/her right cheek.
4. To which cheek will the piece of tape appear to be sticking on his/her image? [Left] If you touch your left ear, your image will be seen touching its right ear.
5. This is because the angle of incidence and angle of reflection are equal for every ray emanating from your face. Every ray bounces off the plane mirror with equal angles of incidence and reflection, but it appears that the ray is emanating from behind the mirror and is turned around so that left is right and right is left.



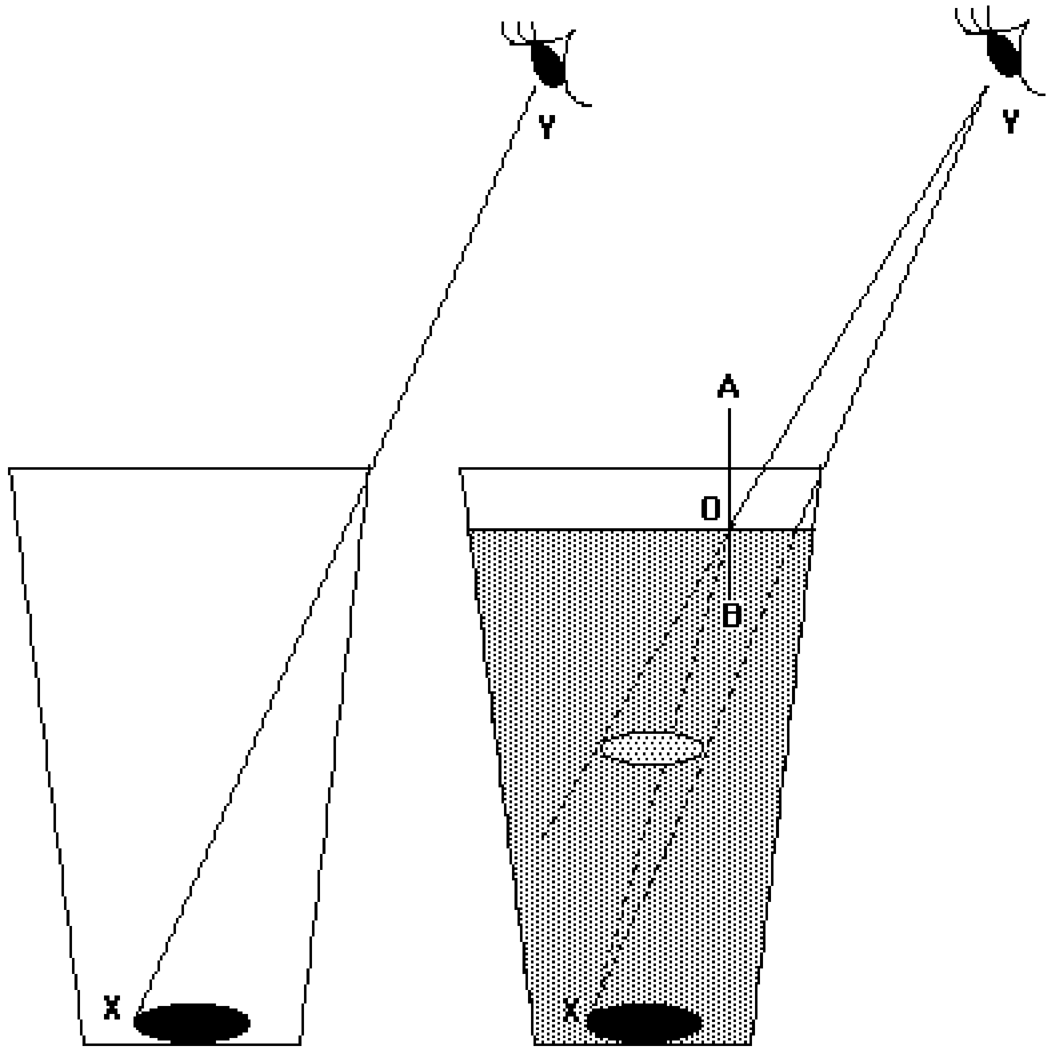
6. The ray coming from point A of the object hits the mirror at O and actually reflects back to D. It appears to our brain, however, to be coming from E beyond the mirror. Likewise the ray coming from the object at B hits the mirror at O and actually reflects back to C. Once again it appears to our brain, that it is coming from F beyond the mirror. Consequently, when we look into a plane mirror the left hand side of the object appears to be behind the mirror on the right and the right hand side of the object appears to be behind the mirror on the left side. In a plane mirror we do not see the reflected image, we see the **Virtual Image**. The virtual image can not be projected on a screen, it is not real, merely virtual. CD is not a real image even though the rays bounce back to this point. Our brain tells us that the image is really at EF, although we know it can't be.
6. To see what others see when they look at you requires two mirrors. Tape two mirrors together so that they hinge at one edge.
7. Place the mirrors perpendicular to each other on the edge of the table. Observe yourself in the two mirrors by looking at the joint corner of the two mirrors.
8. Touch your left ear. Which ear did your image touch? Does this differ from looking into a plane mirror?
9. The light rays are reflected in 90° angles from one mirror to the other and then back to the eye. With the two mirrors perpendicular to each other, anything on the left of the object is reflected to the right hand side. All points of the

