Activities

A Note on Measurement:
These activities use metric units of measure. In a few exceptions, notably within the “materials needed” lists, English units have been listed. In the United States, metric-sized parts, such as screws, wood stock, and pipe are not as accessible as their English equivalents. Therefore, English units have been used to facilitate obtaining required materials.

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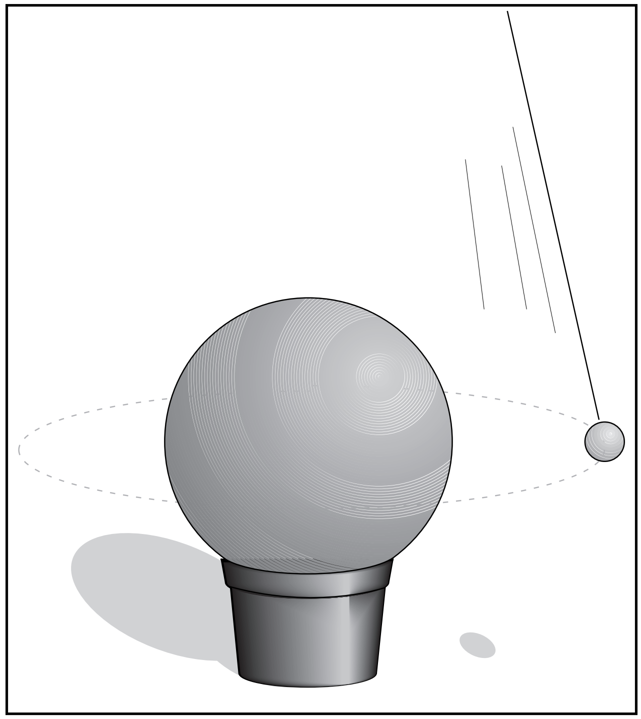
Activity 1

Around The World



OBJECTIVE:

To model how satellites orbit Earth.

BACKGROUND:

The manner in which satellites orbit Earth is often explained as a balance that is achieved when the outward-pulling centrifugal force of a revolving object is equal to the inward pull of gravity. However, if we examine Isaac Newton's First Law of Motion, we can see why this explanation is incomplete. According to this law, objects in motion remain in motion in a straight line unless acted upon by an unbalanced force. Because Earth-orbiting objects follow elliptical paths around Earth and not a straight line, forces cannot, by definition, be balanced. Force is directional. It is a push or a pull in a particular direction. At any one moment, the force of gravity on a satellite is exerted in the direction of a line connecting the center of mass of Earth to the center of mass of the satellite. Because the satellite is not stationary, the direction of this line, and consequently the direction of the force, is constantly changing. This is the unbalanced force that curves the path of the satellite.

A second problem with the satellite orbit explanation is that centrifugal force is not an actual force but an effect. The difference is important. For example, if you are a passenger riding in a car that makes a sharp turn to the left, you feel yourself pushed against the right side door. This is interpreted as an outward directed force but is it really an outward directed force? What would happen to you if the door were to open suddenly? Rather than try to answer these questions in an automobile, a simple demonstration can be done. Attach a ball to a string and twirl the ball in a circle as you hold the other end of the string. The ball travels on a path similar to a satellite orbit. Feel the outward pulling force as you twirl the ball. Next, release the ball and observe where it goes. If that force you experienced were really outward, the ball would fly straight away from you. Instead, the ball travels on a tangent to the circle.

What is actually happening is that the ball is attempting to travel in a straight line due to its inertia. The string, acts as an unbalanced force that changes the ball's path from a straight line to a circle. The outward pull you feel is really the ball's resistance to a change in direction. Through the string, you are forcing the ball from a straight path to a circle. In the case of the automobile example, if the door were to pop open during a turn, you would fall out of the car and continue moving in the same direction the car was moving at the moment the door opened. While you perceive your motion as outward, the automobile is actually turning away from you as you go in a straight line.

In this demonstration, a simple model of a satellite orbiting Earth is created from a large stationary ball and a smaller ball at the end of a string. The ball and string become a pendulum that tries to swing toward the middle of the globe. However, the ball travels in an orbit around the globe when it is given a horizontal velocity in the correct direction. Although the small ball attempts to fall to the center of the larger ball, its falling path becomes circular because of its horizontal velocity.

MATERIALS NEEDED:

Large ball
Small ball
2 meters of string
Flower pot

PROCEDURE:

Step 1. Attach the 2 meter long string to the smaller ball (satellite). This can be done by drilling or poking a hole through the ball, threading it through to the other side, and knotting the string.

Step 2. Place the large ball (Earth) on the flower pot in the center of an open space.

Step 3. Select one student to stand above Earth and hold the satellite by the end of the string attached to it. This student's hand should be directly over the "north pole" of Earth and the satellite ball should rest against the side of Earth at its "equator."

Step 4. Select a second student to launch the satellite. Try pushing the satellite straight out from Earth. Try launching the satellite in other directions.

QUESTIONS:

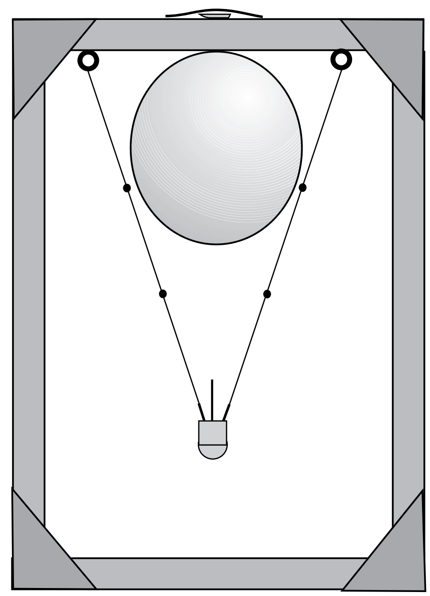
1. What path does the satellite follow when it is launched straight out from Earth?
2. What path does the satellite follow when it is launched at different angles from Earth's surface?
3. What affect is there from launching the satellite at different speeds?
4. Is it correct to say that a satellite is in a continual state of free-fall? Why doesn't the satellite strike Earth?
5. What causes a satellite to return to Earth?

FOR FURTHER RESEARCH:

1. Investigate the mathematical equations that govern satellite orbits such as the relationship between orbital velocity and orbital radius.
2. Learn about different kinds of satellite orbits (e.g., polar, geostationary, geosynchronous, etc.) and what they are used for.

Activity 2

Free Fall Demonstrator



OBJECTIVE:

To demonstrate that free fall eliminates the local effects of gravity.

BACKGROUND:

Microgravity conditions can be created in a number of ways. Amusement park customers feel a second or two of low-gravity on certain high-performance rides. Springboard divers experience low-gravity from the moment they leave the board until they hit the water. NASA achieves several seconds of microgravity with drop towers and drop tubes. Longer periods, from 25 seconds to a minute, can be achieved in airplanes following parabolic trajectories. Microgravity conditions lasting several minutes are possible using unmanned sounding rockets. However, the longest periods of microgravity are achieved with orbiting spacecraft.

The free fall demonstrator in this activity is an ideal device for classroom demonstrations on the effect of low-gravity. When stationary, the lead fishing weight stretches the rubber band so that the weight hangs near the bottom of the frame. When the frame is dropped, the whole apparatus goes into free fall, so the weight (the force of gravity) of the sinker becomes nearly zero. The stretched rubber bands then have no force to counteract their tension, so they pull the sinker, with the pin, up toward the balloon, causing it to pop. (In fact, initially the sinker's acceleration toward the balloon will be at 9.8 m/s^2. Before the frame was dropped, tension in the rubber bands compensated for gravity on the sinker, so the force from that tension will accelerate the sinker at the same rate that gravity would.) If a second frame, with string instead of rubber bands supporting the weight, is used for comparison, the pin will not puncture the balloon as the device falls.

The demonstration works best when students are asked to predict what will happen when the frame is dropped. Will the balloon pop? If so, when will it pop? If your school has videotape equipment, you may wish to videotape the demonstration and use the slow motion controls on the playback machine to determine more precisely when the balloon popped.

MATERIALS NEEDED:

2 pieces of wood 16x2x1 in.
2 pieces of wood 10x2x1 in.
4 wood screws (#8 or #10 by 2 in.)
8 corner brace triangles from 1/4" plywood
Masking Tape
Glue
2 screw eyes
4-6 rubber bands
1 6-oz fishing sinker or several lighter sinkers taped together
Long sewing pin or needle
Small round balloons
Short piece of string
Drill, 1/2 in. bit, and bit for piloting holes for wood screws
Screwdriver
Pillow or chair cushion
(Optional - Make a second frame with string supporting the sinker.)

PROCEDURE:

Step 1. Assemble the rectangular supporting frame as shown in the diagram. Be sure to drill pilot holes for the screws and glue the frame pieces before screwing them together. Brace the front and back of each corner with small triangles of plywood. Glue and nail them in place.

Step 2. Drill a 1/2 inch-diameter hole through the center of the top of the frame. Be sure the hole is free of splinters.

Step 3. Screw the two screw eyes into the underside of the top of the frame as shown in the diagram. (Before doing so, check to see that the metal gap at the eye is wide enough to slip a rubber band over it. If not, use pliers to spread the gap slightly.)

Step 4. Loop three rubber bands together and then loop one end through the metal loop of the fishing sinker(s).

Step 5. Follow the same procedure with the other three rubber bands. The fishing weight should hang downward like a swing, near the bottom of the frame. If the weight hangs near the top, the rubber bands are too strong. Replace them with thinner rubber bands.

Step 6. Attach the pin or needle, with the point upward. There are several ways of doing this depending upon the design of the weight. If the weight has a loop for attaching it to fishing line, hold the pin or needle next to the loop with tape. It may be possible to slip it through the rubber band loops to hold it in place. Another way of attaching the pin or needle is to drill a small hole on the top of the weight to hold the pin or needle.

Step 7. Inflate the balloon, and tie off the nozzle with a short length of string. Thread the string through the hole and pull the balloon nozzle through. Pull the string snugly and use a piece of tape to hold it.

Step 8. Ask the students to predict what will happen when the entire frame is dropped.

Step 9. Place a pillow or cushion on the floor. Raise the demonstrator at least 2 meters off the floor. Do not permit the weight to swing. Drop the entire unit onto the cushion. The balloon will pop almost immediately after release.

Activity 3

Falling Water

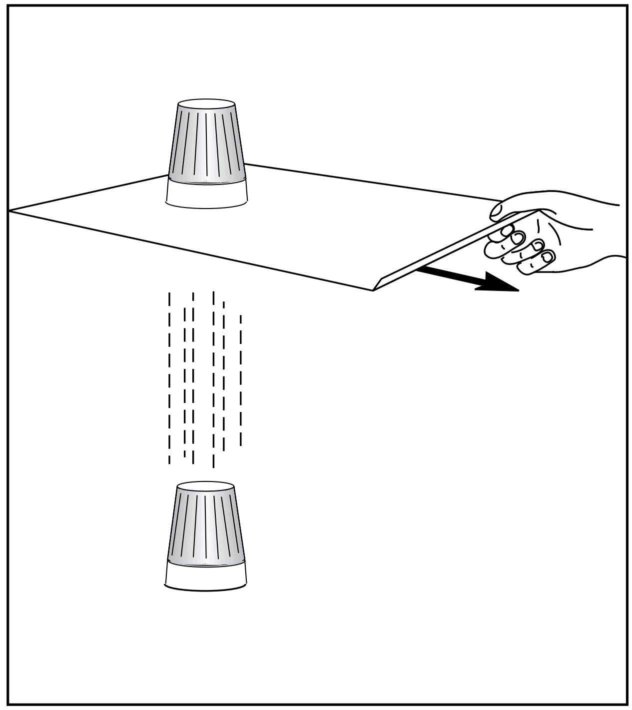
OBJECTIVE:

To demonstrate that free fall eliminates the local effects of gravity.

BACKGROUND:

Weight is a property that is produced by gravitational force. An object at rest on Earth will weigh only one-sixth as much on the Moon because of the lower gravitational force there. That same object will weigh almost three times as much on Jupiter because of the giant planet's greater gravitational attraction. The apparent weight of the object can also change on Earth simply by changing its acceleration. If the object is placed on a fast elevator accelerating upward, its apparent weight would increase. However, if that same elevator were accelerating downward, the object's apparent weight would decrease. Finally, if that elevator were accelerating downward at the same rate as a freely falling object, the object's apparent weight would diminish to near zero.

Free fall is the way scientists create microgravity for their research. Various techniques, including drop towers, airplanes, sounding rockets, and orbiting spacecraft, achieve different degrees of perfection in matching the actual acceleration of a free-falling object.



