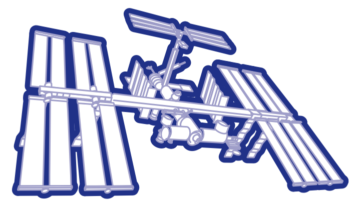
National Aeronautics and
Space Administration

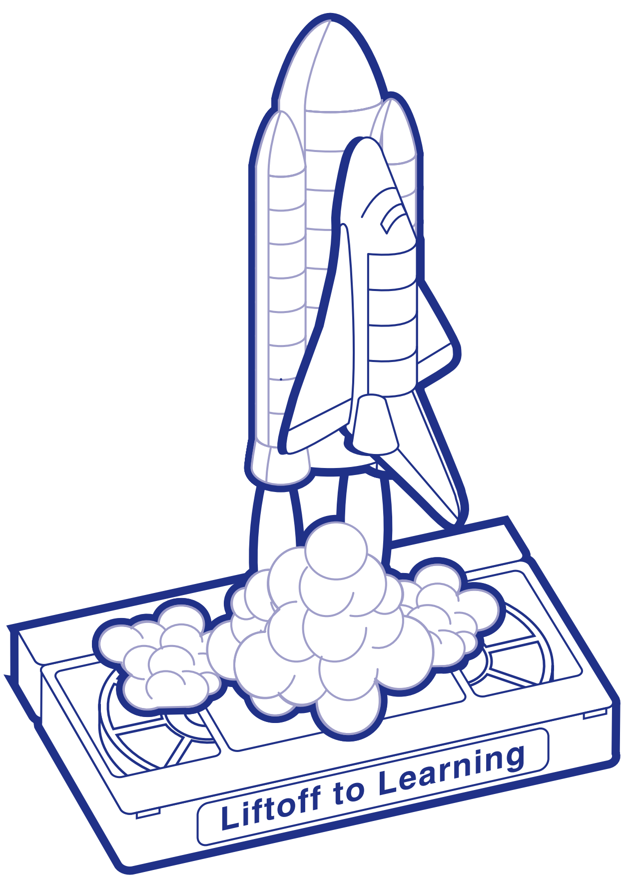
Educational Product	
Educators	Grades 5-12

Liftoff to Learning



Microgravity

A Videotape for Physical Science



Video Resource Guide

EV-1997-07-008-HQ

Video Synopsis

Title: Microgravity

Length: 23:24

Grade Level: 5-12

Subjects: Science, Mathematics, and Technology

Description: Astronaut Jan Davis narrates this program, which deals with the nature of microgravity, different ways of creating microgravity, and the four scientific disciplines in NASA's microgravity research program. Video footage from three Shuttle missions is included.

Science Standards:
Science as Inquiry
-Abilities necessary to do scientific inquiry
-Understanding about scientific inquiry
Physical Science
-Properties and changes of properties in matter
-Motions and forces
-Transfer of energy
-Chemical reactions

Mathematics Standards:
Problem Solving
Connections
Geometry and Spatial Sense

Introduction

This guide provides background information and activities to be used with the Liftoff to Learning series *Microgravity* videotape. In this program we talk about four scientific disciplines. We will also discuss them here, but first we will answer three important questions:

• What is microgravity?

• Why do we go to space to achieve it?

• Why is microgravity an ideal setting for conducting many types of scientific investigations?

What Is Microgravity?

For our purposes, the prefix “micro” means “small.” Microgravity, though, is not "small gravity." In a microgravity environment we reduce the local effects of gravity; we do not take away the force of gravity itself. A microgravity environment is one that will impart a small acceleration to an object. In practice, such accelerations will range from about one hundredth to about one millionth of the gravitational acceleration near the surface of Earth.

If you stepped off a roof five meters above Earth, you would land on the ground in just one second. In a microgravity environment with one hundredth of Earth’s gravitational acceleration, the same drop would take 10 seconds. In a one-millionth g (gravity) environment, the same drop would take 1,000 seconds, or about 17 minutes!