object on the left side are seen on the right. Finally, you can see how others see you. Do you like this view any better than what you have been looking at all these years??

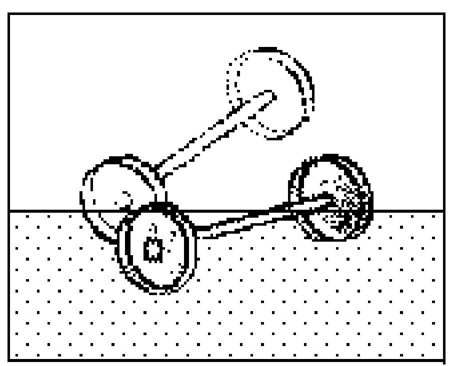


E. Refraction

1. Tape a penny to the inside bottom of an opaque cup (try a Styrofoam® coffee cup) and place it on the table.
2. Move your head down so that the penny just disappears behind the rim of the cup. Hold your head steady so that the penny is still hidden to your eye.
3. Have another student pour water into the cup. What happens? [The penny magically reappears and appears to be floating half-way up from the bottom..]
4. Look at the diagram showing the ray coming from the far edge of the penny. Since the level of your eye was low enough the edge of the cup blocked it from reaching your eye and you can't see the penny.
5. In the second diagram after the water has been added, notice that the eye is in the same location but this time the light ray coming from the far edge of the penny has been bent (refracted) as it passed from the water to the air and on to your eye. The object appears to be located half-way up from the bottom.
6. This is a common phenomenon when light travels from one medium to another medium. This is because the speed of light is different in different media. It was moving slower through the water and faster through the air. It would move fastest in a vacuum.
7. The normal line AB has been drawn in perpendicular to the interface of the water and air. The light bends away from the normal when it speeds up. Notice how angle XOB is smaller than AOY.



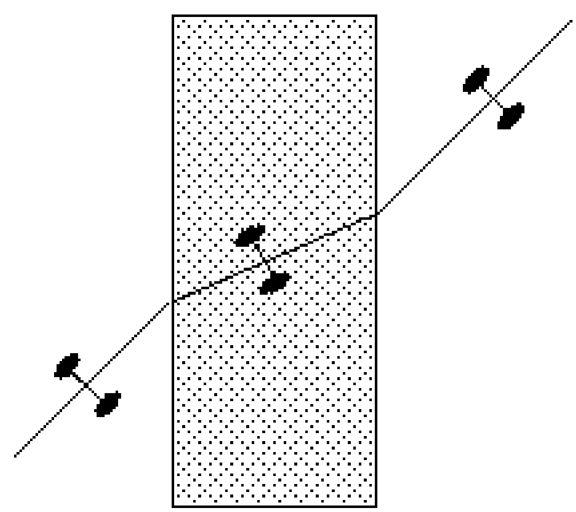
8. To understand how this happens you will need two wheels and an axle. These could come from cannibalizing a toy car, or it could be build with a Tinker Toys® stick and two wheels. Also you will need some sheets of paper, a piece of sandpaper, and a large piece of cardboard.