In this demonstration, a water-filled cup is inverted and dropped. Before release, the forces on the cup and water (their weight, caused by Earth's gravity) are counteracted by the cookie sheet. On release, if no horizontal forces are exerted on the cup when the sheet is removed, the only forces acting (neglecting air) are those of gravity. Since Galileo demonstrated that all objects accelerate similarly in Earth's gravity, the cup and water move together. Consequently, the water remains in the cup throughout the entire fall.

To make this demonstration possible, two additional scientific principles are involved. The cup is first filled with water. A cookie sheet is placed over the cup's mouth, and the sheet and the cup are

MATERIALS NEEDED:
Plastic drinking cup
Cookie sheet (with at least one edge without a rim)
Soda pop can (empty)
Sharp nail
Catch basin (large pail, waste basket)
Water
Chair or step-ladder (optional)
Towels

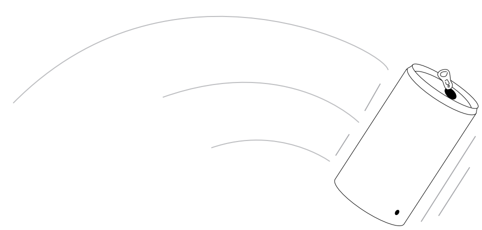
inverted together. Air pressure and surface tension forces keep the water from seeping out of the cup. Next, the cookie sheet is pulled away quickly, like the old trick of removing a table cloth from under a set of dishes. The inertia of the cup and water resists the movement of the cookie sheet so that both are momentarily suspended in air. The inverted cup and the water inside fall together.

PROCEDURE:

Step 1. Place the catch basin in the center of an open area in the classroom.
Step 2. Fill the cup with water.
Step 3. Place the cookie sheet over the opening of the cup. Hold the cup tight to the cookie sheet while inverting the sheet and cup.
Step 4. Hold the cookie sheet and cup high above the catch basin. You may wish to stand on a sturdy table or climb on a step-ladder to raise the cup higher.
Step 5. While holding the cookie sheet level, slowly slide the cup to the edge of the cookie sheet.
Step 6. Observe what happens.
Step 7. Refill the cup with water and invert it on the cookie sheet.
Step 8. Quickly pull the cookie sheet straight out from under the cup.
Step 9. Observe the fall of the cup and water.
Step 10. If your school has videotape equipment, you may wish to tape the activity and replay the fall using slow motion or pause controls to study the action at various points of the fall.

FOR FURTHER RESEARCH:

1. As an alternate or a supportive activity, punch a small hole near the bottom of an empty soda pop can. Fill the can with water and seal the hole with your thumb. Position the can over a catch basin and remove your thumb. Observe the water stream. Toss the can through the air to a second catch basin. Try not to make the can tumble or spin in flight. Observe what happens to the water stream. The flight of the can is a good demonstration of the parabolic trajectory followed by NASA's KC-135. (Note: Recycle the can when you are through.)
2. Why should you avoid tumbling or spinning the can?
3. Drop the can while standing on a chair, desk, or ladder. Compare the results with 1.



Activity 4

Accelerometers

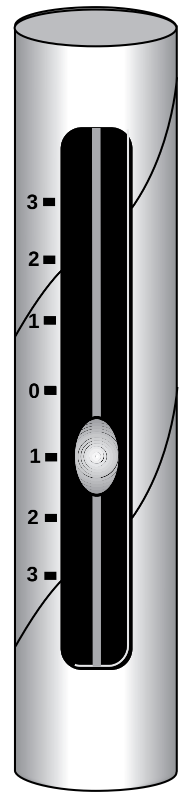
OBJECTIVE:

To measure the acceleration environments created by different motions.

BACKGROUND:

As the Space Shuttle orbits Earth, it collides with thinly spaced gas molecules that produce a minuscule braking effect and eventually causes the Shuttle's orbit to decay. Although not noticeable to astronauts, this braking effect produces a force that is felt by objects inside as an acceleration. *Acceleration* is the rate at which an object's velocity changes with time. *Velocity* is defined as both a speed and a direction. If speed changes, direction changes, or both speed and direction change, the object is said to be undergoing an acceleration. In the case of objects inside of a Space Shuttle, the acceleration causes them to slowly drift from one position in the cabin to another. To avoid this problem objects are usually tethered or stuck to the wall with velcro. However, even a very slight acceleration is a significant problem to sensitive microgravity experiments.

In many microgravity experiments, knowing the magnitude and direction of the acceleration inside an orbiting Space Shuttle is important. At what acceleration do gravity-dependent fluid phenomena, such as buoyancy and sedimentation, become insignificant and other phenomena, such as surface tension, predominate? These and many other questions are



important areas of microgravity research. In this activity, we will experiment with several methods for measuring acceleration.

PROCEDURE:

Step 1. Trim one end of the cardboard tube so that the tube is about 25 centimeters long. Cut a 3 by 15 centimeter window into the side of the tube as shown in the diagram. (The width of the window may have to be modified depending upon the diameter of the tube.)

Step 2. Cut six circles out of the corrugated cardboard equal to the inside diameter of the tube. Test the circles to see that they will fit snugly into the tube ends.

MATERIALS NEEDED:
Cardboard tube
Corugated cardboard
Glue (hot glue works best)
Rubberband
3 lead fishing sinkers (1 oz. "drilled egg")
Marker pen
Metric ruler
Sharp knife or scissors

Step 3. Cut the rubberband so that it forms a long elastic cord. Thread one end of the rubberband through the sinker. You may need a straight-ened paper clip to help you thread the sinker. Slide the sinker to the middle of the cord and stretch the rubberband. Put a drop of glue in both ends of the sinker. Keep the rubberband stretched until the glue hardens.

Step 4. Punch a small hole through the center of the cardboard circles. Glue three of the circles together. As you glue them, aligning the corrugations in different directions to increase strength. You will end up with two circles, each being three layers thick. When the glue has dried, thread one end of the elastic cord through the holes and knot the end. Repeat this step with the other three circles of cardboard.

Step 5. Insert the cardboard circles into the opposite tube ends and glue them in place. It is not important to have the elastic cord stretched tight at this stage.

Step 6. Lay the tube on its side. Stretch the elastic and tie new knots into its ends so that the lead sinker is positioned in the center of the window. Use the marker pen to mark the edges of the tube where the middle of the sinker is located. Label this position "0."

Step 7. Stand the tube upright and mark where the middle of the sinker is located now. Label this position "1." Turn the tube upside down and mark the tube again where the middle of the sinker is located. Label this position "-1."

Step 8. Using a small piece of tape, attach the second sinker to the first and follow step 7 again. This time, mark the positions "2" and "-2." Add the third sinker to the first two and repeat step 7 again. Label the new positions "3" and -3." Remove the extra sinkers. The accelerometer is now calibrated from three times the pull of gravity to negative three times the pull of gravity.

Step 9. Use the accelerometer in various motion situations to measure the accelerations produced. To oper-ate, the long direction of the accel-erometer must be parallel with the direction of the acceleration which, as in the turning automobile ex-ample, may or may not be in the direction of motion. Read the acceleration value of the device by comparing the middle of the sinker to the marks on the tube.

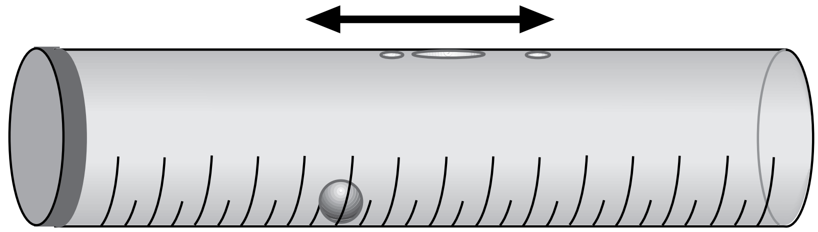
QUESTIONS:

1. What unit is the accelerometer calibrated in? Why did you use the additional sinkers to calibrate the device?
2. What does the device read if you toss it into the air?
3. How does the inner ear work as an accelerometer?
4. Can Faraday's Law be employed to measure acceleration? (Refer to a phys-ics textbook for a discussion of Faraday's Law.)
5. What will the accelerometer read when acceleration stops (such as when a car is moving at a constant speed and direc-tion)?

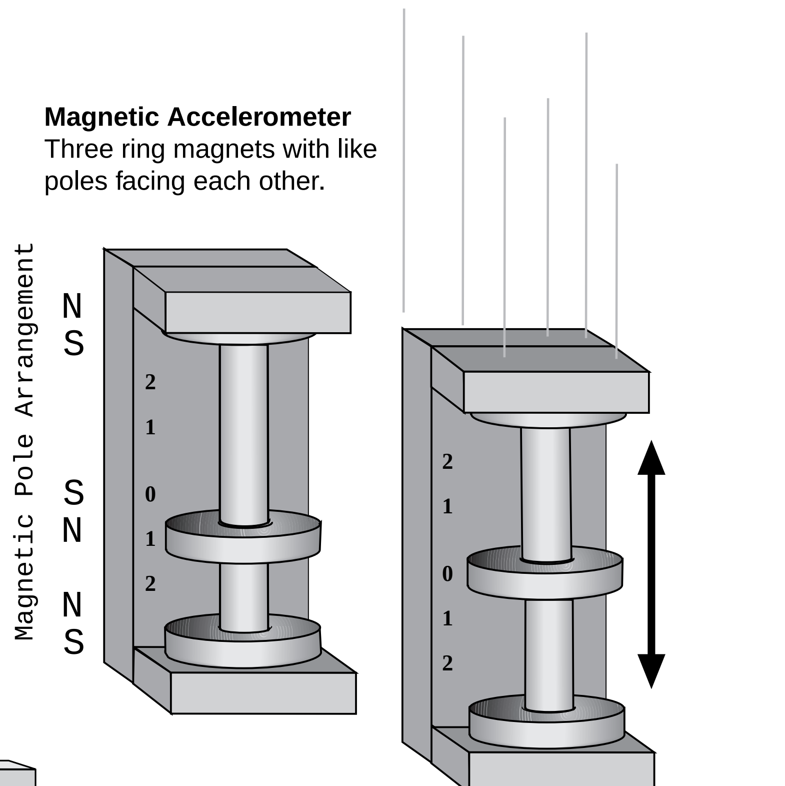
FOR FURTHER RESEARCH:

1. Take the accelerometer to an amusement park and measure the accelerations you experience when you ride a roller coaster and other fast rides.
2. Construct some of the other accelerometers pictured here. How do they work?
3. Design and construct an accelerometer for measuring very slight accelerations such as those that might be encountered on the Space Shuttle.

Falling Sphere Accelerometer
A ball bearing is placed in a graduated cylinder filled with clear liquid soap. How can the ball's falling rate be used to measure acceleration?

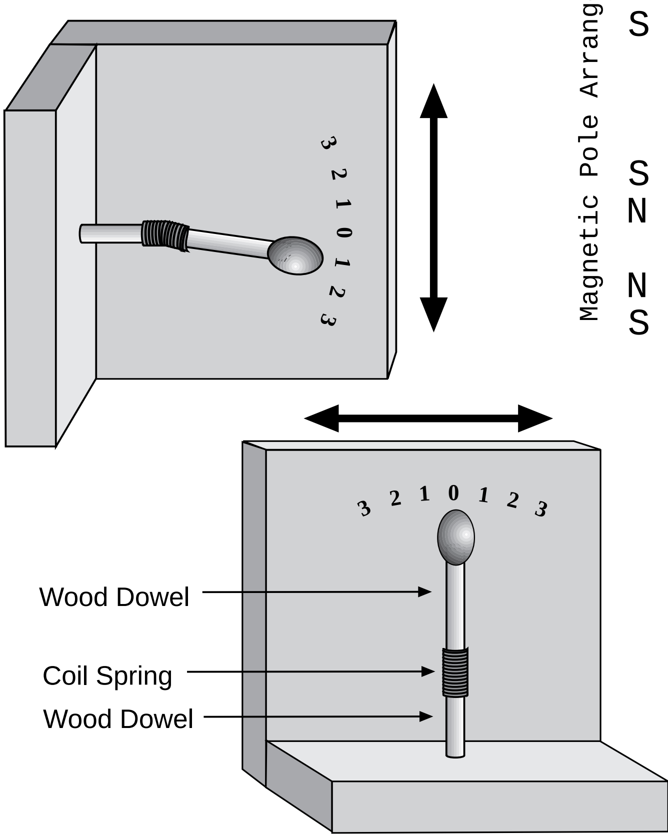


Magnetic Accelerometer
Three ring magnets with like poles facing each other.