It is not necessary to go far out into space to create a microgravity environment. Such an environment can be created through the act of *free-fall*. Imagine riding in an elevator to the top floor of a tall building (see Figure 1).

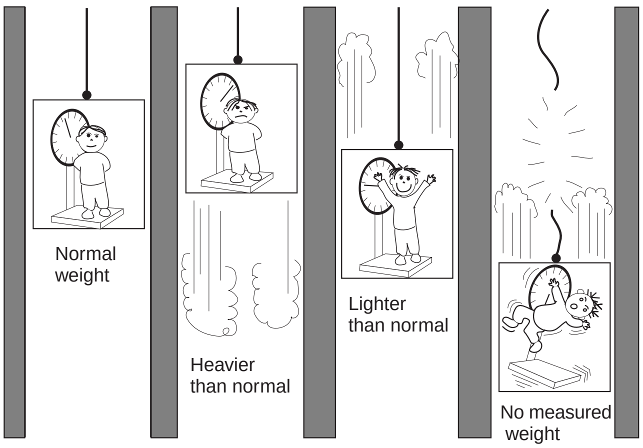


Figure 1

At the top the cables break, causing the car and you to fall to the ground. Since you and the elevator car are falling together, acted on only by gravity, you will float inside the car. In other words, you and the car are accelerating downward at the same rate. If a scale were present, your weight would not register because the scale would be falling too. This is shown in the right-hand column of Figure 1, and in cartoon version in the videotape.

Going to Space for Microgravity

Scientists create microgravity using a number of technologies, each depending upon the act of free fall. Drop towers and drop tubes are "high-tech" versions of the elevator analogy. Airplanes can achieve low-gravity by flying parabolic trajectories.
Figure 2 illustrates a single parabola. The airplane does about 40 of these on each flight. This is comparable to a giant roller coaster ride. As the plane goes across the top of the arc, everything inside is in free-fall.
Small rockets provide a third technology for creating microgravity (Figure 3). A *sounding rocket* follows a suborbital trajectory. One might call such a trajectory a higher and farther extension of the airplane ride. It is similar to a single very high hill on a roller coaster.

Unfortunately, all of these methods for creating microgravity share a common problem—time. After a few seconds or minutes of low-g, Earth gets in the way and the free-fall stops. To conduct longer term experiments, you have to go into Earth orbit. Even here, though, you are still using free-fall. You can think of an orbit as a yet higher and further extension of the rocket flight in Figure 3. This is explained in the videotape, using a cartoon to represent a "thought experiment." A baseball is thrown harder and harder from the top of a very high mountain, until it winds up in orbit.

