

National Aeronautics and
Space Administration

Educational Product

Educators
& Students

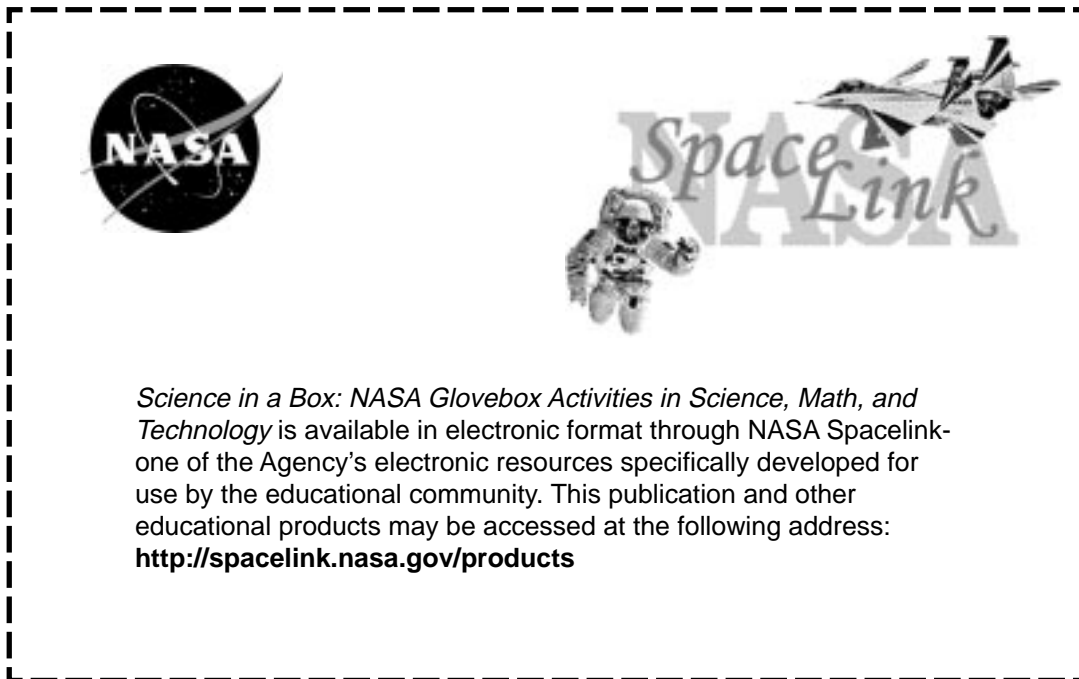
Grades 9-12

EG-2003-01-009-GRC

Science in a Box

An Educator Guide with NASA Glovebox Activities in
Science, Math, and Technology





Science in a Box: NASA Glovebox Activities in Science, Math, and Technology is available in electronic format through NASA Spacelink—one of the Agency’s electronic resources specifically developed for use by the educational community. This publication and other educational products may be accessed at the following address:
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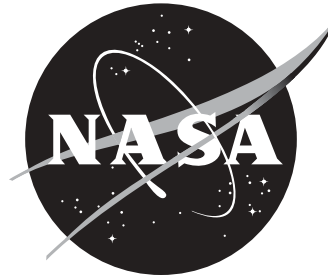
Top Picture: This picture shows how the finished project looks once students build the Glovebox using the directions in this educator guide.

Bottom Left Picture: Payload Specialist Fred Leslie makes use of the versatile U.S. Microgravity Laboratory (USML-2) glovebox to conduct a fluids investigations with the Oscillatory Thermocapillary Flow Experiment (OTFE).

Bottom Right Picture: The Glovebox shown here flew on the first U.S. Microgravity Laboratory (USML-1). The Glovebox (GBX) has an enclosed working space which minimizes the contamination risks to both Spacelab and experiment samples. It is a multi-user facility that supported 16 experiments in fluid dynamics, combustion sciences, crystal growth, and technology demonstration on USML-1.

Science in a Box

NASA Glovebox Activities in Science, Math, and Technology



National Aeronautics and Space Administration

**Office of Biological and Physical Research
Physical Sciences Research Division**

**NASA Headquarters
Education Office**

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**In Memory of
Pamela L. Mountjoy
NASA Education Programs Officer**



Introduction

The Space Shuttle and International Space Station provide a unique microgravity environment for research that is a critical part of NASA's mission to improve the quality of life on Earth, and to enable the health and safety of space explorers for long duration missions beyond our solar system. Such research falls under the purview of the Office of Biological and Physical Research (OBPR). In orbital spacecraft, like the Space Shuttle and the International Space Station, some of the effects of gravity are reduced, creating a weightless environment known as microgravity. The microgravity environment simplifies certain biological and physical properties and processes, allowing scientists to understand them better, and making them simpler to model. The advances from microgravity research result in advances in the fields of biomedical research, biotechnology, designer drugs, industrial applications, materials processes, environmental protection, and diagnostic tool development.

This educator's guide was designed to be used by a science educator and a technology educator in partnership. The technology educator can assign the building of the glovebox as a class project. The science educator would then use the glovebox to conduct the experiments contained in this guide. The activities were designed to supplement many curriculum topics by using the Space Shuttle's Glovebox as a motivational tool to capture students' interest. (A microgravity glovebox has nothing in common with the glove box of an automobile.) The glovebox is a piece of hardware that provides a sealed laboratory setting. Astronauts use glove inserts to operate the experiment inside this laboratory. Because this hardware is not discipline specific, many types of research can be done in it. As a result, the activities in this guide are appropriate for the math, biology, chemistry, and technology classroom.

Where ever possible activities include connections to spaceflight glovebox investigations and other microgravity research. The idea behind this guide is to bridge the gap between laboratory science research and the classroom and to expose students to the purpose and use of real space research. Constructing and using a classroom glovebox will engage students and spark their enthusiasm while giving them the real world connection. Like all NASA educational products, the activities in this guide are designed to be used in partial fulfillment of *The National Science Education Standards* by the National Research Council, the *Curriculum and Evaluation Standards for School Mathematics* by the National Council of Teachers of Mathematics, and the *Standards for Technological Literacy, Content for the Study of Technology* by the International Technology Education Association. Be sure to consult the standards matrix on the following pages to help identify which activities and which sections most meet your curriculum needs and interests.

How to Use This Guide

Science in a Box: NASA Glovebox Activities in Science, Math, and Technology is organized in to three parts to help teachers find the activities and information they seek. Part 1 contains background information. There is an overview of gravity and microgravity, followed by information about the facilities used to create a microgravity environment. The next section covers background information about the purpose of microgravity research. There are sections about the history of the development of gloveboxes and an explanation of their purpose. The last section of Part 1 contains information about the Microgravity Science Glovebox that was designed for the International Space Station as a more advanced facility. Described here is information about the improved capabilities and detailed specifications of its parts and subsystems.



Part 2 of this guide provides assembly instructions for constructing a classroom glovebox based on the Space Shuttle Middeck Microgravity Glovebox. Plans, explanations, materials, and CAD drawings illustrate how to build the glovebox. This project is an excellent technology challenge, having students work in teams on box fabrication, video hookup, a fan, switch, and a lighting system. Once complete, students can perform their experiments in an environment that simulates a real middeck glovebox.

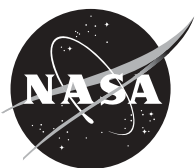
A standards matrix at the front of the guide is included to help teachers select which activities will best meet their curriculum topics based on the national standards for science, mathematics, and technology. Before beginning the activities in the classroom glovebox, we strongly recommend engaging students in some fundamental science skills that give them a chance to understand the process of science, such as, collection of real data using actual sensors. Activities found in Part 3 in the Fundamental Science Section use sensors with graphing calculators. These activities are not done inside the classroom glovebox. The remaining activities are organized into two sections; those that can be implemented inside a classroom glovebox (glovebox Activities) and relate to research done in actual glovebox investigations, and those that relate to space research (Space



National Education Standards Correlations

Standards for Technological Literacy: Content for the Study of Technology, Grades 9-12, 2000.

| Technology Standard | Capillary- driven Heat Transfer | Colloidal Suspensions | Damping | Diffusion Activity with Data Analysis | Displacement- Time Graphs Using the Motion Detector | Finding the Value of "g" on an Incline | Floating Solids Between Liquids | Free Fall |
|--|--|--------------------------|---------|---|---|--|--|--------------|
| Nature of Technology | | | | | | | | |
| <i>scope of technology</i> | ● | ● | ● | ● | | ● | | ● |
| <i>core concepts of technology</i> | | | ● | ● | | | | |
| <i>connections between technology and other fields</i> | ● | ● | ● | ● | ● | ● | | ● |
| Technology and Society | | | | | | | | |
| <i>cultural, social, economic, and political effects of technology</i> | ● | | ● | ● | | ● | | |
| <i>effects of technology on the environment</i> | | | ● | | | | | |
| <i>role of society in development of technology</i> | | | ● | | | | | |
| <i>influence of technology on history</i> | | | | | | ● | | |
| Design | | | | | | | | |
| <i>attributes of design</i> | ● | ● | ● | | | | | |
| <i>engineering design</i> | ● | ● | ● | | | | | |
| <i>problem solving</i> | ● | ● | ● | ● | | ● | | ● |
| Abilities of a Technological World | | | | | | | | |
| <i>apply the design process</i> | | | ● | | | | | |
| <i>use and maintain technological products, systems</i> | | | ● | | | | | |
| <i>assess the impact of products and systems</i> | | | ● | | | | | |
| The Designed World | | | | | | | | |
| <i>medical technologies</i> | | | ● | | | | | |
| <i>agricultural technologies</i> | | | | | | | | |
| <i>energy and power technologies</i> | ● | | ● | | | | | |
| <i>information and communication technologies</i> | | | | | | ● | | ● |
| <i>transportation technologies</i> | | | | | | | | |
| <i>manufacturing technologies</i> | | | ● | ● | | ● | | ● |
| <i>construction technologies</i> | | | ● | | | | | |



| Growing Protein Crystals | Nucleation of Crystals from Solution | Oscillatory Dynamics of Single Bubbles | Oscillatory Heat Flow Experiment | Plant Growth in Microgravity | Spectroscopy | The Inertial Balance | Velocity-Time Graphs Using the Motion Detector | Viscosity of a Fluid | Wetting Characteristics |
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National Science Education Standards, by The National Research Council, Grades 9-12, 1996.