Magnetic acclerometer in free

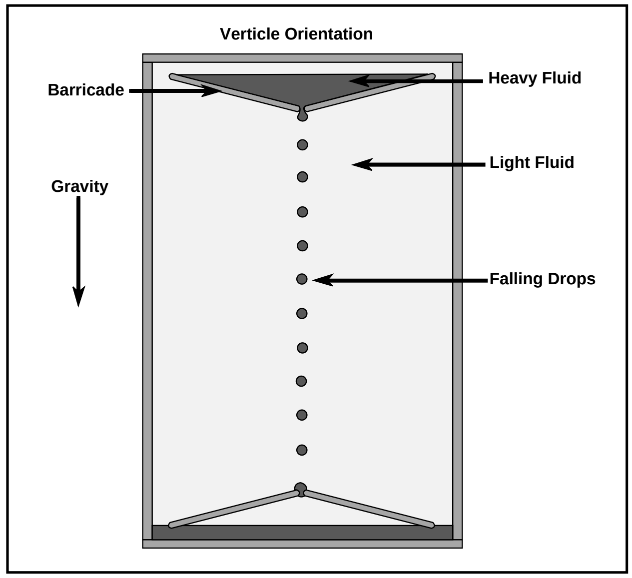
Spring Accelerometer
A lead weight is supported by two dowels joined by a spring.



Arrows indicate the direction of the acceleration measurement.

Activity 5

Gravity and Acceleration



OBJECTIVE:

To use a plasma sheet to observe acceleration forces that are experienced on board a space vehicle.

BACKGROUND:

The accelerations experienced on board a space vehicle during flight are vector quantities resulting from forces acting on the vehicle and the equipment. These accelerations have many sources, such as residual gravity, orbiter rotation, vibration from equipment, and crew activity. The equivalent acceleration vector at any one spot in the orbiter is a combination of many different sources and is thus a very complex vector quantity changing over time. The magnitude and direction of the vector is highly dependent on the activities occurring at any time. The accelerations also depend on what has happened in the recent past due to the structural response (e.g., flexing and relaxing) of the vehicle to some activities, such as thruster firing, etc.

On the other hand, the gravity experienced on Earth is a relatively stable acceleration vector quantity because of the dominating large acceleration toward Earth's center. Some activities, such as earthquakes and subsurface magma movements and altitude changes, may perturb local gravitational acceleration.

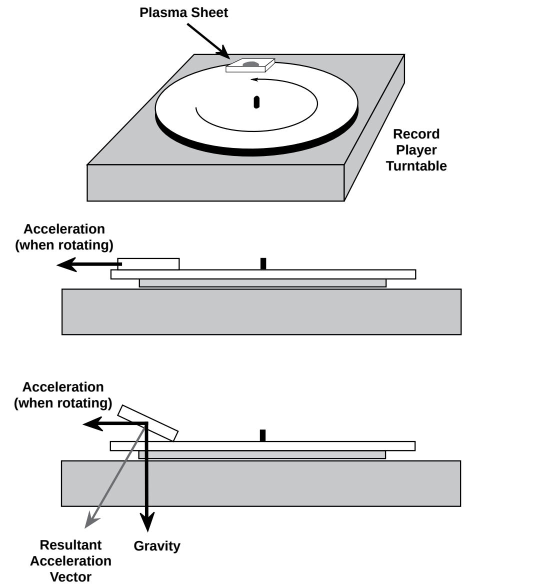
Gravity and artificial accelerations may be investigated and demonstrated visually by using a common toy available in many toy, novelty, and museum stores. The toy consists of a clear, flat, plastic box with two liquids of different densities inside. By changing the orientation of the box, droplets of one liquid will pour through the other to the bottom. For the purposes of this activity, the toy will be referred to as a *plasma sheet*.

PROCEDURE:

Step 1. Lay the plasma sheet on its flat side on the stage of an overhead projector. Project the action inside the sheet on a screen for the entire class to observe. The colored liquids will settle into a dispersed pattern across the sheet.

Step 2. Raise one end of the sheet slightly to add a new component to the acceleration vector, and support it

MATERIALS NEEDED:
Plasma sheet toy
Record turntable
File cards
Overhead projector
Slide projector
Projection screen



Rotational Acceleration Demonstration

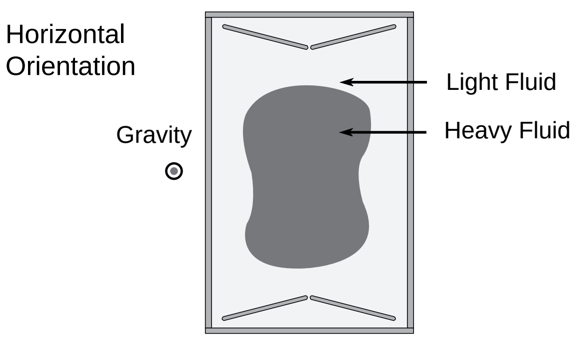
by placing a one-centimeter-thick pile of file cards under the raised end. Observe the movement of the fluids inside.

Step 3. Raise the end of the plasma sheet further and support it with another stack of cards. Again, observe the movements of the fluids.

Step 4. Aim the slide projector at the screen. Project a white beam of light at the screen. Stand the plasma sheet on its end in front of the projected beam to cast shadows. Observe the action of the falling liquids.

Step 5. Lay the plasma sheet on its flat side so that the colored liquid will accumulate in the center. Hold the sheet horizontally in your hand and, using your arm as a pendulum, swing the sheet from side to side several times. Observe what happens to the liquid.

Step 6. Lay the plasma sheet on its flat side on a phonograph record turntable. Start the turntable moving. Observe what happens to the liquid.



Step 7. Experiment with elevating the outer edge of the plasma sheet on the turntable until the acceleration vector produces a distribution of liquid similar to the dispersion observed in step 1.

QUESTIONS:

1. What implications do the plasma sheet demonstrations have for scientific researchers interested in investigating microgravity phenomena? How will Space Shuttle orbiter thruster firings and crew movements affect sensitive experiments?

2. How might acceleration vectors be reduced on the Space Shuttle? Would there be any advantage to the quality of microgravity research by conducting that research on International Space Station?

FOR FURTHER RESEARCH:

1. Investigate how scientists measure acceleration vectors in their research.

2. Challenge the students to design a simple and rugged accelerometer that could be used to measure accelerations experienced in a package sent through the U.S. Mail.

Activity 6

Inertial Balance
Part 1

OBJECTIVE:

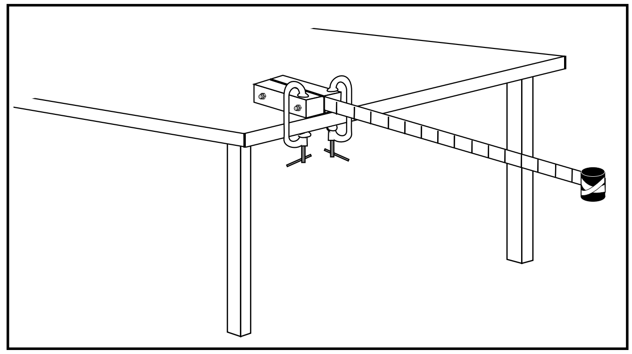
To demonstrate how mass can be measured in microgravity.

BACKGROUND:

The microgravity environment of an orbiting Space Shuttle or space station presents many research challenges for scientists. One of these challenges is the measurement of the mass of experiment samples and subjects. In life sciences research, for example, nutrition studies of astronauts in orbit may require daily monitoring of an astronaut's mass. In materials science research, it may be desirable to determine how the mass of a growing crystal changes daily. To meet these needs, an accurate measurement of mass is vital.

On Earth, mass measurement is simple. The samples and subjects are measured on a scale or beam balance. Calibrated springs in scales are compressed to derive the needed measurement. Beam balances measure an unknown mass by comparison to a known mass (kilogram weights). In both of these methods, the measurement is dependent upon the force produced by Earth's gravitational pull.

In space, neither method works because of the free fall condition of orbit. However, a third method for mass measurement is possible using the principle of inertia. Inertia is the property of matter that causes it to resist acceleration. The



amount of resistance to acceleration is directly proportional to the object's mass.

To measure mass in space, scientists use an inertial balance. An inertial balance is a spring device that vibrates the subject or sample being measured. The frequency of the vibration will vary with the mass of the object and the stiffness of the spring (in this diagram, the yardstick). For a given spring, an object with greater mass will vibrate more slowly than an object with less mass. The object to be measured is placed in the inertial balance, and a spring mechanism starts the vibration. The time needed to complete a given number of cycles is measured, and the mass of the object is calculated.

PROCEDURE:

Step 1. Using the drill and bit to make the necessary holes, bolt two blocks of wood to the opposite sides of one end of the steel yard stick.**Step 2.** Tape an empty plastic film canister to the opposite end of the yardstick. Insert the foam plug.

Step 3. Anchor the wood block end of the inertial balance to a table top with

MATERIALS NEEDED:

Metal yardstick*
2 C-clamps*
Plastic 35mm film canister
Pillow foam (cut in plug shape to fit canister)
Masking tape
Wood blocks
2 bolts and nuts
Drill and bit
Coins or other objects to be measured
Graph paper, ruler, and pencil
Pennies and nickels
Stopwatch
*Available from hardware store

C-clamps. The other end of the yard stick should be free to swing from side to side.

Step 4. Calibrate the inertial balance by placing objects of known mass (pennies) in the sample bucket (canister with foam plug). Begin with just the bucket. Push the end of the yard stick to one side and release it. Using a stopwatch or clock with a second hand, time how long it takes for the stick to complete 25 cycles.

Step 5. Plot the time on a graph above the value of 0. (See sample graph.)

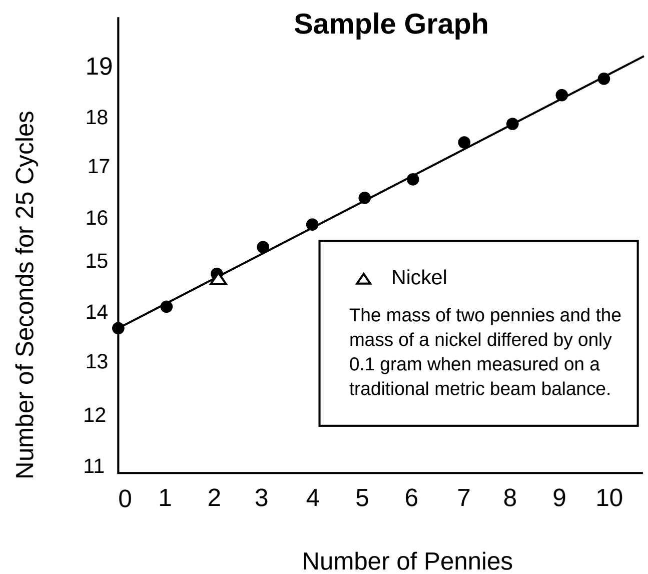
Step 6. Place a single penny in the bucket. Use the foam to anchor the penny so that it does not move inside the bucket. Any movement of the sample mass will result in an error (oscillations of the mass can cause a damping effect). Measure the time needed to complete 25 cycles. Plot the number over the value of 1 on the graph.

Step 7. Repeat the procedure for different numbers of pennies up to 10.

Step 8. Draw a curve on the graph through the plotted points.

Step 9. Place a nickel (object of unknown mass) in the bucket and measure the time required for 25 cycles. Find the horizontal line that represents the number of vibrations for the nickel. Follow the line until it intersects the graph plot. Follow a vertical line from that point on the plot to the penny scale at the bottom of the graph. This will give the mass of the nickel in "penny" units.

Note: This activity makes use of pennies as a standard of measurement. If you have access to a metric beam balance, you can calibrate the inertial balance into metric mass measurements using the weights as the standards.



QUESTIONS:

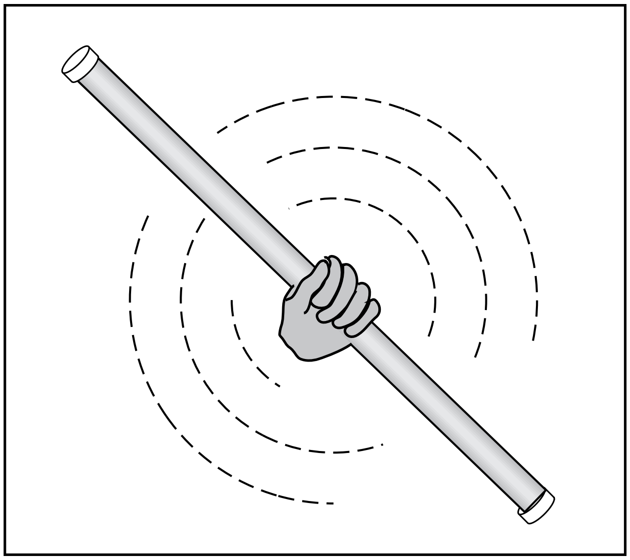
1. Does the length of the ruler make a difference in the results?

2. What are some of the possible sources of error in measuring the cycles?

3. Why is it important to use foam to anchor the pennies in the bucket?

Activity 7

Inertial Balance
Part 2



OBJECTIVE:

To feel how inertia effects acceleration.