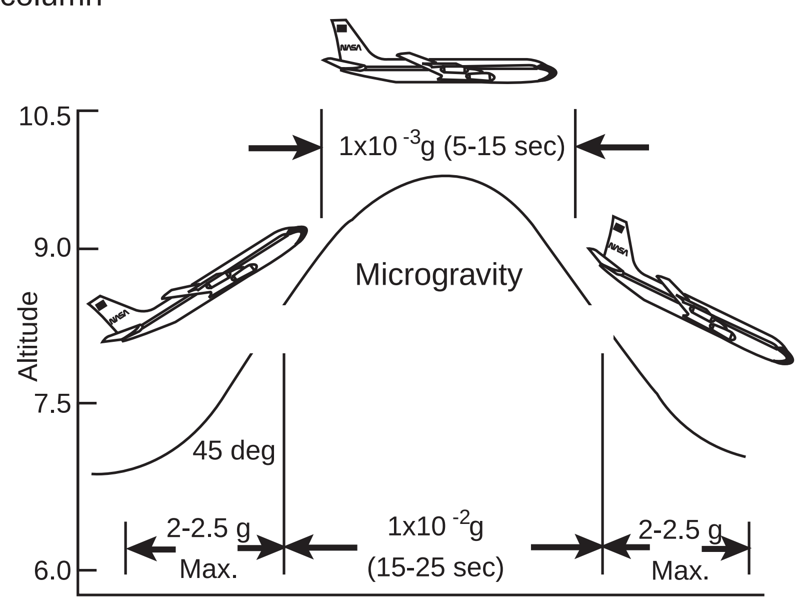


Figure 2

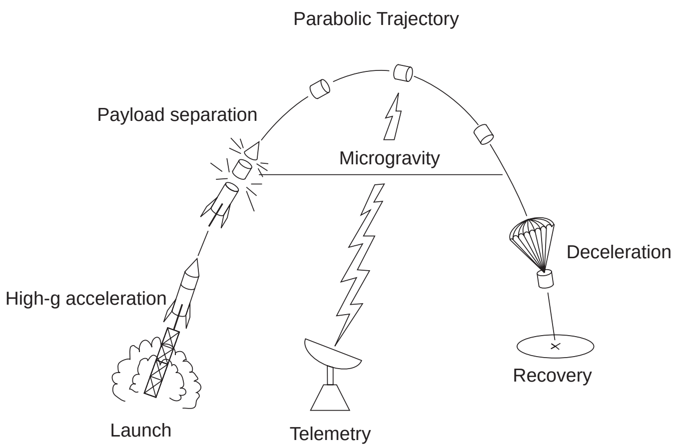


Figure 3

Microgravity—An Ideal Environment

Consider an important term: controls. In the scientific sense, this does not mean that you just change things however you want. You take one factor and change it carefully. You control, or keep constant, all the other factors. For example, you want to see what happens to iron at very high temperatures. You take two identical pieces of iron and heat one of them, keeping the other at a constant temperature. To the best of your ability, you keep things like pressure on the samples the same, varying only the temperature.

This is the sort of thing that scientists can now do with gravity. Let’s say that you want to know what happens to crystals, flames, liquids, or growing tissue when gravity's effects are almost completely eliminated.

Scientists can answer such questions on facilities like the Space Shuttle and the International Space Station. Microgravity, though, does more than provide opportunities to vary a force we usually consider as constant. In our gravity-dominated world, certain processes often stand out. Others are hard to observe.

Buoyancy-driven convection is a very important process on earth. It is so dominant that it makes other important phenomena, like *diffusion* and *surface tension*-driven flows, hard to study. Boiling water is a quite vigorous example of buoyancy-driven convection. The hot water and the air bubbles at the bottom of the pot have low density. They rise and the colder denser water at the top sinks. The water now at the bottom of the pot heats up; it rises along with more air bubbles. The cycle repeats.

Boiling is only one example. A mass of liquid or gas almost always has differences in density within it. It will have significant buoyancy-driven flows, except in a very low-gravity environment. Fluids can also be transported by diffusion and by differences in surface tension. However, such effects can be quite subtle. If you could not create microgravity, these effects would be extremely difficult to study. The videotape speaks about diffusion, using blue dye dispersing through a beaker of water as an example. In reality, diffusion is only one process at work here. The water itself is moving, and this helps spread the dye. Getting pure diffusive mass transport on Earth is much harder than this.

Four Disciplines

NASA’s microgravity research program is primarily interested in four scientific disciplines:

- fluid physics
- materials science
- biotechnology
- combustion science

Fluid Physics

Fluid physics is the study of the basic behavior of liquids and gases. On Earth we say that liquids take the shape of their containers. Water in a glass, for instance, takes the shape of the glass. In microgravity, liquids enter a new realm. Free from the effects of Earth's gravity, surface tension can take over. As seen in the video, free water forms into a sphere. In the first example, the drop is moving through the Shuttle. It forms a distorted and changing spherical shape. The drop is large and the surface tension is not great enough to keep a true spherical shape. Also, the viscosity of the water is not large enough to damp out the disturbances. It is easier to get a perfect sphere when the drop is small and the forces on it are well controlled. This can be done in an apparatus such as the *Drop Physics Module*. In this module, astronauts can study drops carefully. For example, they can maneuver drops with sound waves. The second drop in the videotape is being maneuvered in this way.