| Science Standard | Capillary-driven Heat Transfer | Colloidal Suspensions | Damping | Diffusion Activity with Data Analysis | Displacement-Time Graphs Using the Motion Detector | Finding the Value of "g" on an Incline | Floating Solids Between Liquids | Free Fall |
|---|--------------------------------|-----------------------|---------|---------------------------------------|--|--|---------------------------------|-----------|
| Science as inquiry | | | | | | | | |
| <i>abilities to do inquiry</i> | ● | ● | ● | ● | ● | ● | ● | ● |
| Physical Science | | | | | | | | |
| <i>structure and properties of matter</i> | ● | ● | | ● | | | ● | |
| <i>chemical reactions</i> | | | | | | | | |
| <i>motions and forces</i> | ● | | ● | ● | ● | ● | ● | ● |
| <i>conservation of energy and increase in disorder</i> | ● | ● | ● | ● | | ● | | ● |
| <i>interactions of energy and matter</i> | ● | | ● | ● | | ● | | ● |
| Life Science | | | | | | | | |
| <i>matter, energy, and organization in living systems</i> | | | | | | | | |
| <i>behavior of organisms</i> | | | | | | | | |
| Earth and Space Science | | | | | | | | |
| <i>energy in the Earth System</i> | | | ● | | | ● | | ● |
| Science and Technology | | | | | | | | |
| <i>abilities of technological design</i> | ● | | | | | | | ● |
| <i>understandings about science and technology</i> | ● | ● | ● | | | | | |
| Science in Personal and Social Perspectives | | | | | | | | |
| <i>science and technology in local, national, and global challenges</i> | ● | ● | ● | | | | | |
| History and Nature of Science | | | | | | | | |
| <i>science as a human endeavor</i> | ● | ● | ● | ● | ● | ● | ● | |
| <i>nature of scientific knowledge</i> | ● | ● | ● | ● | ● | ● | ● | ● |
| <i>historical perspectives</i> | ● | ● | | | | ● | ● | |



| Growing Protein Crystals | Nucleation of Crystals from Solution | Oscillatory Dynamics of Single Bubbles | Oscillatory Heat Flow Experiment | Plant Growth in Microgravity | Spectroscopy | The Inertial Balance | Velocity-Time Graphs Using the Motion Detector | Viscosity of a Fluid | Wetting Characteristics |
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Principles and Standards for School Mathematics, by The National Council of Teachers of Mathematics, Grades 9-12, 2000.

| Mathematic Standard | Capillary-driven Heat Transfer | Colloidal Suspensions | Damping | Diffusion Activity with Data Analysis | Displacement-Time Graphs Using the Motion Detector | Finding the Value of "g" on an Incline | Floating Solids Between Liquids | Free Fall |
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| Number and Operations | | | | | | | | |
| representing numbers | | | ● | | | ● | | ● |
| meanings of operations | | | ● | | | ● | | ● |
| compute fluently | | | ● | | | ● | | ● |
| Algebra | | | | | | | | |
| patterns | | | ● | | ● | ● | | ● |
| represent and analyze mathematical models | | | ● | ● | ● | ● | | ● |
| analyze change | | | ● | ● | | ● | | ● |
| Measurement | | | | | | | | |
| measurable attributes | | | ● | ● | | ● | ● | ● |
| appropriate techniques, tools, formulas | | | ● | ● | | ● | | ● |
| Data Analysis and Probability | | | | | | | | |
| formulate questions | | | ● | ● | | ● | | ● |
| select and use statistical methods | | | ● | ● | ● | ● | | ● |
| develop and evaluate | | | ● | ● | | ● | | ● |
| Problem Solving | | | | | | | | |
| build new math knowledge | | | ● | ● | | ● | | ● |
| solve problems that arise | | | ● | ● | | ● | | ● |
| apply appropriate strategies | | | | ● | ● | ● | | ● |
| monitor and reflect on process | | | ● | ● | ● | ● | | ● |
| Reasoning and Proof | | | | | | | | |
| recognize reasoning and proof | | | ● | | | ● | | |
| make and investigate conjectures | | | ● | | | ● | ● | |
| develop and evaluate arguments and proof | | | ● | | | | | |
| use reasoning and proof | | | ● | | | ● | | ● |
| Communication | | | | | | | | |
| organize through communication | | | ● | | ● | ● | | ● |
| communicate math thinking to peers, others | | | ● | | ● | ● | | ● |
| evaluate math thinking of others | | | | | ● | ● | | ● |
| use language of math | | | ● | | ● | ● | | ● |
| Connections | | | | | | | | |
| use connections | | | ● | ● | ● | ● | | ● |
| build on each other to produce a whole | | | | ● | | ● | | |
| apply math in contexts outside of math | | | ● | ● | ● | ● | | ● |
| Representation | | | | | | | | |
| use representations | | | ● | ● | | ● | | ● |
| apply and translate to solve problems | | | ● | ● | | ● | | ● |
| use representations to model world phenom. | | | ● | ● | ● | ● | | ● |



| Growing Protein Crystals | Nucleation of Crystals from Solution | Oscillatory Dynamics of Single Bubbles | Oscillatory Heat Flow Experiment | Plant Growth in Microgravity | Spectroscopy | The Inertial Balance | Velocity-Time Graphs Using the Motion Detector | Viscosity of a Fluid | Wetting Characteristics |
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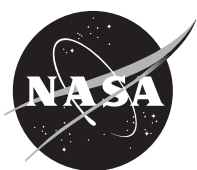


Classroom Activities with Grade Level Appropriateness and Each Related Subject Area

| Activities | Page | Grade Levels | Targeted Subjects | | | | |
|---|------|--------------|-------------------|--------------|------------------|-----------|---------|
| | | | Algebra | Algebra Trig | Physical Science | Chemistry | Biology |
| <i>Capillary-Driven Heat Transfer</i> | 71 | 9–12 | | | ● | | |
| <i>Colloidal Suspensions</i> | 74 | 9–12 | | | ● | ● | ● |
| <i>Damping</i> | 76 | 10–12 | II | ● | ● | | |
| <i>Diffusion Activity with Data Analysis</i> | 49 | 9–12 | | | | | ● |
| <i>Displacement-Time Graphs Using the Motion Detector</i> | 52 | 9–12 | I, II | | ● | | |
| <i>Finding the Value of "g" on an Incline</i> | 59 | 10–12 | II | ● | ● | | |
| <i>Floating Solids between Liquids</i> | 81 | 9–12 | | | ● | | |
| <i>Free Fall</i> | 55 | 10–12 | I, II | ● | ● | | |
| <i>Growing Protein Crystals</i> | 93 | 9–12 | | | | ● | ● |
| <i>Nucleation of Crystals from Solution</i> | 83 | 9–10 | | | ● | | ● |
| <i>Oscillatory Dynamics of Single Bubbles</i> | 87 | 9–12 | | | ● | ● | |
| <i>Oscillatory Heat Flow Experiment</i> | 85 | 9–12 | | | ● | | |
| <i>Plant Growth in Microgravity</i> | 97 | 9–12 | | | | | ● |
| <i>Spectroscopy</i> | 61 | 10–12 | II | ● | ● | | ● |
| <i>The Inertial Balance</i> | 102 | 9–12 | I | | ● | | |
| <i>Velocity-Time Graphs Using the Motion Detector</i> | 67 | 9–12 | I, II | | ● | | |
| <i>Viscosity of a Fluid</i> | 107 | 9–12 | II | | ● | | |
| <i>Wetting Characteristics</i> | 90 | 9–10 | | | ● | | ● |



Part 1. Background Information



This guide provides science, mathematics, and technology teachers and students with information and related activities about microgravity. Some of the included activities relate to basic scientific principles and theories. Other activities have a direct scientific tie-in with past microgravity research on Shuttle missions. Each of these activities has information about Shuttle missions and how and why the research was conducted. This research is important because it allows scientists to investigate the fundamental states of matter—solid, liquid, and gas—and the forces that affect them in a microgravity environment.

What is Gravity?

Gravity is such a part of our lives that we rarely think about it, even though it affects everything we do. Any time we drop or throw something and watch it fall to the ground, we see gravity in action. Gravity anchors us to the ground, prevents the air we breathe from escaping into space, and keeps the Earth orbiting around the Sun.

More than 300 years ago the great English scientist Sir Isaac Newton published the important generalization that mathematically describes this universal force of attraction that is gravity. Newton was the first to realize that gravity extends well beyond the domain of Earth. The basis of this stems from the first of three laws he formulated to describe the motion of objects. Newton's first law, originally developed by Galileo as the law of inertia, states that objects in motion travel in a straight line at a constant velocity unless acted on by an outside force. Because the planets were known to travel in curved paths, Newton reasoned that these paths are the result of an outside force acting upon them. That force, he concluded, is the same force that causes an apple to fall to the ground—gravity.

Newton's discovery of the universal nature of the force of gravity was remarkable in that he was able to interpret the force that causes the fall of an apple to Earth as the same force that causes planets to orbit the Sun. This is recognized as one of the major achievements of human intellectual thought. He was able to see beyond the obvious and familiar to develop an explanation of the way things act and react, thus changing the way scientists understood motion.