BACKGROUND:

The inertial balance in Part 1 of this activity operates by virtue of the fundamental property of all matter that causes it to resist changes in motion. In the case of the inertial balance, the resistance to motion is referred to as *rotational inertia*. This is because the yardstick pivots at the point on the table where it is anchored and the bucket swings through an arc. Unlike linear motion, the placement of mass in rotational movements is important. Rotational inertia increases with increasing distance from the axis of rotation.

The inertial balance in Part 1 uses a metal yardstick as a spring. The bucket for holding samples is located at the end opposite the axis of rotation. Moving the bucket closer to the axis will make a stiffer spring that increases the sensitivity of the device.

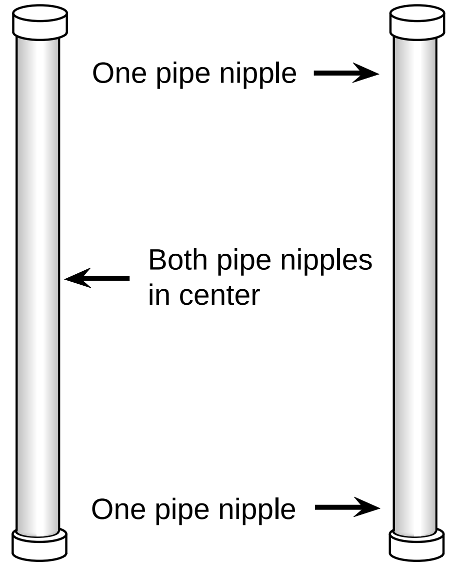
The relationship of the placement of mass to distance from the axis of rotation is easily demonstrated with a set of inertia rods. The rods are identical in appearance and mass and even have identical centers of mass. Yet, one rod is easy to rotate and the other is difficult. The secret of the rods is the location of the mass inside of them. In one rod, the mass is close to the axis of rotation, and in the other, the mass is concentrated at the ends of the rod. Students will be able to feel the difference in rotational inertia between the two rods as they try to rotate them.

PROCEDURE:

Step 1. Using a saw, cut the PVC tube in half. Smooth out the ends, and check to see that the caps fit the ends.

Step 2. Squeeze a generous amount of silicone rubber sealant into the end of one of the tubes. Slide the nipple into the tube. Using the dowel rod, push the nipple to the middle of the tube. Add sealant to the other end of the tube and insert the second nipple. Position both nipples so that they are touching each other and straddling the center of the tube. Set the tube aside to dry.

MATERIALS NEEDED:
PVC 3/4 in. water pipe
(about 1.5 to 2 m long)
4 iron pipe nipples
(sized to fit inside PVC pipe)
4 PVC caps to fit water pipe
Silicone rubber sealant
Scale or beam balance
Saw
Very fine sand paper
1/2 in. dowel rod



Step 3. Squeeze some sealant into the ends of the second tube. Push the remaining pipe nipples into the ends of the tubes until the ends of the nipples are flush with the tube ends. Be sure there is enough compound to cement the nipples in place. Set the tube aside to dry.

Step 4. When the sealant of both tubes is dry, check to see that the nipples are firmly cemented in place. If not, add additional sealant to complete the cementing. Weigh both rods. If one rod is lighter than the other, add small amounts of sealant to both ends of the rod. Re-weigh. Add more sealant if necessary.

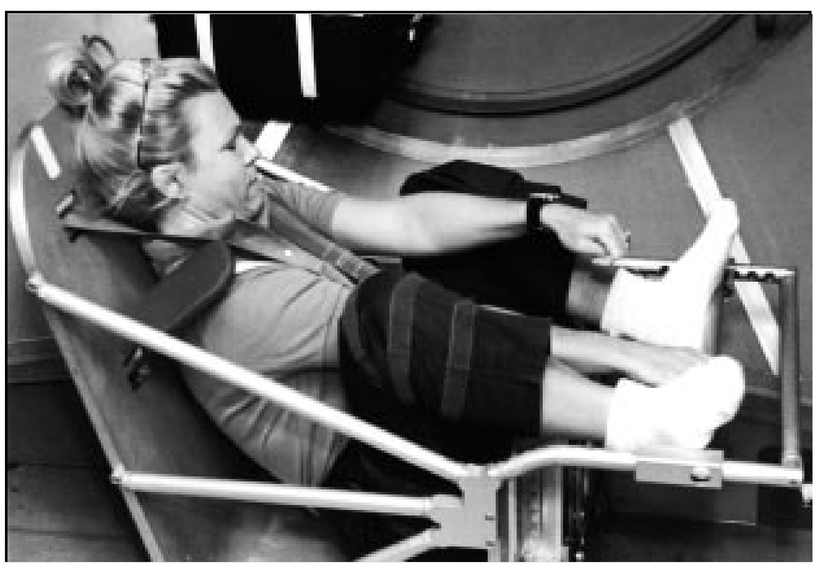
Step 5. Spread some sealant on the inside of the PVC caps. Slide them onto the ends of the tubes to cement them in place.

Step 6. Use fine sand paper to clean the rods.

QUESTIONS:

1. How does the placement of mass in the two rods affect the ease with which they are rotated from side to side? Why?

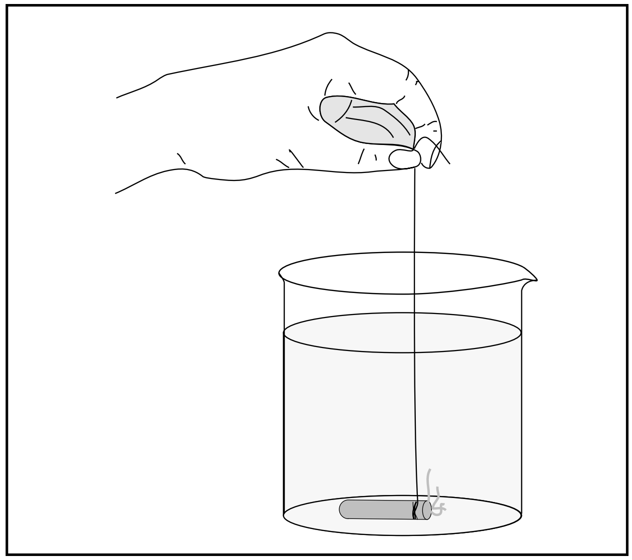
2. If an equal side to side rotational force (known as torque) was exerted on the middle of each rod, which one would accelerate faster?



Payload Commander Rhea Seddon is shown using the Body Mass Measurement Device during the Spacelab Life Sciences-2 mission. The device uses the property of inertia to determine mass.

Activity 8

Gravity-Driven Fluid Flow



OBJECTIVE:

To observe the gravity-driven fluid flow that is caused by differences in solution density.

BACKGROUND:

Many crystals grow in solutions of different compounds. For example, crystals of salt grow in concentrated solutions of salt dissolved in water. Crystals of proteins and other molecules grown in experiments on the Space Shuttle are also grown in similar types of solutions.

Gravity has been shown to cause the fluid around a growing crystal to flow upward. "Up" is defined here as being opposite the direction of gravity. This flow of fluid around the growing crystal is suspected to be detrimental to some types of crystal growth. Such flow may disrupt the arrangement of atoms or molecules on the surface of the growing crystal, making further growth non-uniform.

Understanding and controlling solution flows is vital to studies of crystal growth. The flow appears to be caused by differences in the density of solutions which, in the presence of gravity, create fluid motion around the growing crystal. The solution nearest the crystal surface deposits its chemical material onto the crystal surface, thereby reducing the molecular weight of the solution. The lighter solution tends to float upward, thus creating fluid motion. This experiment recreates the phenomenon of gravity-driven fluid motion and makes it visible.

PROCEDURE:

Step 1. Fill the large glass container with very salty water.
Step 2. Fill the small vial with unsalted water and add two or three drops of food coloring to make it a dark color.
Step 3. Attach a thread to the upper end of the vial, and lower it carefully but quickly into the salt water in the large container. Let the vial sit on the bottom undisturbed.
Step 4. Observe the results.
Step 5. Repeat the experiment using colored salt water in the small vial and unsalted water in the large container.

MATERIALS NEEDED:
Large (500 ml) glass beaker or tall drinking glass
Small (5 to 10 ml) glass vial
Thread
Food coloring
Salt
Spoon or stirring rod

Step 6. Observe the results.
Step 7. Gently remove the two vials and examine the water in them. Are any layers present?

QUESTIONS:

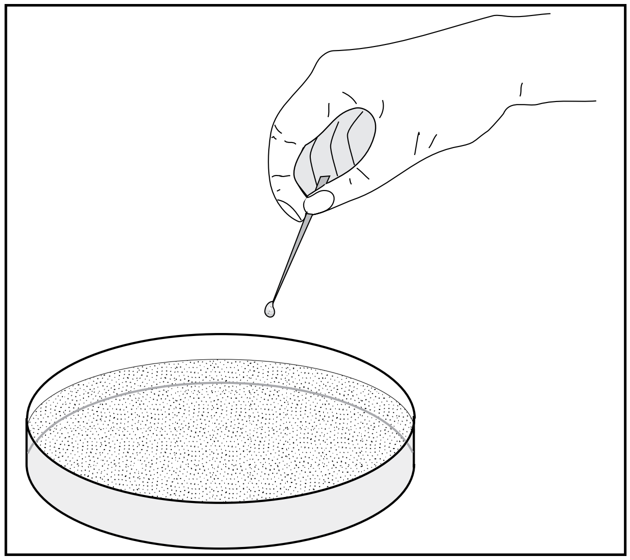
1. Based on your observations, which solution is denser (salt water or un-salted, dyed water)?
2. What do you think would happen if salt water were in both the small vial and the large container? What would happen if unsalted water were in both the small vial and the large container?
3. What results would you expect if the experiment had been performed in a microgravity environment?
4. How does this experiment simulate what happens to a crystal growing in solution?

FOR FURTHER RESEARCH:

1. Repeat the experiment, but replace the water in the small vial with hot, unsalted water. Replace the salt water in the large container with cold, unsalted water.
2. Repeat the experiment with different amounts of salt.
3. Try replacing the salt in the experiment with sugar and/or baking soda.
4. Attempt to control the observed flows by combining the effects of temperature and salinity in each container.
5. Try to observe the fluid flows without using food coloring. You will have to observe carefully to see the effects.

Activity 9

SURFACE TENSION



OBJECTIVE:

To study surface tension and the fluid flows caused by differences in surface tension.

BACKGROUND:

The spherical shape of liquid drops is a result of surface tension. Molecules on the surface of a liquid are attracted to their neighbors in such a way as to cause the surface to behave like an elastic membrane. This can be seen in drops of rain, drops of oil, dewdrops, and water beading on a well-waxed car.

Beneath the surface of a liquid, molecules are attracted to each other from all directions. Because of this attraction, molecules have no tendency to be pulled in any preferred direction. However, a molecule on the surface of a liquid is pulled to each side and inward by neighboring molecules. This causes the surface to adjust to the smallest area possible, a sphere. Surface tension is what allows objects such as needles, razor blades, water bugs, and pepper to float on the surface of liquids.

The addition of a surfactant, such as liquid soap, to a liquid weakens, or reduces, the surface tension. Water molecules do not bond as strongly with soap molecules as they do with themselves. Therefore, the bonding force that enables the molecules to behave like an elastic membrane is weaker.

In a microgravity environment, buoyancy-driven fluid flows and sedimentation are greatly reduced. When this happens, surface tension can become a dominant force. Furthermore, microgravity makes it easier to study surface tension-driven flows then to study them in a normal gravity environment. An analogy to this process would be like trying to listen to a flutist (the surface tension-driven fluid flows) during a thunderstorm (the buoyancy-driven convection).

PROCEDURE:

Step 1. Fill the beaker, jar, or glass with water.

Step 2. Sprinkle some pepper on the water surface. Observe what happens to the pepper.

Step 3. Stir the water vigorously. Observe what happens to the pepper.

Step 4. Add new water to the container and mix in a few drops of liquid soap. Carefully stir the water to dissolve the detergent but try not to create any bubbles.

MATERIALS NEEDED: *
Beaker, clear jar, or drinking glass
Shallow dish or petri dish
Stirring rod
Water
Black pepper
Clear liquid soap
Toothpick
*per group of students

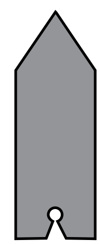
Step 5. Sprinkle pepper on the water surface. Observe what happens to the pepper.
Step 6. Fill the shallow dish or petri dish with water.
Step 7. Sprinkle some pepper on the surface. Observe any movement of the pepper on the surface.
Step 8. Touch one end of the toothpick into a drop of liquid soap to pick up a small amount of the soap. Carefully touch the end of the toothpick to the surface of the water in the center of the dish. Be careful not to disturb the water. Observe any movement.
Step 9 (optional) Steps 6-8 can be demonstrated to the entire class by placing the dish on the stage of an overhead projector.