Experiments like these help scientists to study the basic physics of drops. They also help to assess the benefits of technologies like *containerless processing*. There are many other devices and methodologies that help us learn more about liquids and gases.

Materials Science

The field of materials science is extremely broad. Investigators in this field work with essentially all materials. One important topic in materials science is the study of crystals and how they form. Crystals are solids composed of atoms, ions, or molecules arranged in orderly patterns that repeat in three dimensions. Many of the unique properties of materials are a consequence of crystalline structure. 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.

On the Shuttle, one type of crystal growth process begins with a container filled with a solution. In the liquid is a small seed crystal. The seed is exposed to the solution, and the temperature of the crystal is lowered. As the solution near the crystal cools, the dissolved material reaches the saturation limit and begins depositing on the seed, and we see the crystal growing. This is represented in the video.The dots shown, of course, are tracers for atoms or molecules being deposited. The atoms or molecules themselves would be too small to see.

Biotechnology

The biotechnology program is comprised of three areas of research: protein crystal growth, mammalian cell culture and fundamentals of biotechnology. The video deals with one of these areas: protein crystal growth. These crystals are typically grown from solution, a process that involves fluids and changes in density. In a ground-based laboratory, *sedimentation* and buoyancy-driven convection can disrupt the growth process. This leads to defects that interfere in the precise determination of the protein's structure. But in a microgravity laboratory, superior crystals have been produced.

Combustion Science

A burning candle experiment on the Shuttle helps us to discuss and illustrate the processes of combustion. In the video the candle comes into the scene from the side (Figure 4). If you look carefully, you can see the candle as the igniter lights it.

On Earth or in space, the flame surface itself is where vaporized wax and oxygen mix at high temperature with the release of heat. The hot combustion products are less dense than the surrounding air. Thus, on Earth, buoyancy-driven convection develops. This action has the following effects:

- The hot reaction products are carried away, and fresh oxygen is carried toward the flame.
- To overcome the loss of heat due to buoyancy, the flame anchors itself close to the wick.
- The combination of anchoring and upward flow causes the flame to be shaped like a tear drop.

In microgravity there is no buoyancy-driven convection. Now the supply of oxygen and fuel vapor to the flame is controlled by the much slower process of molecular diffusion. The diminished supply of oxygen and fuel causes the flame temperature to be

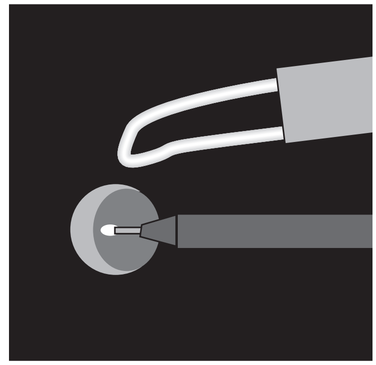


Figure 4

lowered. The flame anchors far from the wick and tends toward sphericity. However, some heat is lost to the top of the candle. The base of the flame is quenched, and only a portion of the sphere is seen.

TERMS

Buoyancy-Driven Convection: Convection created by the difference in density between two or more fluids in a gravitational field or in an accelerating frame not due to free-fall alone.

Containerless Processing: A process used in materials science. In certain experiments, serious problems arise because chemicals interact with the walls of their container. In normal gravity very small masses can sometimes be kept from container walls with magnetic fields. Microgravity offers the possibility of significant advances in containerless processing.

Convection: Energy and/or mass transfer in a fluid by means of bulk motion of the fluid.

Diffusion: Intermixing of atoms and/or molecules of solids, liquids and gases. The atoms or molecules of a certain type move from an area of high concentration to an area of low concentration.