Although gravity is a universal force, there are times when it is not desirable to conduct scientific research under its full influence. In these cases, scientists perform their experiments in microgravity—a condition in which the effects of gravity are greatly reduced, sometimes described as “weightlessness.” This description brings to mind images of astronauts and objects floating inside an orbiting spacecraft; seemingly free of Earth's gravitational field, but these images are misleading. The pull of the Earth's gravity actually extends far into space and is what keeps satellites and the Moon in orbit around our world. Earth's gravitational pull on you is reduced as you move away from Earth. How much gravity's effects change as you move away from Earth is easy to figure out using the relationship $1/r^2$, where r is the distance (radius) from Earth's center to the surface, 6,378 km (3,963 mi). Where you are standing now, $r=1$. If you travel from the center of Earth to a distance $2r$ (12,756 km), Earth's gravitational pull drops to $1/2^2$ or $1/4$ the gravity felt on Earth's surface. To reach a point where Earth's gravity is reduced to one-millionth of that on the Earth's surface — $1/1,000^2$ or $1/1,000,000$, one would have to be 6.37 million kilometers (nearly 4 million miles) away from the Earth (or approximately 17 times farther away than the Moon). The gravitational force on the Shuttle orbiting the Earth at 270 km (168 miles) is about 92% of the gravitational



force on the Earth's surface. Since spacecraft usually orbit between 200-550 km (125-340 miles) above the Earth's surface, there must be another explanation for why gravity appears to be "off."

What is Microgravity?

Any object in free fall experiences microgravity conditions. Free fall occurs when an object falls toward the Earth with an acceleration equal to that due to gravity alone (approximately 9.8 m/s^2 or 32 ft/s^2 on the Earth's surface). This acceleration due to gravity alone is referred to as a 1g environment.

The term "microgravity" can be interpreted in a number of ways, depending on the context. In measurement systems, the prefix micro- (μ) means one-millionth. By this definition, a microgravity environment is one that imparts a net acceleration of one-millionth of the gravity that is felt on Earth. The microgravity environment (μg) referred to by most scientists is defined as an environment where some of the effects of gravity are reduced compared to what is experienced at the Earth's surface. The root word comes directly from the Greek *mikros* meaning "small." Most people use this meaning to refer to microgravity as an environment of small gravity levels or low gravity.

As mentioned previously, spacecraft in orbit around the Earth are bound in orbit by the Earth's gravitational field. They are less than 1/10 of one Earth-radius above the surface. So, how does one experience microgravity at this small distance? It can be explained using a falling elevator. If an elevator were to plunge toward the ground, it and everything (you included) in it would fall together. The elevator car and its contents would all be accelerating downward at the same rate, which is due to gravity alone. (For illustration purposes, disregard the effects of air friction and the safety mechanisms on the elevator). If you were able to lift your feet off the floor of the elevator, you would float inside the car. A spacecraft does the same thing that the plunging elevator car does. It falls toward Earth due to gravitational attraction, but at the same time it is moving forward because of the thrust from the rocket engines, during launch.

The microgravity environment associated with the Space Shuttle, or any orbiting spacecraft, is a result of being "on orbit," which is a state of continuous free fall around the Earth. A circular orbit results when the centripetal acceleration of uniform circular motion is the same as that due to gravity alone. (Centripetal acceleration = v^2/r ; where v is the minimal or critical velocity of the orbiting object required to stay on orbit and r is the distance from the center of the object to the center of the Earth.) Because of the Earth's gravitational pull on the Shuttle, it needs to maintain a critical velocity of 27,800 km/hr (17,300 miles/hr) to stay on orbit.

Microgravity Platforms

A microgravity environment provides the basis for a unique laboratory in which scientists can investigate the three fundamental states of matter: solid, liquid, and gas. Microgravity conditions allow scientists to observe and explore phenomena and processes that are normally masked by the effects of Earth's gravity. Researchers use four types of platforms to create microgravity environments: drop facilities, aircraft, sounding rockets, and orbiting spacecraft.



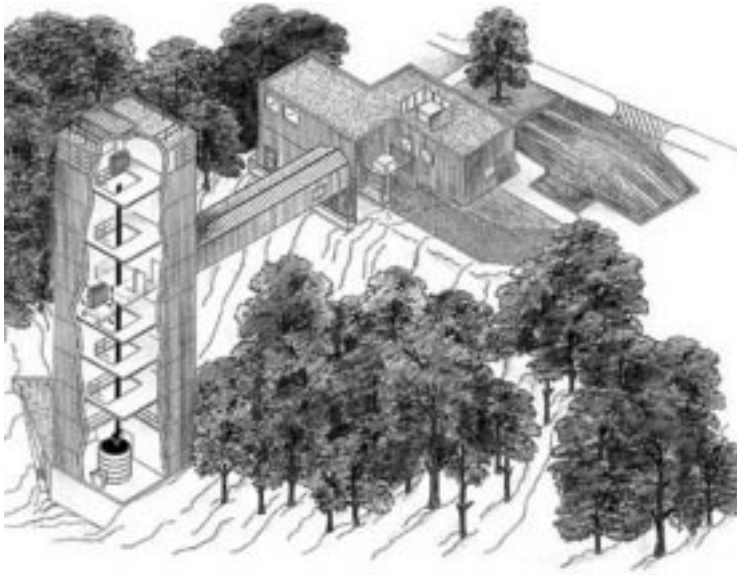


Figure 1. Schematic of the NASA Glenn Research Center's 2.2 second drop tower.

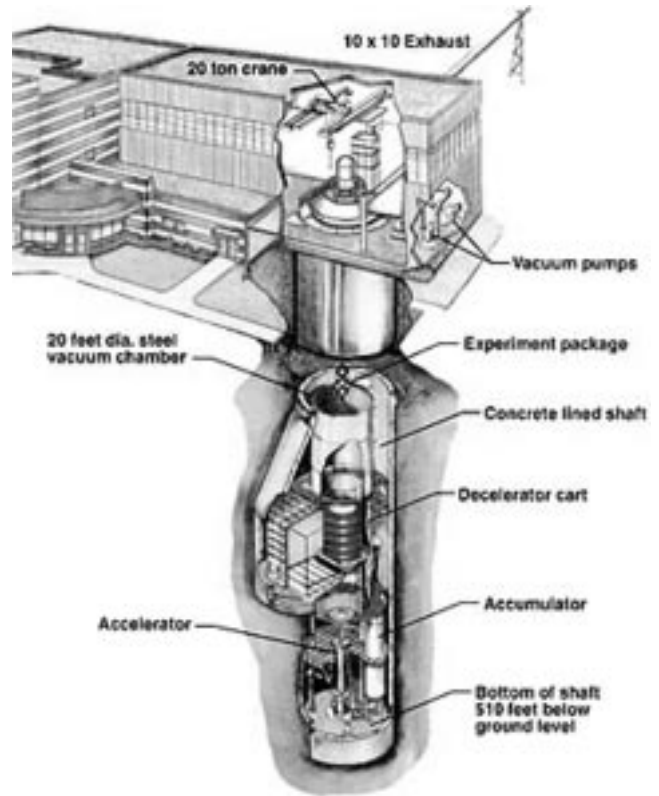


Figure 2. Schematic of the 5.2 second drop facility at NASA Glenn Research Center.

Drop Facilities

A drop tower is a long vertical shaft used for dropping experiment packages, enabling them to achieve microgravity conditions through free fall. Various methods are used to minimize or compensate for air drag on the experiment packages as they fall. Glenn Research Center in Cleveland, Ohio has two drop facilities that can accommodate experiments which need only a short amount of time (2.2-seconds or 5.2-seconds) in microgravity conditions or which are test runs of experiments that will later be performed for longer periods in an aircraft, rocket, or spacecraft. The 2.2 second drop facility (Figure 1.) is 24 m (79 ft) tall. The 5.2 second drop facility (Figure 2.) is 132 m (433 ft) deep. The longest drop time currently available, about 10-seconds, is at a 490 m deep vertical mine shaft in Japan that was converted into a drop facility. Because the distance traveled increases with the square of the time, a 10-second drop tower has to be 100 times taller than a 1-second drop tower. However, experiments that need longer periods of microgravity conditions require different facilities.

Aircraft

Microgravity can be created through the use of special airplanes. These aircraft create microgravity conditions by flying in steep curves, or parabolas. NASA's KC-135 is one of these aircraft. The aircraft has padded walls, foot restraints, handholds, and devices for securing the



Figure 3. The inside of NASA's KC-135.



experiments during flight (Figure 3). During research campaigns, the KC-135 can fly 40–60 parabolas, each lasting for 60–65 seconds. First, the plane climbs at a 45-degree angle to the horizon. This is called a pull up. Then the pilot cuts the engines back so they just make up for the drag. The plane and everything inside coast up, then down, in a parabolic curve. This tracing of a parabola is called a push over. The plane then descends at a 45° angle, called a pull out. As the plane starts to dive, the pilot increases the power to regain control, then pulls up to repeat the process (Figure 4). During the pull up

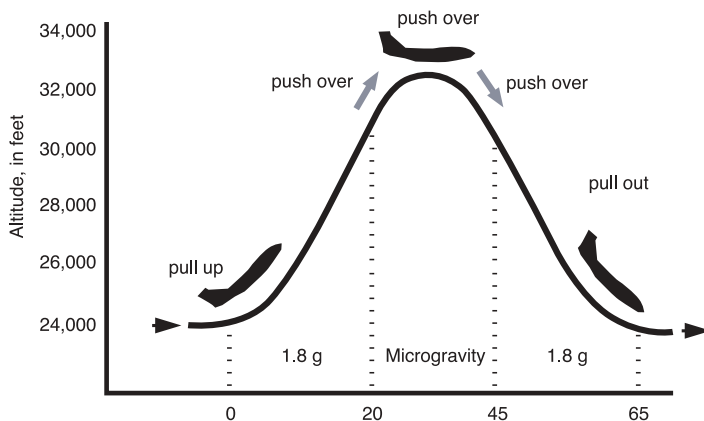


Figure 4. Parabolic Flight Characteristics.

and pull out segments, the crew and experiments experience accelerations of about 2 g's. During the parabola, the net accelerations drop as low as 0.015 g for about 15 seconds. Reduced gravity conditions created by the same type of parabolic motion described can be experienced on the series of "floater" hills that are usually located at the end of roller coaster rides and when driving over swells or steep hills in the road.