QUESTIONS:

1. Why did the pepper float on the water?
2. Why did the pepper sink when the water was stirred?
3. Does the amount of liquid soap affect the results of the experiment? Is more or less detergent better?
4. How does liquid soap enable us to wash dishes?

FOR FURTHER RESEARCH:

1. Make a surface tension-propelled paper boat by cutting a small piece of paper in the shape shown below and floating it on clean water. Touch a small amount of liquid soap to the water in the hole at the back of the boat.
2. Design an experiment to test whether the temperature of a liquid has any effect on surface tension.
3. Try floating needles on water and observe what happens when liquid soap is added.



Surface Tension Paper Boat*
(actual size)

*Note: Make sure that there is a small opening between the notch and the hole.

Activity 10

Candle Flames

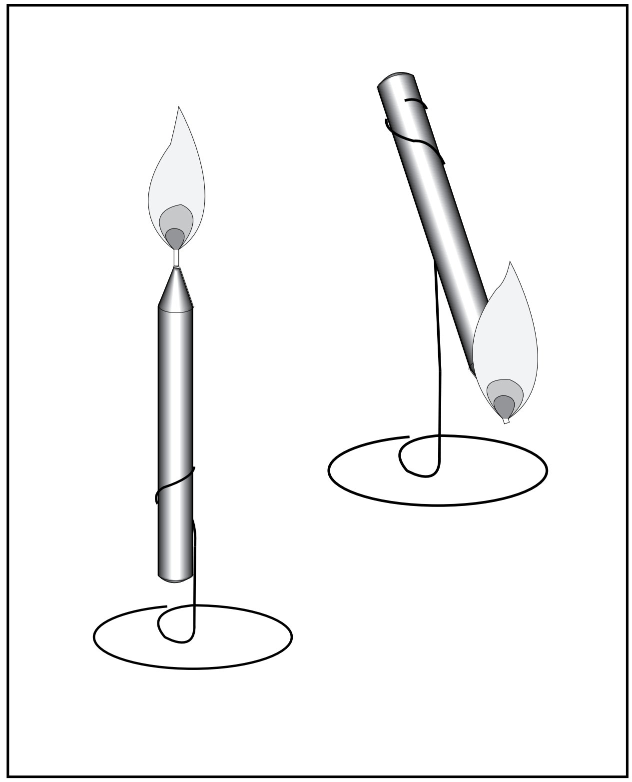
OBJECTIVE:

To illustrate the effects of gravity on the burning rate of candles.

BACKGROUND:

A candle flame is often used to illustrate the complicated physio-chemical processes of combustion. The flame surface itself represents the location where fuel vapor and oxygen mix at high temperature and with the release of heat. Heat from the flame melts the wax (typically a C_{20} to C_{35} hydrocarbon) at the base of the exposed wick. The liquid wax rises by capillary action up the wick, bringing it into closer proximity to the hot flame. This close proximity causes the liquid wax to vaporize. The wax vapors then migrate toward the flame surface, breaking down into smaller hydrocarbons enroute. Oxygen from the surrounding atmosphere also migrates toward the flame surface by diffusion and convection. The survival and location of the flame surface is determined by the balance of these processes.

In normal gravity, buoyancy-driven convection develops due to the hot, less dense combustion products. This action has several effects: (a) the hot reaction products are carried away due to their buoyancy, and fresh oxygen is carried toward the flame zone; (b) solid particles of soot form in the region between the flame and the wick and are convected upward, where they burn off, yielding the bright yellow tip of the flame; (c) to overcome the loss of heat due to buoyancy, the flame anchors itself close to the wick; (d) the combination of these effects causes the flame to be shaped like a tear drop.



In the absence of buoyancy-driven convection, as in microgravity, the supply of oxygen and fuel vapor to the flame is controlled by the much slower process of molecular diffusion. Where there is no "up" or "down," the flame tends toward sphericity. Heat lost to the top of the candle causes the base of the flame to be quenched, and only a portion of the sphere is seen. The diminished supply of oxygen and fuel causes the flame temperature to be lowered to the point that little or no soot forms. It also causes the flame to anchor far from the wick, so that the burning rate (the amount of wax consumed per unit time) is reduced.

MATERIALS NEEDED:
Birthday candles (several)
Matches
Balance beam scale (0.1 gm or greater sensitivity)
Clock with second-hand or stopwatch
Wire cutter/pliers
Wire
Small pan to collect dripping wax

PROCEDURE:

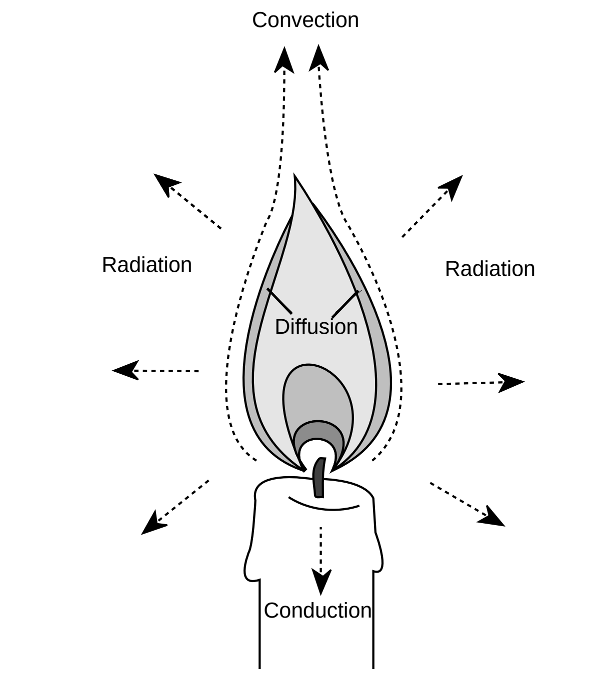
Step 1. Form candle holders from the wire as shown in the diagram. Determine and record the weight of each candle and its holder.
Step 2. Light the "upright" candle and permit it to burn for one minute. As it burns, record the colors, size, and shape of the candle flame.
Step 3. Weigh the candle and holder and calculate how much mass was lost.
Step 4. Place the inverted candle on a small pan to collect dripping wax. (Note: The candle should be inverted to an angle of about 70 degrees from the horizontal. If the candle is too steep, dripping wax will extinguish the flame.)
Step 5. Light the candle and permit it to burn for one minute. As it burns, record the colors, size, and shape of the candle flame.
Step 6. Weigh the candle and holder and calculate how much mass was lost.

QUESTIONS:

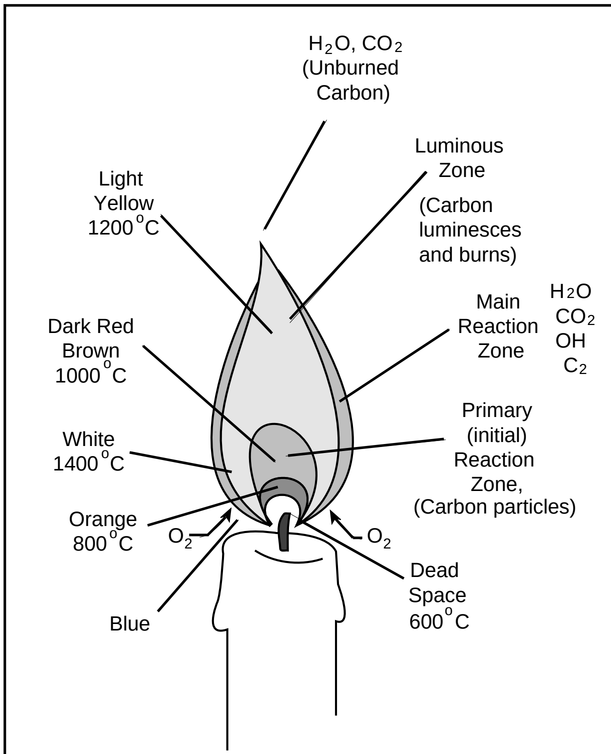
1. Which candle burned faster? Why?
2. How were the colors and flame shapes and sizes different?
3. Why did one candle drip and the other not?
4. Which candle was easier to blow out?
5. What do you think would happen if you burned a candle horizontally?

FOR FURTHER RESEARCH:

1. Burn a horizontally-held candle. As it burns, record the colors, size, and shape of the candle flame. Weigh the candle and calculate how much mass was lost after one minute.
2. Repeat the above experiments with the candles inside a large jar. Let the candles burn to completion. Record the time it takes each candle to burn. Determine how and why the burning rate changed.
3. Burn two candles which are close together. Record the burning rate and weigh the candles. Is it faster or slower than each candle alone? Why?
4. Obtain a copy of Michael Faraday's book, <u>The Chemical History of a Candle</u>, and do the experiments described. (See suggested reading list.)



Candle Flame Energy Flow*

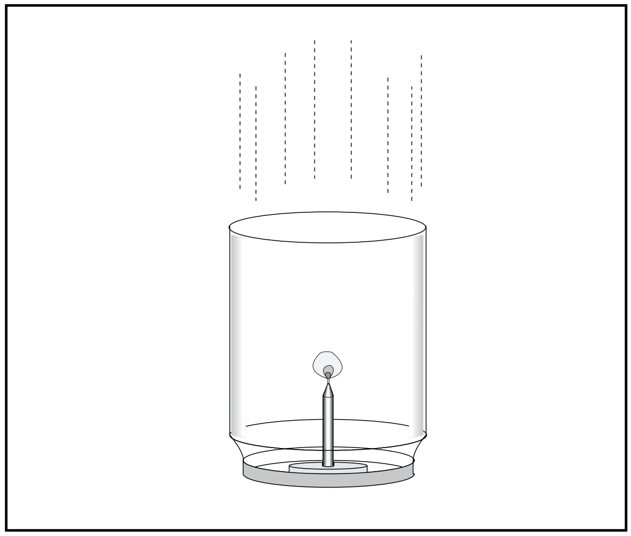


Candle Flame Reaction Zones,
Emissions, and Temperature*

*Candle flame diagrams adapted from "The Science of Flames poster," National Energy Foundation, Salt Lake City, UT.

Activity 11

Candle Drop



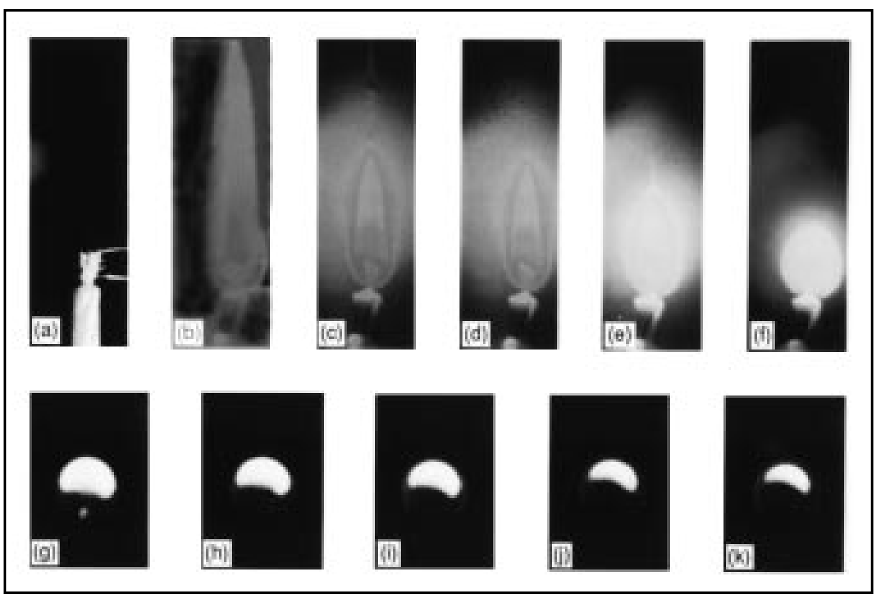
OBJECTIVE:

To observe candle flame properties in free fall.

BACKGROUND:

Drop tower and Space Shuttle experiments have provided scientists valuable insights on the dynamics and chemistry of combustion. In both research environments, a flammable material is ignited by a hot wire, and the combustion process is recorded by movie cameras and other data collection devices.

The sequence of pictures beginning at the bottom of this page illustrates a combustion experiment conducted at the NASA Lewis Research Center 150 Meter Drop Tower. These pictures of a candle flame were recorded during a 5-second drop tower test. An electrically-heated wire was used to ignite the candle and then withdrawn one second into the drop. As the pictures illus-



trate, the flame stabilizes quickly, and its shape appears to be constant throughout the remainder of the drop.

Microgravity tests performed on the Space Shuttle furthered this research by determining the survivability of a candle flame. If the oxygen does not diffuse rapidly enough to the flame front, the flame temperature will diminish. Consequently, the heat feedback to and vaporization of the candle wax will be reduced. If the flame temperature and these other processes fall below critical values, the candle flame will be extinguished. Candles on board the first United States Microgravity Laboratory, launched in June 1992, burned from 45 seconds to longer than 60 seconds.