9. Build a ramp with the piece of cardboard. To the piece of cardboard tape the

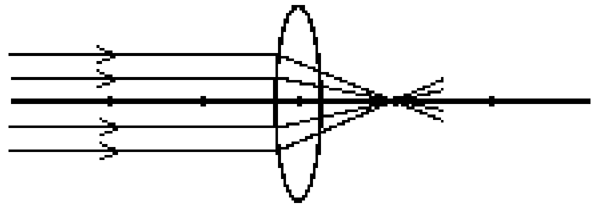
sheet of sandpaper. Tape next to it sheets of paper so that they equal the thickness of the sandpaper. Place the sandpaper/paper boundary at an angle of 45° with the long axis of the cardboard ramp. Now allow the wheels to roll down the ramp. Make sure that they will hit the boundary between the sandpaper and regular paper. Notice what happens when the leading edge of the first wheel hits the different surface. If it is going from paper to sandpaper it will veer one way because its speed is changing (slowing down). If it is going from the sandpaper to the paper it will veer the other way because its speed is changing (speeding up). In the first case it turns toward the normal and in the second case it turns away from the normal until both wheels are on the same surface. At this point the wheels once again continue on a straight path. The angle of the ramp can not be very steep or gravity will wipe out the refraction.

10. Another way to picture this refraction is to envision a pair of toy-cart wheels that can spin independently of one another rolling at some angle other than 90° from a smooth surface onto a patch of grass. Moving from the smooth surface to the grass the leading wheel will slow down and the direction will be changed until the trailing wheel hits the grass. For a while, as long as both wheels are moving on the grass the wheel assembly will move straight. Then, once again the lead wheel will hit the smooth surface on the other side of the patch of grass and will speed up. This will turn the wheel assembly until the trailing wheel also hits the smooth surface. Once again the wheel assembly will move ahead in a straight path.



F. Convex Lenses

1. As light passes through glass it bends (refracts) because for a short time its speed is changed. Depending on the angle at which the light hits the glass and length of its path a ray of light can be bent to different degrees.
2. If parallel rays of light pass through different thicknesses of glass the rays will be bent to different degrees and depending on the shape and thickness of the glass the rays can be made to converge. The distance from the center of the lens to where they converge is known as the focal length of the lens. Measure the focal length of the magnifying glass used in the EXPLORATION phase of this lesson. At the top of the next page is a diagram of a typical converging lens.



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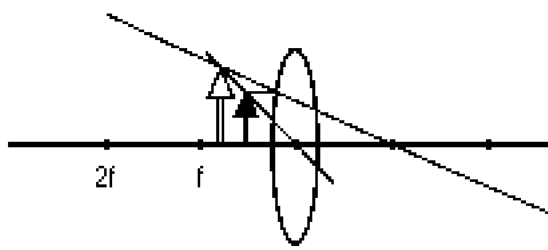
FOCAL LENGTH

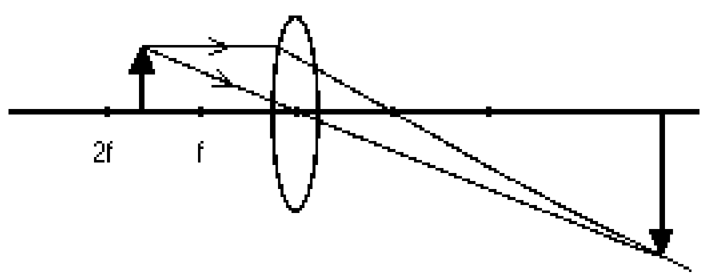
3. Using this focal length set up the lens, the candle and the poster board screen according to the table below.