Figure 5. The Black Brant XII Sounding Rocket.

Sounding Rockets

Like the KC-135, sounding rockets follow a parabolic curve. However, unlike the plane, the rockets are unmanned and travel above the atmosphere. They are basically divided into two parts—a solid fueled rocket motor and the payload. The payload is the section that carries the instruments to conduct the experiment and send the data back to Earth. NASA currently uses 14 different sounding rockets. The rockets come in a variety of sizes from the single-stage Super Arca which stands 2 m (7 ft) tall, to the four-stage Black Brant XII which stands at 20 m (65 ft) tall. These rockets can carry scientific payloads of various weights to altitudes from 48 km (30 mi) to more than 1,287 km (800 mi). Following the launch, as the rocket motor uses its fuel, the experiment compartment remotely detaches from the vehicle

and continues into space to begin conducting the experiments. The experiment will experience up to 6 minutes of free fall before entering the atmosphere and parachuting back to the ground.

The flight profile of a sounding rocket follows a parabolic trajectory and the flight time is less than 30 minutes. However, invaluable data can be received in this short flight time. Sounding rockets produce higher quality microgravity conditions for longer periods of time than parabolic flight aircraft, but the disadvantage is that the experimenter cannot fly with the experiment and, as a result, the experiment's sophistication is often limited.

NASA launches an average of 30 sounding rockets each year with a success rate of about 98%. They are launched from established sites such as Wallops Flight Facility, Virginia; White Sands Missile



Range, New Mexico; and Poker Flat Research Range, Alaska; as well as sites in Canada, Norway, and Sweden.

Orbiting Spacecraft

Although drop facilities, airplanes, and sounding rockets can create a microgravity environment, they all share a common problem. They only offer a few seconds or minutes of free fall. To conduct longer scientific investigations, another type of facility is needed, a spacecraft.

In order to understand how to establish microgravity conditions for extended periods of time, one must first understand what keeps a spacecraft in orbit. Two common assumptions are the rocket engines fire and hold the spacecraft in orbit or there is no gravity in space.



Figure 6. The Space Shuttle at take-off.

The first assumption is theoretically possible, but no craft could carry enough fuel to maintain its altitude for more than a few minutes.

The second assumption is also incorrect. As stated earlier, at the altitude the Space Shuttle, as well as the International Space Station, typically orbit the Earth, the gravitational pull by the Earth is about 90% of what it is at the Earth's surface.

In a previous section, it was established that Isaac Newton reasoned that planets travel in curved paths because of gravity's presence. Newton expanded on this conclusion about gravity and hypothesized how an artificial satellite could be made to orbit Earth. He envisioned a very tall mountain extending above Earth's atmosphere so that air friction would not be a factor. He then imagined a cannon at the top of the mountain firing cannonballs parallel to the ground. Two forces acted on each cannonball as it was fired. One force, due to the explosion of the black powder, propelled the cannonball straight outward. If no other force were to act on the cannonball, the shot would

travel in a straight line at a constant velocity. But Newton knew that a second force would act on the cannonball; gravitational attraction would cause the cannonball's path to bend into a curved path ending at Earth's surface.

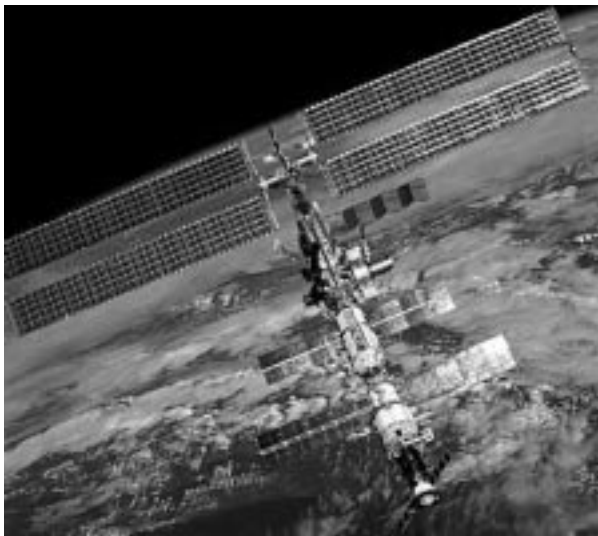


Figure 7. The International Space Station.

Newton considered how additional cannonballs would travel farther from the mountain each time the cannon fired using more powder. With each shot, the path would lengthen and soon the cannonballs would disappear over the horizon. Eventually, if one fired a cannonball with enough energy, it would fall entirely around the Earth. The cannonball would be in orbit around the Earth. Provided no force other than gravity interfered with the cannonball's motion, it would continue circling the Earth in that orbit.



This is how the Space Shuttle and the International Space Station stay in orbit. The Shuttle is launched on a path that arcs above Earth so that the orbiter travels at the right speed to keep it falling while maintaining a constant altitude above the Earth's surface. Because the Shuttle and the International Space Station are in a state of free fall around the Earth, they and their contents are in a microgravity environment.

The Space Shuttle can carry experiments for up to 17 days. The International Space Station has the capacity to fly experiments for years. The U. S. Laboratory on the International Space Station is named *Destiny*. This is the module where the Microgravity Science Glovebox will be located.



Figure 8. Astronaut Cady Coleman using a Glovebox during USML-2

What is a Glovebox?

When you put science in a box, all kinds of things are possible. Of course, this box is a good deal more than just an ordinary box. Astronauts can place their hands inside it, add and remove experiment components, and manipulate experiments within it all while the box remains sealed. It's not magic, but it is a powerful research tool. This device, called a glovebox, offers an enclosed work space for investigations that may be affected by– or may adversely affect– a spacecraft's crew or the spacecraft environment (Figure 8.).

The basic glovebox design includes an airlock for equipment installation and removal. Experiments can be mounted to the floor or walls of the glovebox, elevated by jacks, or held in place by magnetic bases or strips. Specially sealed openings equipped with rugged gloves allow an astronaut conducting an experiment to put his or her hands inside the sealed chamber. The heavy gloves can be exchanged for surgical ones to accommodate more delicate procedures. Window openings allow activity inside the chamber to be viewed by the astronaut and recorded by cameras. Air pressure levels inside the chamber are maintained at lower levels than outside air pressure so that if an accidental leak of gases occurs air will be suctioned into the chamber rather than leaked out of it. A special air filtering system provides backup in case of a major failure. These precautions are necessary because some glovebox experiments involve hazardous substances.



Figure 9. The Microgravity Science Glovebox Rack.



Why Use a Glovebox?

The glovebox has been ideal for experiments that do not require very large or specialized equipment. The ability of the glovebox to offer containment, the opportunity to manipulate experiment components on orbit, shorter development time for experiments that can make use of its multiuser resources, and the chance to test the operation of hardware prior to making costly investments have proven valuable over the years. Glovebox investigations are smaller in size, less hardware intensive, but more crew intensive than the typical experiment flown on the Shuttle or the International Space Station.

Special care is required when scientists wish to study certain kinds of substances. When toxic substances are in use, three levels of containment are required to ensure safety. The experimenter provides the first level of containment, such as sealed ampoules. The glovebox provides two levels of containment—a sealed chamber and an air filter system. With these barriers in place, the glovebox offers an extra margin of safety in studies of materials that may be toxic if touched, ingested, or aspired.

Many experiments require adjustments during flight. An investigation being done in a glovebox allows the astronaut conducting the experiment to place his or her hands inside the glovebox and make fine adjustments to the equipment for the experiment so that a variety of factors can be examined. Instead of only being able to study one variable per flight, the glovebox allows for the study of multiple variables. This ability to manipulate an experiment has proven invaluable.

Glovebox designers were thinking about the needs of a broad range of experiments during its development. Built-in resources such as power, lighting, ventilation and instruments for data and video collection and downlinking mean that researchers do not need to be concerned with devising and developing these tools for their individual experiments, thereby cutting down on the time it takes to prepare an experiment for flight. These multiuser resources make it possible for glovebox investigations to be flown in two to three years as opposed to the normal seven to eight years for non-glovebox experiments.

Gloveboxes in Space

The first glovebox was designed by the European Space Agency (ESA) in an agreement with NASA that allowed ESA to use the facility on the Space Shuttle with no exchange of funds between the two agencies. The success of the glovebox program is largely linked to the adaptability of the facility. The design has allowed the glovebox concept to be adapted to both the Shuttle's Spacelab module and the middeck area and to the Priorda module of the Russian Space Station Mir.

NASA's success in partnering with ESA on gloveboxes has led to the design and development of a new facility, called the Microgravity Science Glovebox (MSG), for investigations on the International Space Station (ISS). Experience gained by operating successful glovebox programs on the Shuttle and Mir has proved to be valuable in determining the science requirements for the MSG.