MATERIALS NEEDED:

Clear plastic jar and lid (2 liter volume)*
Wood block
Screws
Birthday-size candles
Matches
Drill and bit
Video camera and monitor (optional)
* Empty large plastic peanut butter jar can be used.

PROCEDURE:

Step 1. Cut a small wood block to fit inside the lid of the jar. Attach the block to the jar lid with screws from the top.

Step 2. Drill a hole in the center of the block to serve as a candle-holder.

Step 3. Insert a candle into the hole. Darken the room. With the lid on the bottom, light the candle and quickly screw the plastic jar over the candle.

Step 4. Observe the shape, brightness, and color of the candle flame. If the oxygen inside the jar is depleted before the observations are completed, remove the jar and flush out the foul air. Relight the candle and seal the jar again.

Step 5. Raise the jar towards the ceiling of the room. Drop the jar with the lit candle to the floor. Position a student near the floor to catch the jar.

Step 6. As the candle drops, observe the shape, brightness, and color of the candle flame. Because the action takes place very quickly, perform several drops to complete the observation process.

QUESTIONS:

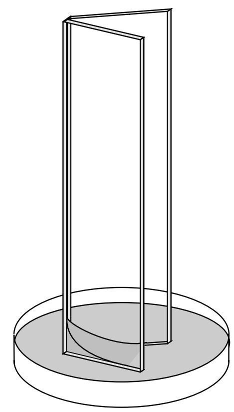
1. Did the candle flame change shape during the drop? If so, what new form did the flame take and why?
2. Did the brightness of the candle flame change? If it did change, why?
3. Did the candle flame go out? If the flame did go out, when did it go out and why?
4. Were the observations consistent from drop to drop?

FOR FURTHER RESEARCH:

1. If videotape equipment is available, videotape the candle flame during the drop. Use the pause control during the playback to examine the flame shape.
2. If a balcony is available, drop the jar from a greater distance than is possible in a classroom. Does the candle continue to burn through the entire drop? For longer drops, it is recommended that a catch basin be used to catch the jar. Fill up a large box or a plastic trash can with styrofoam packing material or loosely crumpled newspaper.

Activity 12

Contact Angle



OBJECTIVE:

To measure the contact angle of a fluid.

BACKGROUND:

In the absence of the stabilizing effect of gravity, fluids partly filling a container in space are acted on primarily by surface forces and can behave in striking, unfamiliar ways. Scientists must understand this behavior to manage fluids in space effectively.

Liquids always meet clean, smooth, solid surfaces in a definite angle, called the contact angle. This angle can be measured by observing the attraction of fluid into sharp corners by surface forces. Even in Earth's gravity, the measurement technique can be observed. If a corner is vertical and sharp enough, surface forces win out over the downward pull of gravity, and the fluid moves upward into the corner. If the angle between the two glass planes is slowly decreased, the fluid the glass is standing in jumps up suddenly when the critical value of the corner angle is reached. In the absence of gravity's effects, the jump would be very striking, with a large amount of fluid pulled into the corner.

PROCEDURE:

Step 1. Place a small amount of distilled water in a dish. (Note: It is important that the dish and the slides are clean.)

Step 2. Place two clean microscope slides into the water so that their ends touch the bottom of the dish and the long slides touch each other at an angle of at least 30 degrees. (Optional step: You may find it easier to manipulate the slides if a tape hinge is used to hold the slides together.)

Step 3. Slowly close the angle between the two slides.

Step 4. Stop closing the angle when the water rises between the slides. Use the protractor to measure the contact angle (angle the water rises up between the slides). Also measure the angle between the two slides.

MATERIALS NEEDED:

Distilled water
Microscope slides
Shallow dish
Protractor
Cellophane tape

QUESTIONS:

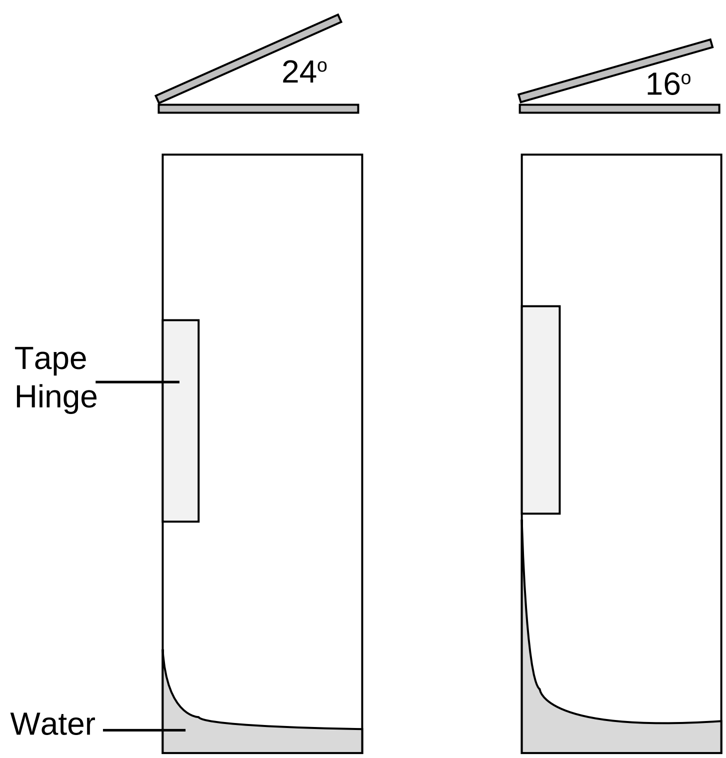
1. What is the mathematical relationship between the contact angle and the angle between the two slides?

Contact angle = 90 -1/2 wedge angle

2. Why is it important to understand the behavior of fluids in microgravity?

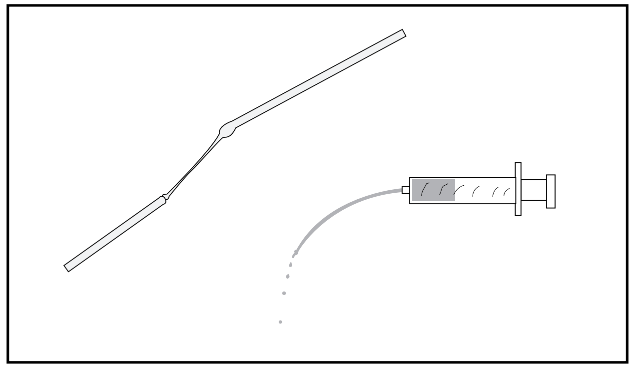
FOR FURTHER RESEARCH:

1. Add some food coloring to the water to make it easier to see. Does the addition of coloring change the contact angle?
2. Measure the contact angle for other liquids. Add a drop of liquid soap or alcohol to the water to see if it alters water's contact angle.
3. Try opening the wedge of the two slides after the water has risen. Does the water come back down easily to its original position?



Activity 13

Fiber Pulling



OBJECTIVE:

To illustrate the effects of gravity and surface tension on fiber pulling.

BACKGROUND:

Fiber pulling is an important process in the manufacture of synthetic fabrics such as nylon and polyester and more recently, in the manufacture of optical fibers for communication networks. Chances are, when you use the telephone for long distance calls, your voice is carried by light waves over optical fibers.

Fibers can be drawn successfully only when the fluid is sufficiently viscous or "sticky." Two effects limit the process: gravity tends to cause the fiber to stretch and break under its own weight, and surface tension causes the fluid to have as little surface area as possible for a given volume. A long slender column of liquid responds to this latter effect by breaking up into a series of small droplets. A sphere has less surface area than a cylinder of the same volume. This effect is known as the "Rayleigh instability" after the work of Lord Rayleigh who explained this behavior mathematically in the late 1800's. A high viscosity slows the fluid motion and allows the fiber to stiffen as it cools before these effects cause the strand to break apart.

Some of the new exotic glass systems under consideration for improved optical fibers are much less viscous in the melt than the quartz used to make the fibers presently in use: this low viscosity makes them difficult to draw into fibers. The destructive effects of gravity could be reduced by forming fibers in space. However, the Rayleigh instability is still a factor in microgravity. Can a reduction in gravity's effects extend the range of viscosities over which fibers can be successfully drawn? This question must be answered before we invest heavily in developing expensive experiment apparatus to test high temperature melts in microgravity. Fortunately, there are a number of liquids that, at room temperature, have fluid properties similar to those of molten glass. This allows us to use common fluids to model the behavior of molten materials in microgravity.

PROCEDURE: (for several demonstrations)

Step 1. While wearing eye and hand protection, use the propane torch or Bunsen burner to melt a blob of glass at one end of a stirring rod. Touch a second rod to the melted blob and pull a thin strand downward. Measure how long the fiber gets before it breaks. **Caution: When broken, the fiber fragments are sharp. Dispose of safely.**

MATERIALS NEEDED:
Propane torch or Bunsen burner
Small-diameter glass stirring rods (soft glass)
Disposable syringes (10 ml) without needles
Various fluids (water, honey, corn syrup, mineral oil, and light cooking oil)
Small ball bearings or BBs
Small graduated cylinders or test tubes (at least 5 times the diameter of the ball bearing)
Stopwatch or clock with second-hand
Eye protection
Protective gloves
Metric ruler

Step 2. Squirt a small stream of water from the syringe. Observe how the stream breaks up into small droplets after a short distance. This breakup is caused by the Rayleigh instability of the liquid stream. Measure the length of the stream to the point where the break-up occurs. Do the same for other liquids and compare the results.

Step 3. Touch the end of a cold stirring rod to the surface of a small quantity of water. Try to draw a fiber.

Step 4. Repeat #3 with more viscous fluids, such as honey.

Step 5. Compare the ability to pull strands of the various fluids with the molten glass and with the measurements made in step 2.

Step 6. Pour about 5 centimeters of water into a small test tube. Drop the ball bearing into the tube. Record the time it takes for the ball bearing to reach the bottom. (This is a measure of the viscosity of the fluid.)

Step 7. Repeat #6 for each of the fluids. Record the fall times through each fluid.

QUESTIONS:

1. Which of the fluids has the closest behavior to molten glass? Which fluid has the least similar behavior to molten glass? (Rank the fluids.)

2. How do the different fluids compare in viscosity (ball bearing fall times)? What property of the fluid is the most important for modeling the behavior of the glass melt?

3. What is the relationship between fiber length and viscosity of the fluid?

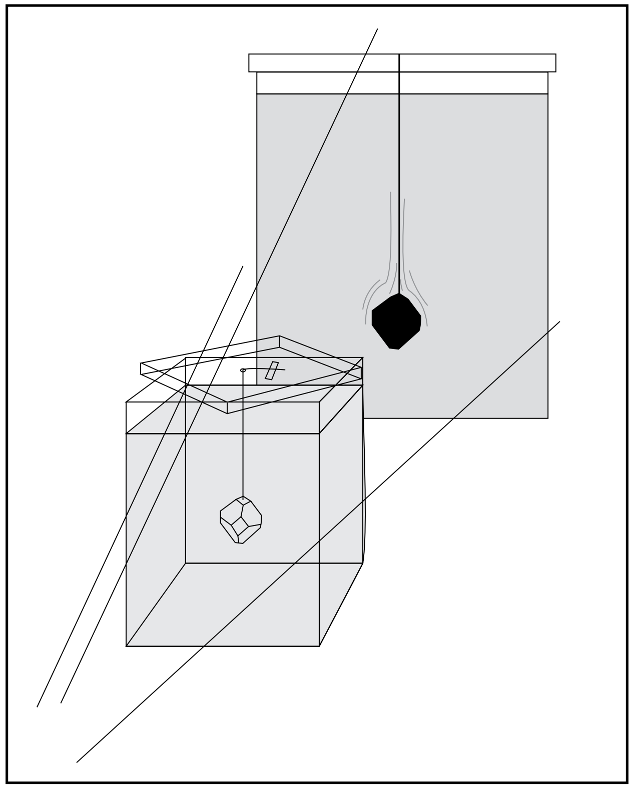
FOR FURTHER RESEARCH:

1. With a syringe, squirt a thin continuous stream of each of the test fluids downward into a pan or bucket. Carefully observe the behavior of the stream as it falls. Does it break up? How does it break up? Can you distinguish whether the breakup is due to gravity effects or to the Rayleigh instability? How does the strand break when the syringe runs out of fluid? (For more viscous fluids, it may be necessary to do this experiment in the stairwell with students stationed at different levels to observe the breakup.)