Position of Object	Nature of Image		
	Real or Virtual?	Magnified?	Inverted or Erect?
Beyond f	REAL	YES & NO	INVERTED
At f	NO IMAGE	-------	-------
Within f	VIRTUAL	YES	ERECT

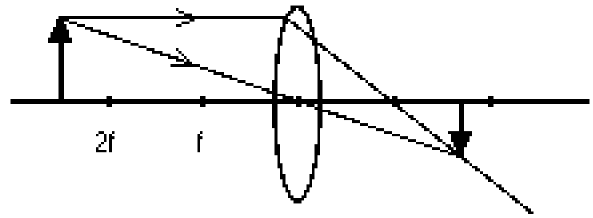
4. Where in relation to the focal length (f) from the lens is the object when the image appears right-side up (erect)?



5. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and larger than the object?

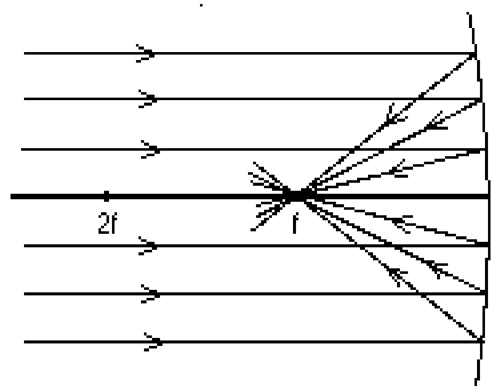


6. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and smaller than the object?



G. Concave Mirrors

1. A mirror reflects light to form an image instead of refracting it as in the case of lenses. All images created by looking into a plane mirror are **VIRTUAL**. This means that you can not project them on to a screen. They appear as though they are coming from behind the mirror.
2. Concave mirrors, such as the inside of the bowl of a spoon, form both virtual images and **REAL** images. Real images can be projected onto a screen.
3. As parallel rays of light hit the surface of a concave mirror they are reflected through the same point in front of the mirror. This point is called the focal point.

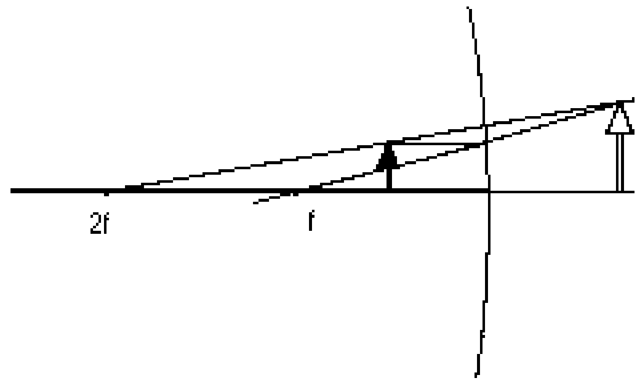


4. As in the case of the convex lens, the distance from the focal point to the center of the mirror is called the focal length of the mirror. Measure the focal length, f, for the mirror used in part D of the EXPLORATION section of this lesson.
5. Instead of the light coming into the mirror in parallel rays form a source such as the sun, put a point source of light right at the focal point of the mirror. What will happen? [This is the principal of how a automobile headlight works. The tiny bulb is put at the focal point and the rays are directed off the reflector parallel to each other resulting in a parallel beam of light instead of light scattered in all directions.

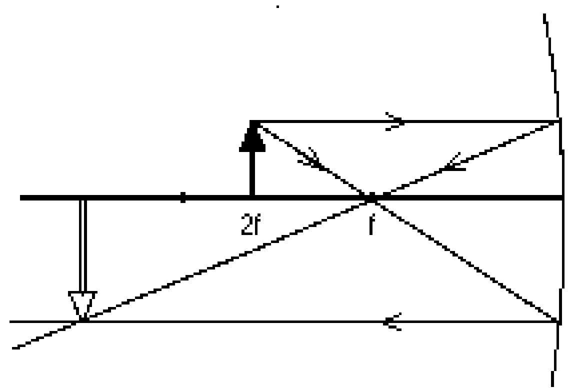
Position of Object	Nature of Image		
	Real or Virtual?	Magnified?	Inverted or Erect?
Beyond **f**	REAL	YES & NO	INVERTED
At **f**	NO IMAGE	-------	-------
Within **f**	VIRTUAL	YES	ERECT