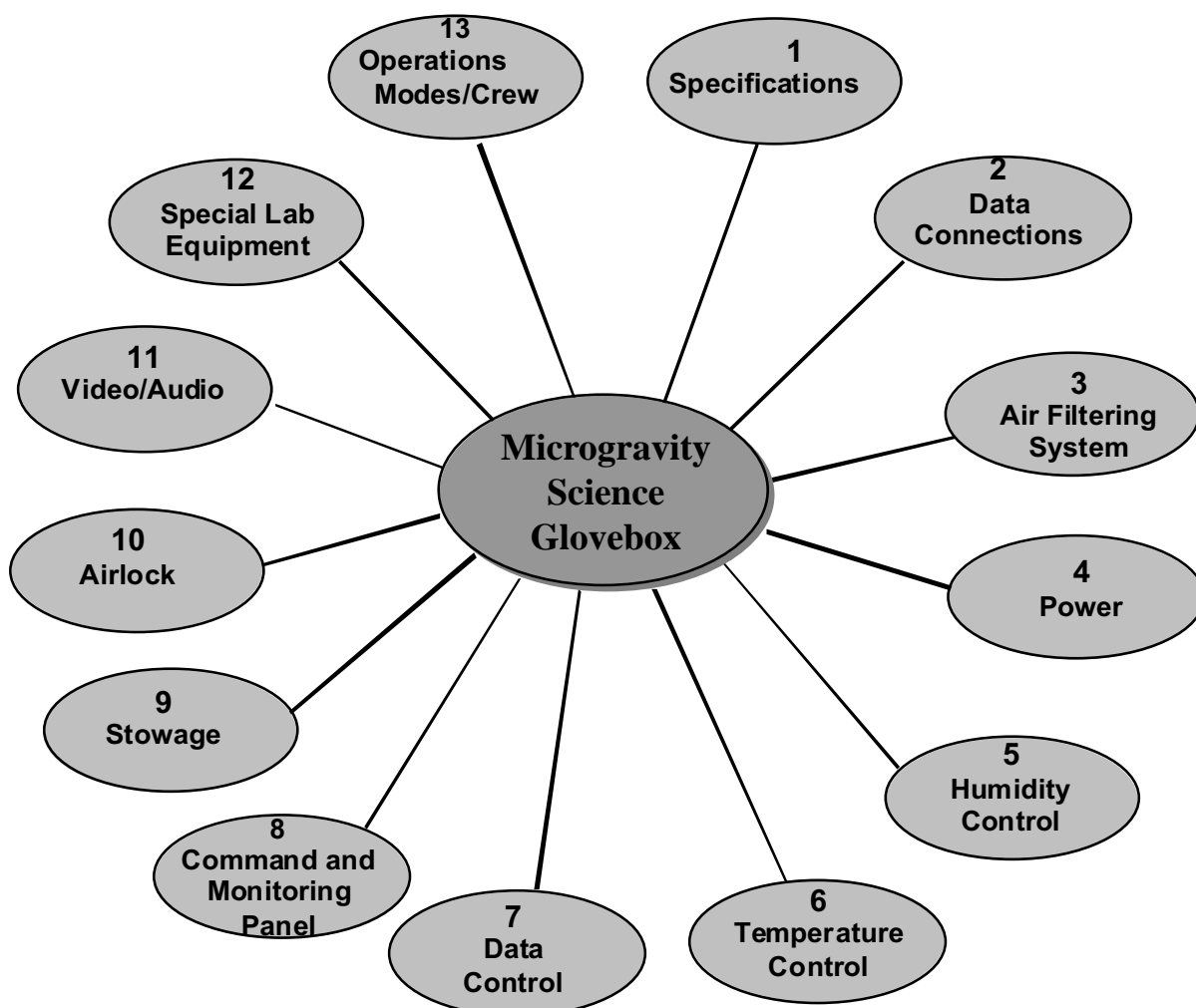


The Microgravity Science Glovebox

The Microgravity Science Glovebox on the International Space Station (ISS) provides a sealed work area for experiments conducted in the unique, near-weightless, microgravity environment aboard the ISS. The MSG supports experiments in biotechnology, combustion science, fluid physics, fundamental physics, and materials science.

The MSG is a versatile facility designed to accommodate substantial experimental hardware in an interactive configuration. This approach allows for crew setup, operation, and monitoring with participation from ground-based investigators via data and video links. The facility provides a large enclosed work volume, power, data, video, vacuum connections, heat rejection, stowage, filtered air, gaseous nitrogen, lighting, physical positioning and hold-down attachments. The system is designed to be a versatile, multi-function workbench for performing investigations that require the microgravity environment of the ISS and crew interaction.

The work volume of the MSG is nearly six times (255 liters) the work volume of the Middeck Glovebox (44 liters) flown on the Space Shuttle. It will occupy a double, floor-to-ceiling rack inside the bus-size



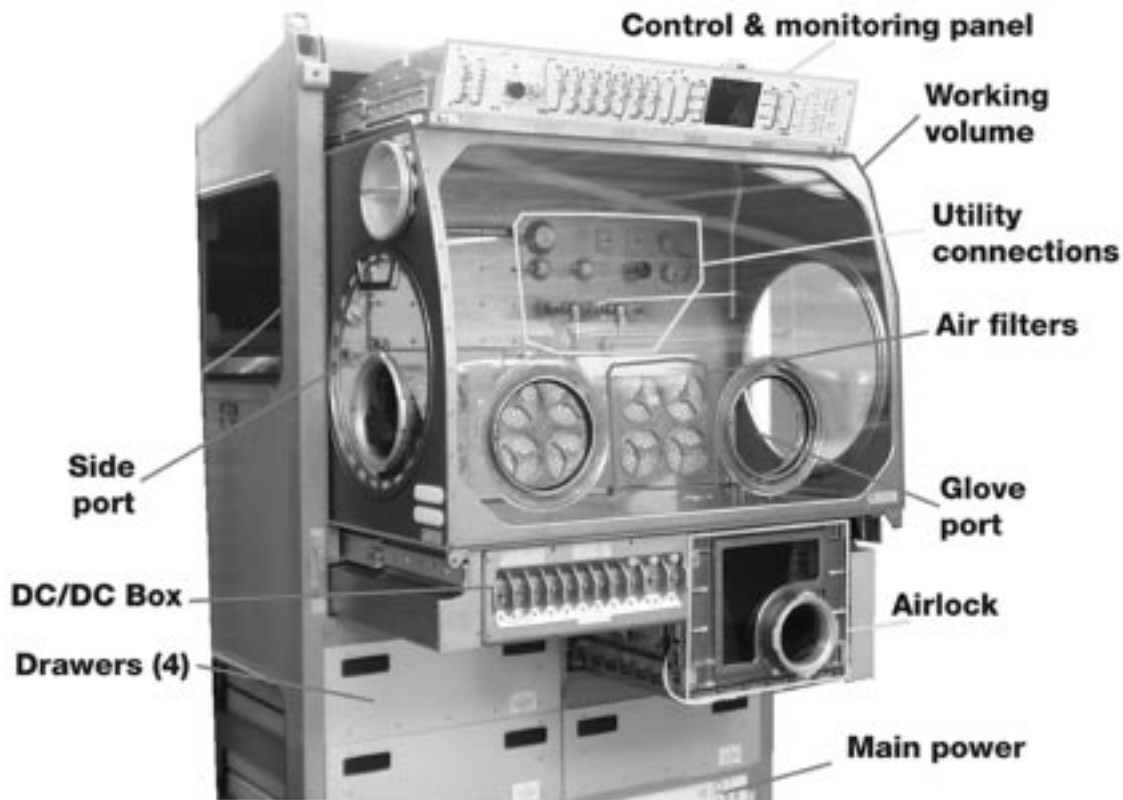


Figure 10. Key components of the MSG.

Destiny module. This more sophisticated glovebox holds larger experiments; allows investigators to control their experiments from the ground; is equipped with a microscope inside the chamber; has the capacity to send video footage to scientists on Earth; and has a cold plate that can be used to cool hot furnaces and samples. The next section describes in more detail the major technologies of the MSG.

The Microgravity Science Glovebox Subsystems

The diagram on the previous page shows the subsystems of the Microgravity Science Glovebox (MSG). Details on each of the subsystems follows.

1. Specifications

Rack: An International Standard Payload Rack (ISPR) made of aluminum that has been modified and strengthened to accommodate a large work volume.

Work volume: The main element of the MSG core facility is a large sealed and environmentally controlled enclosure with access ports, windows, and glove ports to contain investigations that

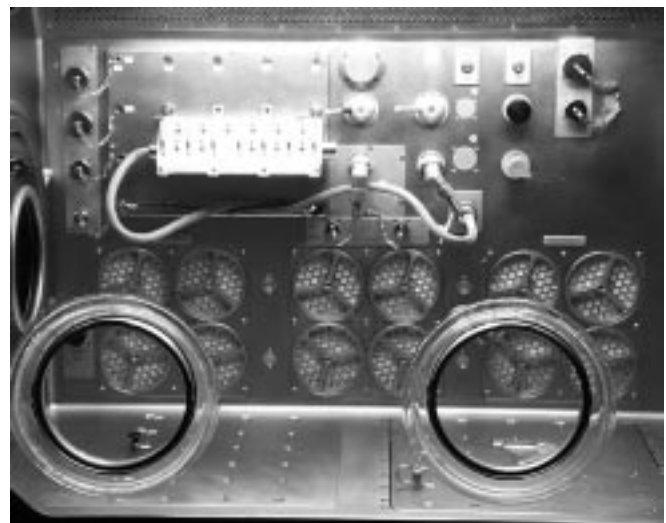
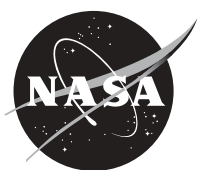


Figure 11. Work volume and containment features of the MSG.



require multiple levels of containment. The size of the work volume is 255 liters (~9 cu ft). The interior dimensions are 93.4 cm wide, 66.6 cm high, 54.8 cm lower depth (36.8 in x 26.2 in x 21.6 in), and 36.9 cm (14.5 in) upper depth.