2. Have the students calculate the curved surface area (ignore the area of the end caps) of cylinders with length to diameter ratios of 1, 2, 3, and 4 of equal volume. Now, calculate the surface area of a sphere with the same volume. Since nature wants to minimize the surface area of a given volume of free liquid, what can you conclude by comparing these various ratios of surface area to volume ratios? (Note: This calculation is only an approximation of what actually happens. The cylinder (without the end caps) will have less surface area than a sphere of the same volume until its length exceeds 2.25 times its diameter from the above calculation. Rayleigh's theory calculates the increase in surface area resulting from a disturbance in the form of a periodic surface wave. He showed that for a fixed volume, the surface area would increase if the wavelength was less than π times the diameter, but would decrease for longer waves. Therefore, a long slender column of liquid will become unstable and will break into droplets separated by π times the diameter of the column.)

Activity 14

Crystal Growth



OBJECTIVE:

To observe crystal growth phenomena in a 1-g environment.

BACKGROUND:

A number of crystals having practical applications, such as L-arginine phosphate (LAP) and triglycine sulfate (TGS), may be grown from solutions. In a one-gravity environment, buoyancy-driven convection may be responsible for the formation of liquid inclusions and other defects which can degrade the performance of devices made from these materials. The virtual absence of convection in a microgravity environment may result in far fewer inclusions than in crystals grown on Earth. For this reason, solution crystal growth is an active area of microgravity research.

Crystal growing experiments consist of a controlled growth environment on Earth and an experimental growth environment in microgravity on a spacecraft. In this activity, students will become familiar with crystal growing in 1-g. One or more crystals of alum (aluminum potassium sulfate or $AlK(SO_4)_2 \cdot 12H_2 0$ will be grown from seed crystals suspended in a crystal growth solution. With the use of collimated light, shadowgraph views of the growing crystals will reveal buoyancy-driven convective plumes in the growth solution. (Refer to activity 6 for additional background information.)

PROCEDURE:

Step 1. Create a seed crystal of alum by dissolving some alum in a small quantity of water in a beaker. Permit the water to evaporate over several days. Small crystals will form along the sides and bottom of the beaker.

Step 2. Remove one of the small crystals of alum and attach it to a short length of monofilament fishing line with a dab of silicone cement.

Step 3. Prepare the crystal growth solution by dissolving powdered or crystalline alum in a beaker of warm

MATERIALS NEEDED:

Aluminum Potassium Sulfate
$AlK(SO_4)_2 \cdot 12H_20$*
Square acrylic box**
Distilled water
Stirring rod
Monofiliment fishing line
Silicone cement
Beaker
Slide projector
Projection screen
Eye protection
Hot plate
Thermometer
Balance

* Refer to the chart on the next page for the amount of alum needed for the capacity of the growth chamber (bottle) you use.
** Clear acrylic boxes, about 10x10x13 cm are available from craft stores. Select a box that has no optical distortions.

water. The amount of alum that can be dissolved in the water depends upon the amount of the water used and its temperature. Refer to the table (Alum Solubility in Water) for the quantity required.

Step 4. When no more alum can be dissolved in the water, transfer the solution to the growth chamber acrylic box.

Step 5. Punch a small hole through the center of the lid of the box. Thread the seed crystal line through the hole and secure it in place with a small amount of tape. Place the seed crystal in the box and place the lid on the box at a 45 degree angle. This will expose the surface of the solution to the outside air to promote evaporation. It may be necessary to adjust the length of the line so that the seed crystal is several centimeters above the bottom of the bottle.

Step 6. Set the box aside in a place where it can be observed for several days without being disturbed. If the crystal should disappear, dissolve more alum into the solution and suspend a new seed crystal.

Step 7. Record the growth rate of the crystal by comparing it to a metric ruler. The crystal may also be removed and its mass measured on a balance.

Step 8. Periodically observe the fluid flow associated with the crystal's growth by directing the light beam of a slide projector through the box to a projection screen. Observe plumes around the shadow of the crystal. Convection currents in the growth solution distort the light passing through the growth solution.

QUESTIONS:

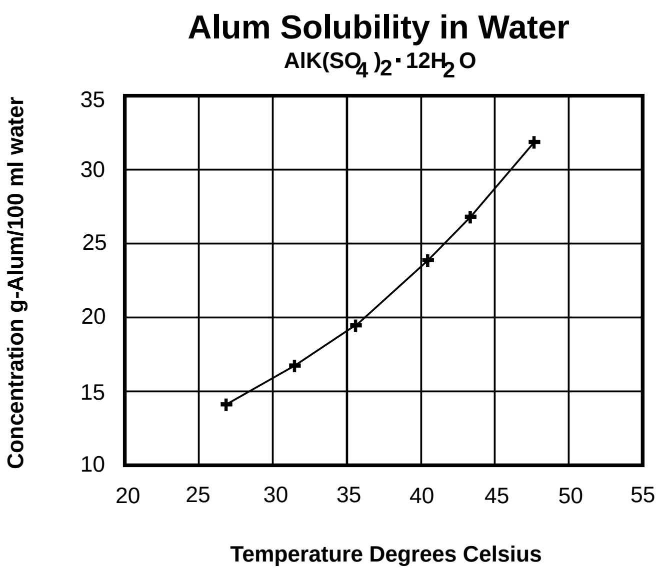
1. What is the geometric shape of the alum crystal?
2. What can cause more than one crystal to form around a seed?
3. What do shadowgraph plumes around the growing crystal indicate? Do you think that plumes would form around crystals growing in microgravity?
4. Does the growth rate of the crystal remain constant? Why or why not?
5. What would cause a seed crystal to disappear? Could a crystal decrease in size? Why?
6. What are some of the possible applications for space-grown crystals?

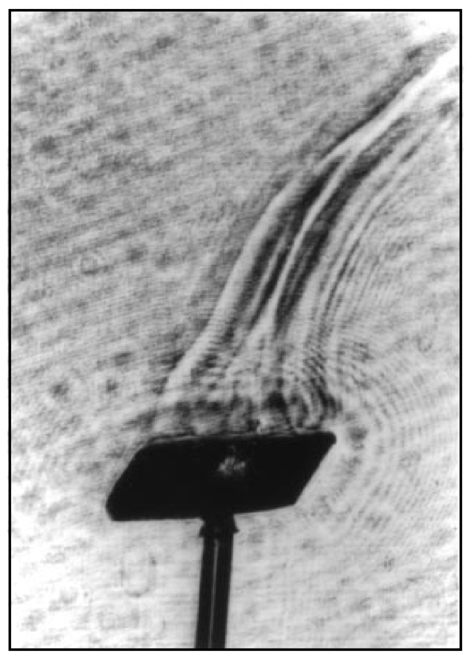
FOR FURTHER RESEARCH:

1. Grow additional alum crystals without the cap placed over the box. In one experiment, permit the growth solution to evaporate at room temperature. In another, place the growth chamber in a warm area or even on a hot plate set at the lowest possible setting. Are there any differences in the crystals produced compared to the first one grown? How does the growth rate compare in each of the experiments?

2. Experiment with growing crystals of other chemicals such as table salt, copper sulfate, chrome alum, Rochelle salt, etc. Caution: Become familiar with potential hazards of any of the chemicals you choose and take appropriate safety precautions.

3. Review scientific literature for results from microgravity crystal growing experiments.

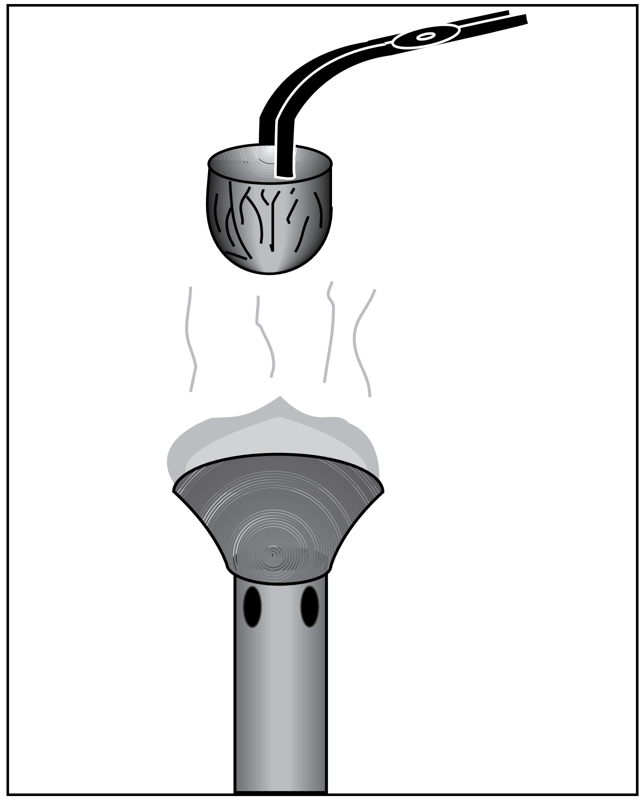




Shadowgraph image of a growth plume rising from a growing crystal.

Activity 15

Rapid Crystallization



OBJECTIVE:

To investigate the growth of crystals by two different methods under different temperature conditions.

BACKGROUND:

Crystals are solids composed of atoms, ions, or molecules arranged in orderly patterns that repeat in three dimensions. The geometric form of a crystal visible to the naked eye can be an external expression of the orderly arrangement inside. Many of the unique properties of materials, such as strength and ductility, are a consequence of crystalline structure.

It is easy to get confused about the nature of crystals because the word crystal is frequently misused. For example, a crystal chandelier is not crystal at all. Crystal chandeliers are made of glass. Glass is an *amorphous* material because it lacks a regular interior arrangement of atoms.

Scientists are very interested in growing crystals in microgravity because gravity often interferes with the crystal growing process to indirectly produce different types of defects in the crystal structure. The goal of growing crystals in microgravity is not to develop crystal factories in space but to better understand the crystal growing process and the effects that gravity can have on it.

In this activity, crystal growth will be studied with chemicals that crystallize rapidly in two different ways. The first part of the activity demonstrates the difference between a crystalline material and an amorphous material by manipulating the cooling rate to control how fast the material freezes or solidifies from a molten state. The second part of the activity permits students to observe close-up crystallization from solution. It employs chemical hand warmers.

The hand warmers are sold in full-line camping and hunting stores. They consist of a plastic pouch filled with a food-grade solution of sodium acetate and water. Also in the pouch is a small disk of stainless steel. By snapping the disk, the precipitation and crystallization of the sodium acetate is triggered. As the solid material forms from solution (precipitation) the chemicals release heat (*heat of solution*) that maintains the pouch temperature at about 54 degrees Celsius for a half hour. This makes the pouch ideal for a hand warmer. Furthermore, the pouch is reusable indefinitely by reheating and dissolving the solid contents again.

The pouch is designed so that at room temperature, the water contains many more molecules of sodium acetate than would normally dissolve at that temperature. This is called a *supersaturated* solution. The solution remains that way until it comes in contact with a seed crystal or some way of rapidly introducing energy into the solution which acts as a trigger for the start of crystallization. Snapping the metal disk inside the pouch delivers a sharp mechanical energy input to the solution that triggers the crystallization process. Crystallization takes place so rapidly that the growth of crystals can easily be observed.

PROCEDURE: (Part 1, Crystalline or Amorphous?)

Note: This activity is a demonstration. Make sure you have adequate ventilation. A small quantity of sulfur fumes may be released. Be sure to wear eye protection while heating the sulfur.

MATERIALS, PART 1

Eye protection
Heavy duty aluminum foil
Scissors
Fat test tube
Tongs
Bunsen Burner
Powdered sulfur
Beaker of cold water
Heat resistant surface
Adequate ventilation

Step 1. Make two disposable aluminum crucibles by wrapping heavy duty aluminum foil around the lower end of a large test tube. Remove the foil and trim each crucible with scissors.

Step 2. Place enough sulfur in each crucible to cover the bottom to about 1 centimeter deep. Using the tongs to hold the first crucible, <u>gently and slowly</u> heat the crucible with a low flame from a Bunsen burner until the sulfur melts. Do not heat the sulfur enough to cause it to ignite. Place the crucible on a heat resistant surface to cool and cover it with a small beaker or another piece of foil.

Step 3. Repeat step 2 with the second crucible. When the sulfur melts, immediately thrust it into a beaker of cold water to cool.

Step 4. When both samples are cool to the touch, peel back the aluminum foil to examine the surface of the sulfur. One sample will show crystalline structure while the other will have a glassy surface. Break each sample in half and examine the edges of the break with a magnifying glass.

QUESTIONS

1. What is the difference between the two sulfur samples?

2. How do the properties of these samples relate to the rate in which they cooled?

FOR FURTHER RESEARCH

1. Compare a piece of granite with a piece of obsidian. Both rocks have approximately the same composition. Why are they different from each other.

2. Learn about some of the applications of crystalline and amorphous materials.

PROCEDURE: (Part 2, Heat Packs)

Note: This activity is an activity involving small groups of students. Because the activity involves boiling water, students should be cautioned to remove the heat packs from the boiler carefully to avoid scalding burns. If you would prefer, handle this part of the activity yourself.