Drop Physics Module: An important apparatus on the Shuttle during the United States Microgravity Lab missions (USML-1 and USML-2). It allows the manipulation and close study of water drops in microgravity.

Free-fall: Moving freely in a gravitational environment. This simply means that gravity, and nothing else, is causing acceleration.

Microgravity: An environment, produced by free-fall, that alters the local effects of gravity and makes objects seem weightless.

Sedimentation: The tendency of a dense material to "settle out of," or go to the bottom of, a mixture.

Sounding Rocket: "Sounding" is used here in the sense of "probing" or "looking into." A sounding rocket is used to make various observations without going into orbit.

Surface Tension: Tendency of the surface of a liquid to behave as if it were an elastic membrane. For example, certain insects, too dense to float in water, can stay on the surface of a pond because of surface tension.

Classroom Activities

The following hands-on activities can be used to demonstrate some of the concepts presented in this videotape.

Falling Coffee Cup

Materials
Styrofoam coffee cup
Sharp pencil
Catch basin or bucket
Water

Background
Scientists create microgravity using a number of technologies. This guide and the microgravity video mention drop tubes, drop towers, airplanes on parabolic trajectories, sounding rockets, and spacecraft. In Activity 1 we demonstrate microgravity much as it would occur in a drop tower. A cup and the water in it fall together. Before the cup is released, water drains from it. In free-fall the water no longer drains from the cup. There is some air resistance on the cup. In a drop tower this would be reduced by placing a shield around the cup. In a drop tube most of the air would be pumped out before the experiment; this is highly effective and very low g values can be obtained. In Activity 1, of course, we cannot eliminate the air. For our purposes, though, this is not important. The fall takes less than a second, and the air resistance does not build up to a significant value.

Procedure
1. Fill the cup with water.
2. With a pencil, punch a hole near the bottom of the cup. Be sure to hold the cup over the catch basin as you do this.
3. Observe how gravity causes the water to pour through the hole and into the basin.
4. Place a finger over the hole. Refill the cup with water. What do you think will happen if you drop it?
5. Drop the cup from a height of 2 meters into the catch basin or bucket.

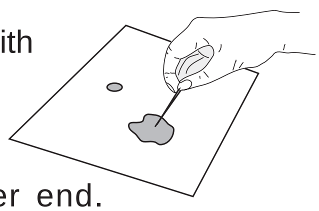
Discussion
1. Does the water pour from the hole as the cup falls? Why or why not?
2. Simulate a sounding rocket or a plane on a parabolic trajectory. Don't just drop the cup. Toss it gently through the air. You may find that the cup wants to rotate. Don't allow this; keep it upright. Compare the effect of the cup and its contents with a plane on a parabolic trajectory. Which method, dropping or tossing, was more successful for you? Explain.

Surface Tension and Water Drops

Materials
Water
Liquid dish detergent
Toothpicks
Eyedroppers
Wax paper squares (20 x 20 cm)

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. On Earth we cannot study water drops as closely and thoroughly as the astronauts using the Drop Physics Module can, however, we are able to do some interesting observations.

Procedure



1. Fill an eyedropper with water. Carefully squeeze the bulb of the dropper to form a drop at the other end. Make sketches of the shape of the drop as it forms.
   Note: If a faucet is available, it can prove very useful here. Start the water flowing. Then slow it down gradually. You should be able to adjust the faucet to form water drops quite slowly. Then you can make your observations and sketches. The large drops from the faucet may allow you to make more accurate observations than the small ones from the dropper. Which are more spherical--the large drops or the small ones?
2. Place a small drop of water on a square of wax paper. Make a sketch of its shape as it appears from both the top and the side. Measure the drop's diameter and height. Some extra care may be needed here. Often the zero mark on a ruler is not exactly at the end of the ruler. To solve this problem, you could simply use a piece of paper. Put the zero mark right on one corner, then put centimeter marks up the edge.
3. Add a second drop of water to the first and again sketch its shape and measure its diameter and height.
4. Continue adding water to the first drop. What happens to the shape? At various stages, try to pull the drop over the surface of the wax paper with the dropper. At some point, friction overcomes surface tension. The drop will break up, not allowing you to pull all of it. How large a drop can you pull in one piece?
5. Add a small amount of liquid detergent to the drop. Write a brief description of what happens to the drop.