Containment: The MSG provides two levels of containment for investigations. The first level is the physically sealed structure of the work volume. The second is the negative pressure induced by the filtered air system.

Ports: Two glove ports are located on the front window of the work volume. They are the main ports used by the crew to perform gloved operations inside the MSG. On each side of the work volume is a large removable access port for loading, unloading, and initial setup of investigations. These ports are 40.6 cm (16 in) in diameter. A glove port is also located in each side access port.

Window: The front of the work volume is a large observation window made of Lexan™. It is scratch resistant coated. The window is curved inward at the top to provide more strength for the window and increase the visibility and usability of the command and monitoring panel (CMP).

Fluid System: Gaseous nitrogen is available for investigations. Gaseous nitrogen can be connected directly to the investigations via a .64 cm (1/4 in) quick-disconnect coupling located at the rear wall of the work volume. The MSG does not require gaseous nitrogen itself. A vacuum vent and vacuum exhaust lines are available for investigations. The vacuum vent and exhaust are connected directly to the investigations via a 1.27 cm (1/2 inch) quick-disconnect coupling located at the rear wall of the work volume.

Illumination: At the top inside of the work volume are three banks of lights (left, center and right), which provide the light source for the general illumination system. Each bank has 12 bulbs. Together they can provide a maximum of 975 lux of illumination. The lighting level is variable from 0 up to 975 lux. A spotlight is also available for doing precision tasks that require additional light.

2. Data Connections

Several data connections are available inside and one outside the work volume. A MIL-BUS-1553B connection is available both inside and outside the work volume. An analog/digital data system is also available. Eight 16-bit analog and eight digital data acquisition channels can be monitored and downlinked. Eight digital data output channels are available for investigation commanding. All of



Figure 12. The MSG side port.



Figure 13. The MSG utility connections.



these data connections are routed through the standard payload computer (SPLC) for downlink and uplink to the ISS data system. This two-way data communication connection with the ISS data system allows for ground commanding of the facility and the investigations. Investigation science data can also be downlinked. Facility health and status data and verification of facility commanding (both from ground and orbit) can also be downlinked. Two medium rate Ethernet connections are inside the work volume. They do not pass through the SPLC but are connected directly to the Station. These Ethernet connections are for connecting an investigation or a laptop computer to the Station for a more direct and faster communication connection with the ground telescope center or other payloads on orbit.



Figure 14. The MSG Air Filters

3. Air Filtering System

The work volume's air filtration system helps to provide a 100,000 one-half micron particles per square foot cleanroom capability. The 12 filters are a three-part HEPA, charcoal, and catalyst unit. The HEPA removes particles greater than 0.3 microns in diameter, the charcoal filters gases, and the catalyst converts carbon monoxide to carbon dioxide.

4. Power

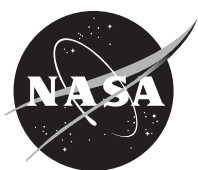
One thousand watts of 120 VDC power are available for high power investigations. Two hundred watts of power are available at 28 VDC. Other voltages available are ± 12 VDC and 5 VDC.

5. Humidity Control

The work volume is designed to maintain an inside humidity between 25% and 70%.

6. Temperature Control

The filtered air circulating inside the work volume is passed through an air/water heat exchanger. The air is then returned to the work volume. The water passing through the heat exchanger is connected to the ISS moderate temperature-cooling loop (MTCL). The water from the MTCL first passes through this air/water heat exchanger before continuing on to other components. Thus, the air temperature inside the work volume is expected to very closely follow the temperature profile of the MTCL (approximately 18° to 20° Celsius or 64° to 68° F) if no heat is rejected inside the work volume. If heat is rejected inside the work volume, the heat exchanger is sized such that 200 Watts of heat can be removed via filtered airflow. After the filtered air/water heat exchanger, the MTCL cooling water flows through a 33 cm by 38 cm (13 in by 15 in) coldplate located in the bottom of the work volume. This coldplate has provisions for investigations directly mounted to it. It can remove 800 Watts of heat with a surface temperature of 50° Celsius (122° F). After leaving the work volume coldplate, the MTCL cooling water passes through several other components in the rack requiring cooling. Most of these components are electrical or data system items. The only exception being another air/water heat exchanger, called the avionics air assembly (AAA), which cools circulating



air in the rear of the rack. Together, the cooled filtered air and the coldplate can remove 1000 Watts of heat from an investigation. One thousand Watts is the total power available to investigations.

7. Data Control

The MSG communicates through its MIL-BUS-1553B connection to the ISS. The 1553 passes ground commanding for the facility and investigations to MSG and returns facility health and status and investigation science data from the MSG. Investigations can communicate via MIL-BUS-1553B or RS-422 to the SPLC, which processes the information for communication to the ISS. The medium rate Ethernet is a direct connection between either investigations or a laptop computer and the ISS. The MSG SPLC is not connected to the Ethernet.

8. Command and Monitoring Panel

Attached to the top of the work volume is the command and monitoring panel (CMP). The CMP is the human-machine interface for controlling the data system of the MSG. It also is the interface for controlling work volume illumination and work volume airflow rate. Health and status parameters are monitored on a screen and by LEDs.

9. Stowage

Four drawers are located under the work volume for stowage of facility ancillary equipment such as spares and consumables. Stowage for investigations and the support hardware for each investigation will be located outside of the MSG rack.

10. Airlock

An airlock is provided for transfer of items to the work volume and as a temporary work platform. The airlock is the holding area for the investigations. Its primary function is to ensure that two levels of containment can be provided while transferring items into and out of the work volume while in sealed mode.

Features of the airlock include:

- a. Accommodate investigations and equipment module: 25.4 cm x 34.3 cm x 29.9 cm (10 in x 13.5 in x 11.8 in);
- b. One 10.16 cm (4 in) diameter access port;
- c. Continuously filtered air;
- d. Maintain negative pressure between airlock and ISS cabin;
- e. Sealing capability between work volume and airlock;
- f. Humidity control: 25-70% of 500 lux illumination;
- g. Maximum heat removal 35 Watts;
- h. Restraint of items via pip pins Standard Payload.

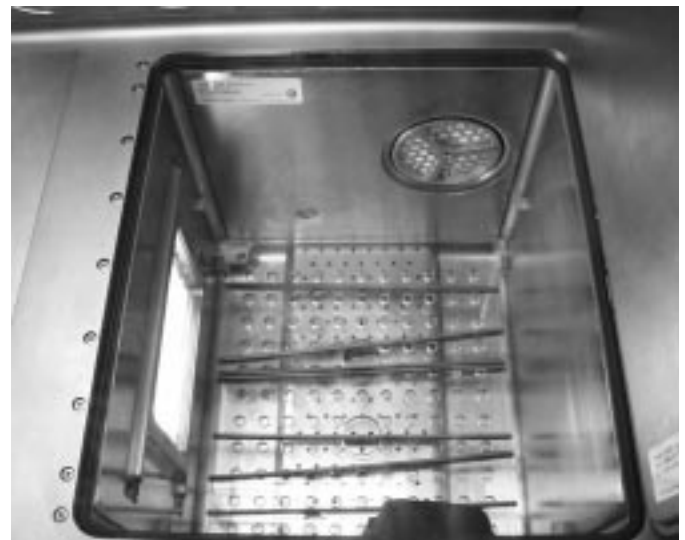


Figure 15. The MSG Airlock.



11. Video/Audio

The high quality video system has 3 color cameras and 1 black and white camera. There are 3 digital recorders connected to the cameras via a Y/C connection. Two 25.4 cm (10-inch) color LCD video monitors are mountable either inside or outside the work volume. The video is downlinked through the ISS's video system. A hard disk recorder is also available for frame storing video sequences acting as a time-lapse recorder. The cameras, recorders, monitors, compressor, and time-lapse recorder are all connected to the MSG SPLC to allow the entire system to be controlled from the ground. A laptop computer can also be connected to control the video system.

12. Special Lab Equipment

Lab Support Equipment: Several pieces of lab support equipment (LSE) are available to investigators. Some of these include: compound microscope, dissecting microscope, digital multimeter and thermometer, still camera, video camcorder, freezers, mass measuring devices, pH meters, cleaning equipment, general purpose tools, and fluid handling tools.

Outfitting Equipment: Standard payload outfitting equipment (SPOE) are components common to several facilities. These components are developed by others and purchased by the ISS facilities that want to use them. The ESA SPOE items include: remote power distribution assembly (RPDA), rack maintenance switch assembly (RMSA), avionics air assembly (AAA), and standard payload computer (SPLC). The NASA SPOE item is the area smoke detector assembly (ASDA).

13. Operations Modes/Crew

Modes of Operation: There are 4 modes of operation for the MSG: normal mode, sealed mode, open mode, and donning mode. Normal mode is when all ports are closed and air is circulating normally in the workspace. Sealed mode is when the work volume ports are closed and no air is circulating in the Glovebox. Open mode is when the work volume fans are circulating air and a negative pressure is established but the ports are open. Donning mode is the same as normal mode except that the work volume fan speed is maximized to create the greatest negative pressure possible. This allows for the crew member to enter and exit the gloves (don and doff) more easily.