Step 1. Prepare the heat packs by boiling each until all crystals have dissolved. Using tongs, remove the pouches and place them down on towels so that the remaining hot water can be dried off.

Step 2. Each student group should place a pouch on a styrofoam food tray and slide the bulb of a thermometer under the pack. When the pouch temperature is below 54° C, the internal metal disk can be snapped to trigger crystal growth. Before doing so, the disk should be moved to one corner of the pouch.

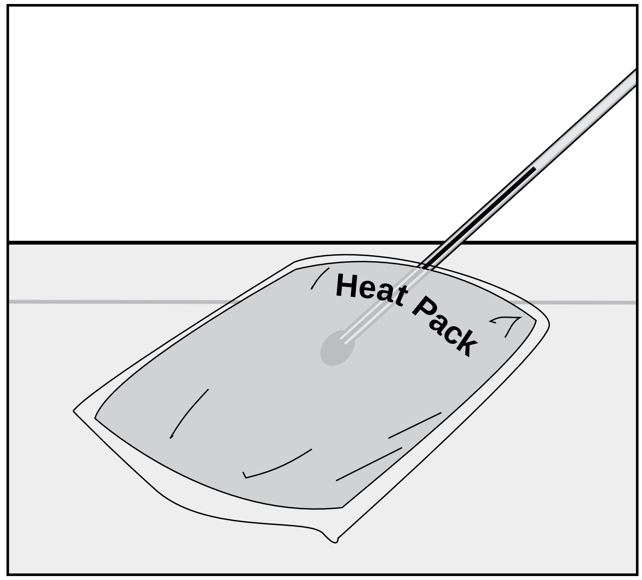
Step 3. Using the data sheet on the next page, the students should observe the crystal growth in the pouch.

Step 4. Repeat the activity several times but cool the pouch to different temperatures. To encourage the pouch to cool more rapidly, place it on a hard surface such as a metal cookie sheet or a table top. Return it to the styrofoam to measure its temperature and trigger the crystallization.

QUESTIONS

1. Is there any relationship between the initial temperature of the pouch and the temperature of the pouch during crystallization?

2. Is there a relationship between the initial temperature of the pouch and the time it takes for the pouch to completely solidify?



3. Do other materials, such as water, release heat when they freeze?

FOR FURTHER RESEARCH

1. What do you think would happen if the heat pack were crystallized in microgravity? What effect does gravity have? Hold the pack vertically with the steel disk at the bottom and trigger the solidification. Repeat with the disk at the top. Using two thermometers, measure the temperature of the top and bottom of the pack during crystallization.

2. Try chilling a heat pack pouch in a freezer and then triggering the solidification.

3. Identify other ways the word "crystal" is misused.

MATERIALS, PART 2

Heat pack hand warmers (1 or more per group)
Water boiler (an electric kitchen hot pot can be used)
Styrofoam meat tray (1 per group)
Metric thermometer (1 or more per group)
Observation and data table (1 per student)

Heat Pack Experiment Data Sheet

Name: ______________________________

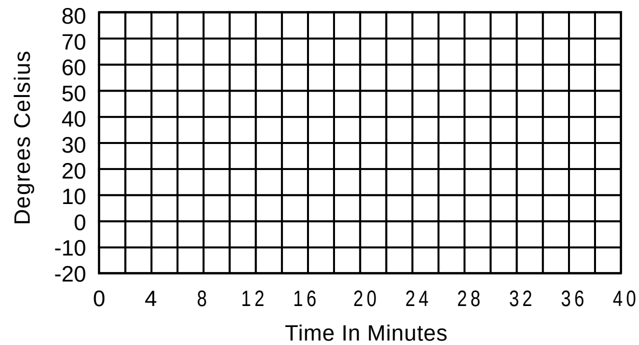
<u>Test Number:</u> ___________

Initial Temperature of Pouch: ____________

Final Temperature
at end of crystallization: ____________

Describe the crystals
(shape, growth rate, size, etc.)

Cooling Graph



Sketch of Crystals

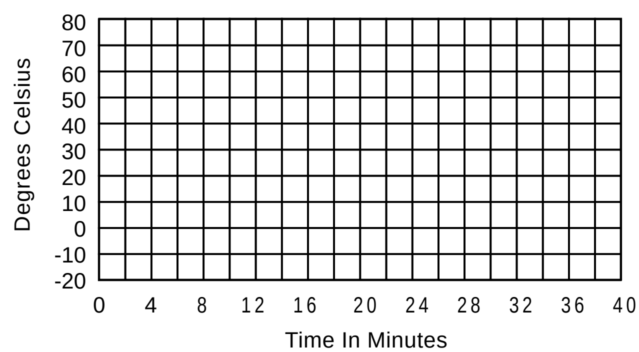
<u>Test Number:</u> ___________

Initial Temperature of Pouch: ____________

Final Temperature
at end of crystallization: ____________

Describe the crystals
(shape, growth rate, size, etc.)

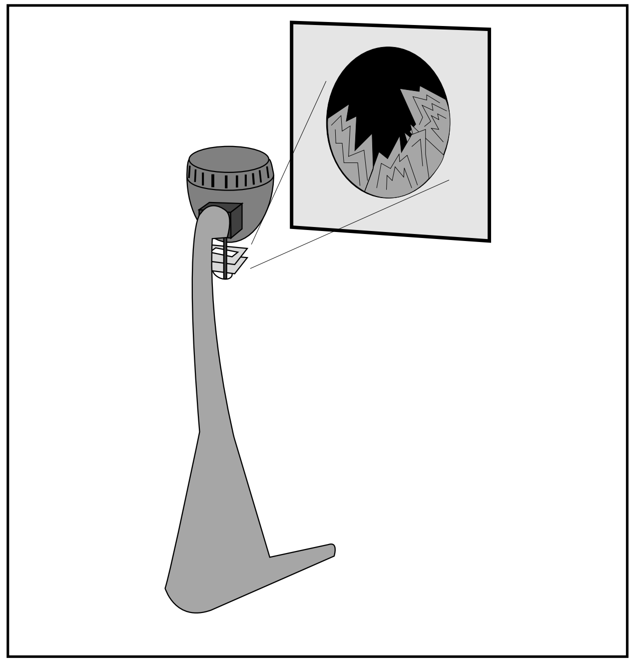
Cooling Graph



Sketch of Crystals

Activity 16

Microscopic Observation of Crystal Growth



OBJECTIVE:

To observe crystal nucleation and growth rate during directional solidification.

BACKGROUND:

Directional solidification refers to a process by which a liquid is transformed (by freezing) into a solid through the application of a temperature gradient in which heat is removed from one direction. A container of liquid will turn to a solid in the direction the temperature is lowered. If this liquid has a solute present, typically, some of the solute will be rejected into the liquid ahead of the liquid/solid interface. However, this rejection does not always occur, and in some cases, the solute is incorporated into the solid. This phenomenon has many important consequences for the solid. As a result, solute rejection is studied extensively in solidification experiments.

The rejected material tends to build up at the interface to form a mass boundary layer. This experiment demonstrates what happens when the growth rate is too fast and solute in the boundary layer is trapped.

Fluid flow in the melt can also affect the buildup of the mass boundary layer. On Earth, fluids that expand become less dense. This causes a vertical flow of liquid which will interfere with the mass boundary layer. In space, by avoiding this fluid flow, a more uniform mass boundary layer will be achieved. This, in turn, will improve the uniformity with which the solute is incorporated into the growing crystal.

PROCEDURE:

Observations of Mannite*

Step 1. Place a small amount of mannite on a microscope slide and place the slide on a hot plate. Raise the temperature of the hot plate until the mannite melts. **Caution: Be careful not to touch the hotplate or heated slide. Handle the slide with forceps.**

MATERIALS NEEDED:

Bismarck Brown Y**
Mannite (d-Mannitol)
$HOCH_2(CHOH)_4CH_2OH$*
Salol (Phenyl Salicylate)
$C_{13}H_{10}O_3$**
Microprojector
Student microscopes (alternate to microprojector)
Glass microscope slides with cover glass
Ceramic bread and butter plate
Refrigerator
Hot plate
Desktop coffee cup warmer
Forceps
Dissecting needle
Spatula
Eye protection
Gloves
Marker pen for writing on slides

Step 2. After melting, cover the mannite with a cover glass and place the slide on a ceramic bread-and-butter plate that has been chilled in a refrigerator. Permit the liquid mannite to crystallize.

Step 3. Observe the sample with a microprojector. Note the size, shape, number, and boundaries of the crystals.

Step 4. Prepare a second slide, but place it immediately on the microprojector stage. Permit the mannite to cool slowly. Again, observe the size, shape, and boundaries of the crystals. Mark and save the two slides for comparison using student microscopes. Forty power is sufficient for comparison. Have the students make sketches of the crystals on the two slides and label them by cooling rate.

Observations of Salol

Step 5. Repeat the procedure for mannite (steps 1-4) with the salol, but do not use glass cover slips. Use a desktop coffee cup warmer to melt the salol. It may be necessary to add a seed crystal to the liquid on each slide to start the crystallization. Use a spatula to carry the seed to the salol. If the seed melts, wait a moment and try again when the liquid is a bit cooler. (If the microprojector you use does not have heat filters, the heat from the lamp may remelt the salol before crystallization is completed. The chemical thymol ($C_{10}H_{14}O$) may be substituted for the salol. Avoid breathing its vapors. Do not substitute thymol for salol if student microscopes are used.)

Step 6. Prepare a new salol slide and place it on the microprojector stage. Drop a tiny seed crystal into the melt and observe the solid-liquid interface.

Step 7. Remelt the salol on the slide and sprinkle a tiny amount of Bismarck Brown on the melt. Drop a seed crystal into the melt and observe the motion of the Bismarck Brown granules. The granules will make the movements of the liquid visible. Pay close attention to the granules near the growing edges and points of the salol crystals. How is the liquid moving?

NOTES ON CHEMICALS USED:

Bismarck Brown Y

Bismarck Brown is a stain used to dye bone specimens for microscope slides. Because Bismarck Brown is a stain, avoid getting it on your fingers. Bismarck Brown is water solulable.

Mannite (d-Mannitol)

$HOCH_2(CHOH)_4CH_2OH$

Mannite has a melting point of approximately 168° C. It may be harmful if inhaled or swallowed. **Caution: Wear eye protection and gloves when handling this chemical. Conduct the experiment in a well ventilated area.**

Salol (Phenyl Salicylate)

$C_{13}H_{10}O_3$

It has a melting point of 43° C. It may irritate eyes. **Caution: Wear eye protection.**

QUESTIONS:

1. What happens to crystals when they begin growing from multiple nuclei?

2. Are there any differences in crystals that form from a melt that has cooled rapidly and from one that has cooled slowly? What are those differences?

3. What happens to the resulting crystals when impurities exist in the melt?

4. What caused the circulation patterns of the liquid around the growing crystal faces? Do you think these circulation patterns affect the atomic arrangements of the crystals?

5. How do you think the growth of the crystals would be affected by growing them in microgravity?

FOR FURTHER RESEARCH:

1. Design a crystal growing experiment that could be flown in space. The experiment should be self-contained and the only astronaut involvement that of turning on and off a switch.

2. Design a crystal growing experiment for space flight that requires astronaut observations and interpretations.

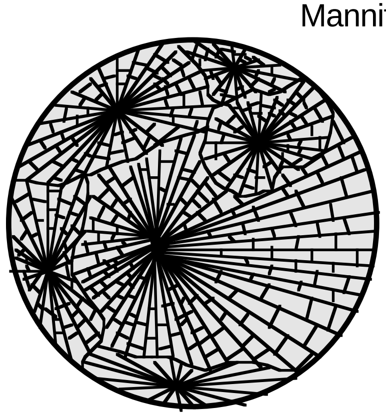
3. Research previous crystal growing experiments in space and some of the potential benefits researchers expect from space-grown crystals.

* Because of the higher temperatures involved, the mannite slides should be prepared by the teacher. If you wish, you may process the mannite slides at home in an oven. By doing so, you will eliminate the need for a hotplate. Mark the two prepared slides by cooling rate.

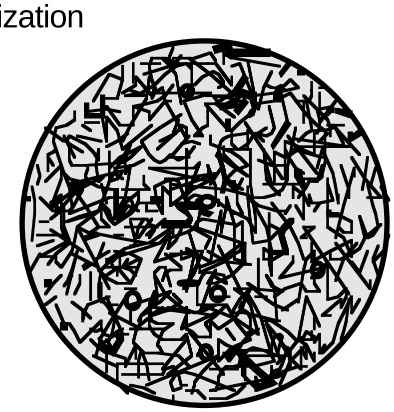
** Obtain the smallest quantities available from chemical supply houses.

Sample Microscope Sketches

Mannite Crystallization



Slow Cooling



Fast Cooling