6. Arrange the concave mirror and candle as you did in part D of the EXPLORATION section of this lesson. Move the screen to from a sharp image of the candle. Is it real or virtual? smaller or larger than the object? inverted or erect?
7. Using this focal length set up the mirror, the candle and the poster board screen according to the table below.

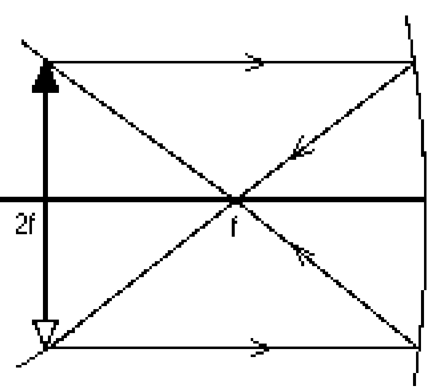
8. Where in relation to the focal length (f) from the mirror is the object when the image appears right-side up (erect)?



9. Where in relation to the focal length (f) from the mirror is the object when the image appears inverted and larger than the object?



10. Where in relation to the focal length (f) from the lens is the object when the image appears inverted and the same size as the object?



H. Convex Mirrors

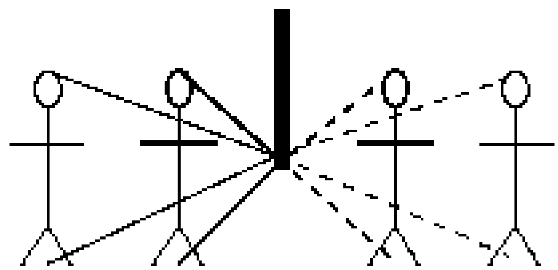
1. A mirror that is curved like the back of a spoon is a convex mirror. The image formed here, like a plane mirror, is always virtual. Is it inverted or erect? Is it larger, smaller, or the same size as the object?
2. Where are convex mirrors used? Why not use a plane mirror for this same purpose? What is the advantage of the convex mirror?

CONCEPT EXTENSION

A. How High Do I Have to Hang a Wall Mirror in Order to See All of Myself Including My Shoes?

1. Which of the following position(s), A, B, or C could the mirror be hung to allow you to see both your head and your feet at the same time?

2. Let two students hold a mirror against the wall while a third student stands in front of the mirror and attempts to see both her head and feet. The fourth student should measure how high off the floor the mirror would have to be hung to see both head and feet.
3. Would the distance off the floor be different for either the tallest person in class or for the shortest person in class? [Once it was adjusted for the shortest person, everyone else would be able to see both their head and feet without further adjustment.]
4. Would the distance off the floor be different if you stood nearer or farther away from the mirror than for the original determination? [No, see sketch below.]
5. The solution involves the students finding out that the bottom of the mirror must be placed on the wall at least as high as half the height of the shortest student. The rays from the feet must be able to hit at the bottom of the mirror and bounce up to the eyes. Since the angle of incidence and angle of reflection must be equal, the lowest part of the mirror must be halfway between the floor and the student's head. The distance from the student to the mirror is not important. The minimum height is the same.