Crew: General operations require the crew to unstow experiment modules and specimens, move them to the Glovebox enclosure, and place them inside. Most of the experiment modules in the Glovebox have magnetic bases or strips that hold them to the metal floor of the enclosure, or they can be mounted to attachment points on the floor, while others attach to a laboratory jack in the enclosure that can position the module at a chosen height above the cabinet floor. Experiment equipment also may be bolted to the left wall of the working space or attached outside the facility with Velcro®. Once the experiment is secured, the crew proceeds with operations specific to the investigation. Following the experiment, the crew will clean up any spills or leaks in the workspace, reassemble the hardware if necessary, and move it back into stowage. They also store any samples that must be preserved for post flight analysis.



Images of Astronaut Peggy Whitson with the Microgravity Science Glovebox



Part 2. Classroom Glovebox Assembly Instructions

Note: Any mention of a particular product or manufacturer is meant to be helpful information to the educator, it in no way implies an endorsement by NASA.



Assembly Instructions



This project is for demonstration purposes only. The classroom glovebox you will build is not intended to be used for true scientific experimentation. Please use it only as described in the suggested demonstrations that are part of this Educators' Guide.

Procedures in these instructions are provided as a guideline. Do not attempt assembly without proper supervision of woodworking and electronic technical personnel. The classroom glovebox is intended as a teaching aid for qualified instructors familiar with the skills necessary to complete this project.

These instructions are intended as a guide for the construction and assembly of a glovebox similar to the ones NASA uses on the middeck of the Space Shuttle. This project consists of several components:

Shell Assembly - this is a lesson in basic woodworking;

Camera Unit Assembly - this is a basic lesson in metal smithing, audio/video component assembly, and simple electronics;

Electrical Component Assembly - like the camera unit, this requires some metal working, but more advanced skill in electronics;

Glove Assembly - simple assembly of off-the-shelf components, used in creative ways other than as intended.

All parts used in this project are simple off-the-shelf items. Part of the fun will be shopping for the component parts and sometimes using them in unusual ways. A complete parts and vendor list can be found at the end of this section. As part of the process, these component parts may be constructed by different student teams and then assembled, either as a group, or a student team.



Shell Assembly Instructions

Skill requirement: basic woodworking

Warning: Use of power tools can be dangerous. Only attempt to perform these tasks under supervision of skilled personnel. When using power and hand tools, please follow all safety guidelines stipulated in the user manuals that come with your tools.

Refer to the shell assembly diagram on pages 30-31 for dimensions and a parts list. A list of tools and materials needed to build the shell unit is on page 29.

Figure 1

Use a table saw or circular saw with a combination blade to cut the basic shapes of pieces (A1) through (A5). The combination type saw blade allows you to make rip and cross cuts without changing blades. Cut pieces from 1/2" birch plywood or equivalent.

Hints:

- Score the cross cut lines with a razor knife to keep the stock from splintering.
- Cut all of your miters before changing your saw set up, then set up and cut all of your rabbets.

As shown in the Shell Assembly Diagram:

- Pieces (A1) and (A2) are mitered at a $67\text{-}1/2^\circ$ angle on both sides, so that they form a 135° angle when joined.
- Pieces (A3) have the $67\text{-}1/2^\circ$ miter *on the front edge only*. The back edge is 45° .
- All of the panel pieces are rabbeted on the top and bottom edges. The rabbets have a 1/2" face and a 1/4" shoulder.
- Cut piece (A5) to its 14" x 16-1/2" dimension. Mark piece (A5) as shown in the diagram and make the angle cuts where pieces (A1-A3) will be attached. The angles of the joints are 135° .

Now you are ready to cut the appropriate openings in pieces (A1) through (A3).

You will use a jigsaw with a finish blade for this operation.

- Mark the cut lines shown in the shell assembly diagram.
- Drill a hole larger than the width of the jig saw blade in one corner of the area to be removed.
- Insert the jigsaw blade into the hole and start your cut there following the drawn cut lines.
- The cuts can be cleaned up with a wood rasp and 100 grit sandpaper.
- Pieces (A3) require a 1/4" face x 1/8" shoulder rabbet around the inside perimeter of the opening.
- Cut a piece of 1/8" clear acrylic to size and insert it in the window opening. The clear acrylic will fit flush with the inside face of the (A3) side access panels. Secure it in place with 1/2" thumb button hardware (A14) (see diagram on page 30).
- Use spray adhesive to apply the provided graphic of the MGBX control panel to the (A4) shell back panel. Cut out around the fan and the switch openings with a razor knife. Cut out the location of the 3 LEDs (A12) and drill holes 1/2" in diameter.
- Attach the side panels (A1) through (A4) to the bottom panel (A5) with 1/2" #6 wood screws.
- Attach the 1" 135° corner brackets (A9) in the top corners of pieces (A1) through (A4). It may be necessary to bend 90° brackets to the correct angle. Use a vice and pliers if bending is necessary.

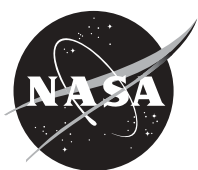


Figure 2

Now you are ready to build the top. Do not peel the protective paper coating from the clear acrylic until you are completely finished with the construction and installation.

- Lay a 15" x 17" piece of 1/2" thick clear acrylic (A6) over the assembled shell body.
- Mark the acrylic to custom fit inside the rabbeted edges.
- Cut it to shape using a 40-tooth carbide saw blade.
- After the top has been fitted, cut a 3" strip off the back edge.
- Align the piano hinge (A7) and mark the screw holes.
- Drill and tap the screw holes between the two pieces so that machine screws can be screwed directly into the plastic to mount the hinge. Attach the hinge.
- Attach the top to the back wall of the shell body (A4) using four 1" #6 wood screws. Put screws in from the top, down into the top edge of the back panel (A4).
- Pre-drill the screw holes in the top back edge and sides of the acrylic using a 1/8" bit and counter sink.
- Put one screw through the top of each side panel just behind the hinge as shown in the diagram.
- Drill holes and attach handle (A8) as indicated.

Shell Assembly Tools / Materials Not Shown

Materials

- 2' x 4' piece of 1/2" finish grade plywood
- Sand paper – 100 grit
- 1" corner brackets (4 ea.)
- Spray adhesive
- Wood putty
- #6 wood screws, 1" and 1/2"
- 1/2" thumb buttons (4 ea.)
- Clear acrylic 1/2" cut 15"x17"
- 1/2" X 17" long continuous hinge (piano hinge)
- Machine screws 4-40
- Drawer pull - 3" (U-handle)