Discussion
1. According to the video and this resource guide, what shape does water take in a microgravity environment? Does it always take this shape? Why or why not?
2. What did the detergent do to the surface tension of the water in number 5 above?
3. Do all liquids have the same surface tension? Would they all act the same way on the wax paper?

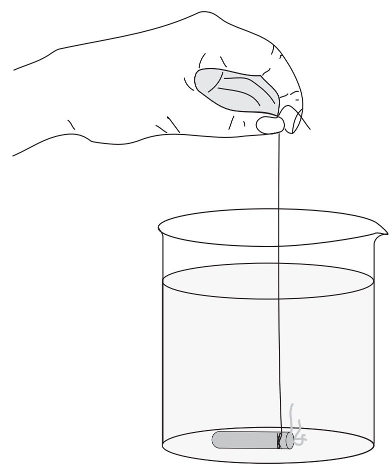
Gravity-Driven Fluid Flow

Materials
Large (500 ml) glass vial
Small (5 to 10 ml) glass vial
Thread
Food coloring
Salt
Spoon and stirring rod

Background
In the video, we saw the importance of gravity for some types of fluid flow. In particular, we talked about buoyancy-driven convection and diffusion. Activity 3 creates buoyancy-driven convection and makes it visible. A less dense fluid (e.g. fresh water) will rise through a more dense fluid (e.g. salt water). Food coloring makes this process visible.

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

Discussion
1. Is diffusion taking place in this activity? Justify your answer. (Hint: Read the definition of diffusion given in this guide.)
2. Think about boiling in microgravity. You have a pot of water on a hot plate. The water on the bottom gets very hot and starts to boil. What happens now? How will this be different from what happens in your kitchen?
3. Could you do this activity without using salt? For example, could you use only fresh water at different temperatures? Could you use liquids other than water?



Rapid Crystallization

Materials

In this activity, crystal growth will be studied chemical hand warmers. The hand warmers are sold in camping and hunting stores.

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

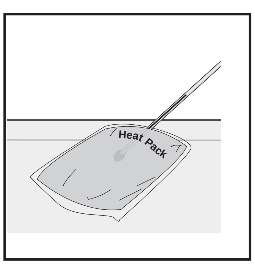
Background

The video compares crystal growth in 1 g (normal earth gravity) to crystal growth in microgravity. In this activity, students do another comparison: crystal growth at different temperatures. In the hand warmer there is a supersaturated solution of sodium acetate. When a student clicks the metal tab in the warmer, the sodium acetate begins to come out of solution and form crystals. The students do this at different temperatures and record the results

Procedure

Note: This activity involves small groups of students. Because the activity uses 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.

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



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 ^{o} 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.
3. Using the data sheet on the next page, the students should observe the crystal growth in the pouch.
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.

Discussion

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?

Heat Pack Experiment Student Data Sheet

Name: ______________________________

Test number: [   ]

Initial temperature of pouch: __________

Final temperature
at end of crystallization: ____________

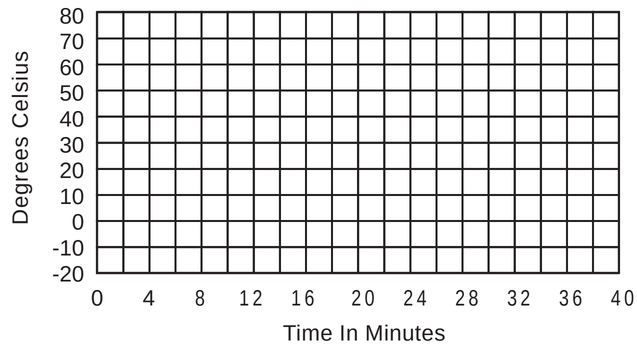
Describe the crystals (shape, growth rate, size, etc.):