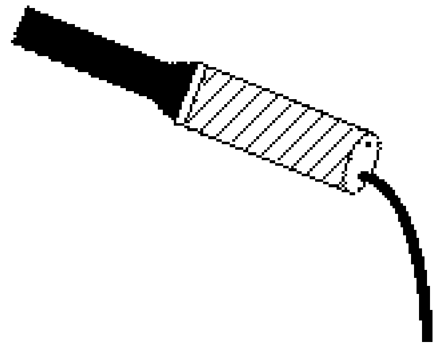


VIRTUAL IMAGES

B. Critical Angle

1. If you swim underwater and look up, you will see some objects above the water. To your surprise you also might see a reflection of an object from in front and underneath you.
2. Against a black background place a deep aquarium. Get a waterproof flashlight and submerge it. Shine the beam of light from the bottom of the aquarium up toward the top surface of the water. Notice what happens to the beam of light. Now change the angle of the beam shining on the underneath surface of the water. When the angle is about 43° from the normal, what happens? (see diagram below)

3. When the angle of incidence is greater than 43° with the normal, light is totally reflected at the boundary of the water and air. This special angle is called the critical angle. It differs for each two adjacent media that the light passes through. For the boundary of glass and air it is about 48°; for the boundary of a diamond and air it is about 24°. This is the principal utilized in fiber optical instruments.
4. Fill a straight glass tube with water. Seal one end with some type of kitchen plastic wrap. Shine a flashlight from one end and look at the other end of the tube. Does light travel down the tube so that you can see it coming out the other end? [Yes] This should be no great surprise since we know that light travels in straight lines. What would happen if you used a curved glass tube? Would you be able to see light coming out of the bottom of the curved tube. [No] Could you design a way to "pour" light so that light would undergo total reflection and finally come out the bottom end?
5. Obtain a tall skinny bottle (some types of olive jars will work). With a nail put a large hole at the edge in the metal lid. Put a smaller hole on the opposite edge. To the bottom of the jar attach a flashlight. Duct tape works well. Wrap some newspaper around the jar so that light doesn't escape out the sides. Fill the jar within about two centimeters of the top, then screw on the lid. Turn the flashlight on. Tilt the jar/flashlight apparatus so that water pours out the hole. If the water is poured out in a darkened room, the light will be contained (because of total reflection) in the curved stream of water. All light hitting the water/air boundary at greater than about 43° will be totally reflected internally over and over until it comes out the end of the stream of water. If you stick your finger into the stream of water, light will fall on it. This will happen if you put your finger in the water near where it comes out of the jar or in the curved part of the stream near the sink.



6. Are there other substances that allow light to travel a curved path by way of total reflection? [A curved piece of Lucite® will work.]

C. Mirages

1. We have seen that refraction occurs because light travels at different speeds through two different media such as air and glass. We also know that light travels at different speeds in a given medium depending on the temperature.
2. Would light traveling through two adjacent regions of the same medium heated to different temperature be refracted? How could this be used to explain the formation of mirages in the desert or on the highways when it is very hot?

D. Predictions

1. Write your name on a note card and prop it up on a table so that it is perpendicular to the table top. You may need to support it with a book or other object. Get a 16 oz or 20 oz plastic soft drink bottle. Rip off the plastic wrapper so that the clear plastic is visible. Fill the bottle with water and set it in front of the note card containing your name. What will you see?
2. Cut the top and bottom off of a plastic 2 L soft drink bottle. This will give you a plastic cylinder about 15 cm tall. Stretch a piece of Saran Wrap® over one end and secure it with a rubber band. Lay your note card down flat on the table and place the cylinder over it. Predict what you will see as you add more and more water to the Saran Wrap.
3. Take another note card and on one side with a red pen write in capital letters COKE. On the other side write with a blue pen in capital letters PEPSI. Place the card on a flat table. Obtain a glass rod with diameter of at least one centimeter. Place the rod over the COKE on one side of the card and then over PEPSI on the other side of the card. Predict what you will see each time. Explain your observations.
[When looking through the rod at the word COKE they will see the same thing that they would without the rod. Looking at the word PEPSI they will see

Because there is a horizontal line of symmetry for each letter in COKE, the top half of COKE and the bottom half are identical, and when reflected from top to bottom look the same as before they were reflected. Since there is not a horizontal line of symmetry in each letter of the word PEPSI, only the E and I will look the same before and after reflection. The other three letters are backwards. See if you can disequilibrate the students into thinking that the different colors are responsible for what they see.]

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