____

____

____

Cooling Graph



Sketch of Crystals

Test number: [   ]

Initial temperature of pouch: __________

Final temperature
at end of crystallization: ____________

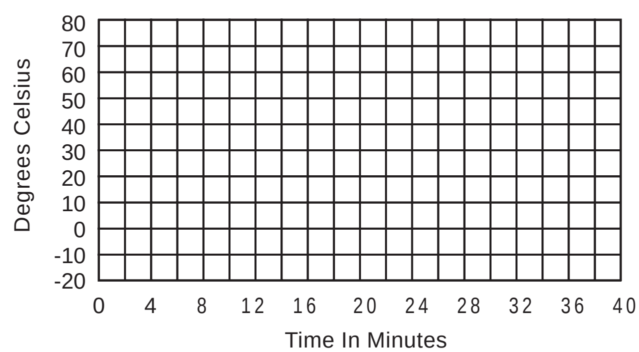
Describe the crystals (shape, growth rate, size, etc.):

____

____

____

Cooling Graph



Sketch of Crystals

Candle Flames

Materials

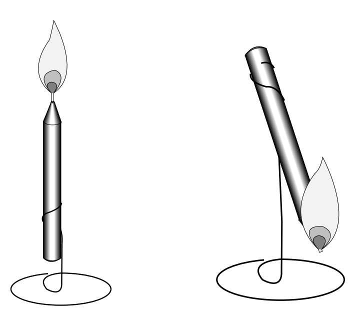
Birthday candles (several)
Matches
Balance beam scale (0.1 gm sensitivity or greater)
Clock with second hand or stopwatch
Wire cutter/pliers
Wire
Small pan to collect dripping wax

Background

Gravity is very important to combustion. The temperature and shape of a flame on the Shuttle are different from what we normally experience on Earth. In this activity, students observe effects of gravity on a candle flame.

Procedure

1. Form candle holders from the wire as shown in the diagram. Determine and record the weight of each candle and its holder.
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.
3. Weigh the candle and holder and calulate how much mass was lost.
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.)



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.
6. Weigh the candle and holder and calculate how much mass was lost.

Discussion

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?
6. What do you think would happen if you burned a candle in microgravity? For example, about how much mass loss do you think might occur in one minute with the same candle in microgravity? Would the candle burn as long? What would the flame look like?

References

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Other web sites of interest:
http://www.jsc.nasa.gov
http://www.hq.nasa/gov/office/olmsa

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Astronaut Biography

N. Jan Davis (Ph.D.), Host/Narrator of "Microgravity" Liftoff to Learning Video

Jan Davis was born in Cocoa Beach, Florida, but considers Huntsville, Alabama, to be her hometown. She earned bachelor of science degrees in applied biology from the Georgia Institute of Technology and in mechanical engineering from Auburn University, and a master of science degree and a doctorate in mechanical engineering from the University of Alabama, Huntsville. Her graduate research was on the long-term viscoelastic strength of composite pressure vessels. As an aerospace engineer for NASA's Marshall Space Flight Center in Huntsville, she was responsible for the structural analysis and verification of Shuttle payloads. She was also the lead engineer for the redesign of the solid rocket booster external tank attach ring. Davis was named an astronaut in 1987 and has flown twice in space as a mission specialist aboard STS-47 and STS-60.

The "Microgravity" video also features footage from the following missions:
the First International Microgravity Laboratory, the First U.S. Microgravity Laboratory, and the Second U.S. Microgravity Laboratory (IML-1, USML-1, and USML-2). These were Shuttle missions STS-47, STS-50, and STS-73.

NASA Liftoff to Learning
Microgravity

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Video Resource Guide

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