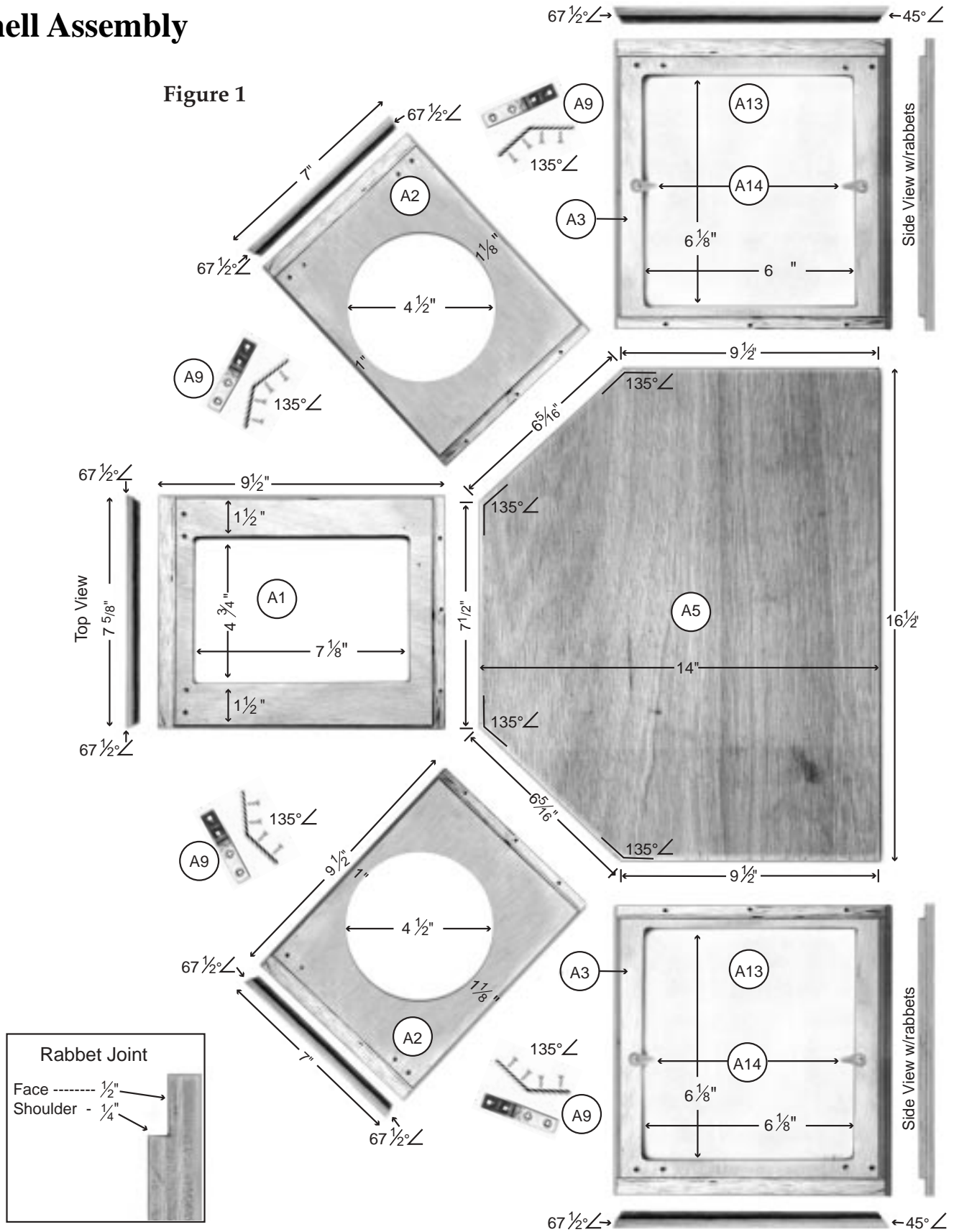
Tools

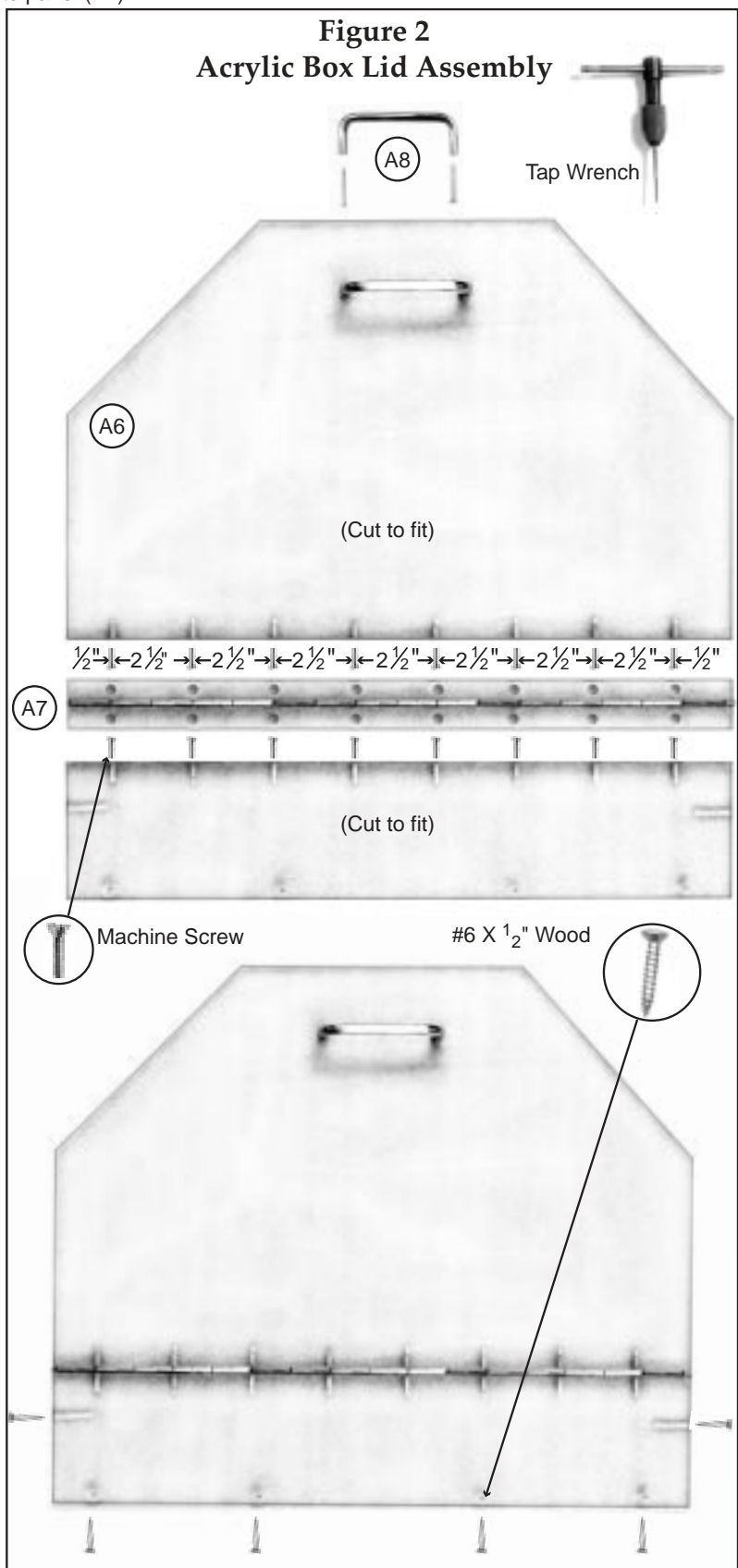
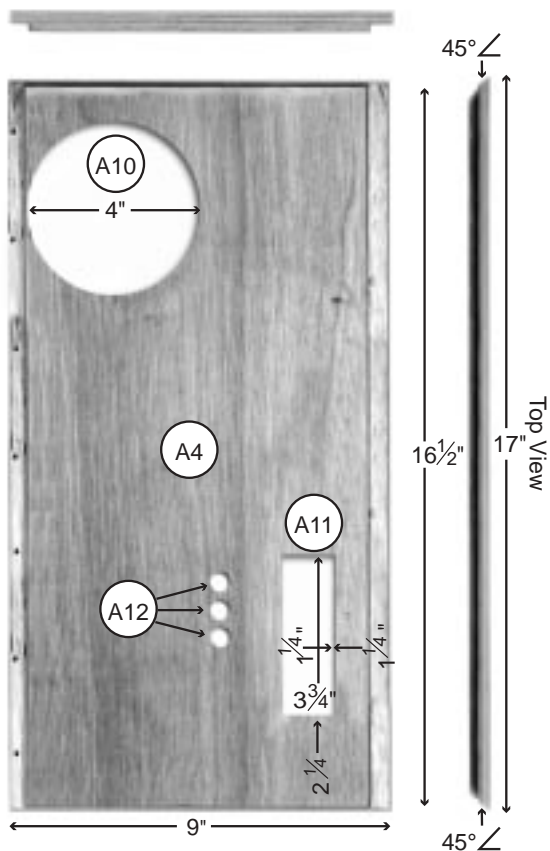
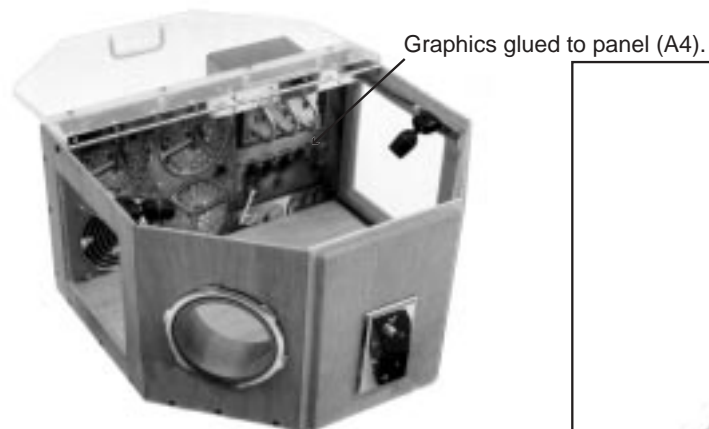
- Table saw or circular saw with combination blade and 40 tooth carbide blade
- Jigsaw with finish blade
- Orbital sander
- Router with 1/4" rabbet bit
- Assorted flat and phillips screw drivers
- Tap wrench and 4-40 Tap
- Drill with 3/8" chuck
- Drill bits: 1/8", 3/8", 3/16", 3/32", and 1/2" paddle bit
- Slip jaw pliers
- Hammer
- Wood rasp
- Razor knife



Shell Assembly

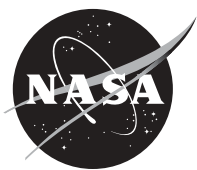
Figure 1





Parts

- A1. Camera mount panel
- A2. Glove mount panel
- A3. Side access panel
- A4. Back panel
- A5. Bottom
- A6. Acrylic lid
- A7. Piano hinge
- A8. U handle
- A9. 135° angle bracket (top and side views)
- A10. Fan cutout
- A11. Switch cutout
- A12. LED holes
- A13. Acrylic panel
- A14. Thumb button





Camera Unit Assembly Instructions

Skill requirement: basic electronics, metal smithing, audio/video

When using power and hand tools, please follow all safety guidelines stipulated in the user manuals that come with your tools.

Refer to the Camera Unit Assembly Diagram on pages 34-35 for dimensions and a list of parts. A list of tools and materials necessary to build the camera unit is on page 35.

Figure 3

Using a table or circular saw with a combination blade, cut the primary (B10) and secondary (B11) camera plates to size from 1/2" birch plywood. The combination saw blade lets you make rip and cross cuts without having to change blades.

Align the primary (B10) and secondary (B11) camera mount panels and screw together with 3/4" #6 wood screws.

You will use a jigsaw with a medium toothed blade to cut the opening for the project box (B2a/b) in the assembled camera panels (B12).

- Draw the cut lines where the project box will be inserted.
- Drill a hole larger than the width of the jigsaw blade in one corner of the area to be removed.
- Insert the jigsaw blade into the hole and start your cut there following the drawn cut lines.
- The cuts can be cleaned up with a wood rasp and 100 grit sandpaper.
- Attach the butterfly latches (B8) at the edges of the secondary camera plate (B11) as shown in the diagram (Figure 3.). Use the screws provided by the latch manufacturer.



Figure 4

(within Figure 3 box)

With a scratch awl or felt pen, scribe the camera window dimensions on the project box (B2b) as indicated on the camera assembly diagram.

- After marking the cut lines, drill a hole larger than the width of the saw blade in one corner of the area to be removed.
- With a fine toothed metal cutting blade in your jigsaw, insert the blade into the hole and cut along the scribed lines.

Hint: *Clamping the piece to your workbench before drilling and cutting will allow you to perform these operations safely and accurately.*

- Use a file to remove any burrs or sharp edges.

Drill a 7/16" hole in the side of the project box (B2b) to mount the coaxial DC power plug (B6). Pay close attention to the camera assembly diagram and make sure to mount the plug on the correct side of the project box (B2b). The side the plug is mounted to determines the side of the glovebox shell on which the camera wiring will run. A wiring diagram will be provided with the camera at purchase.

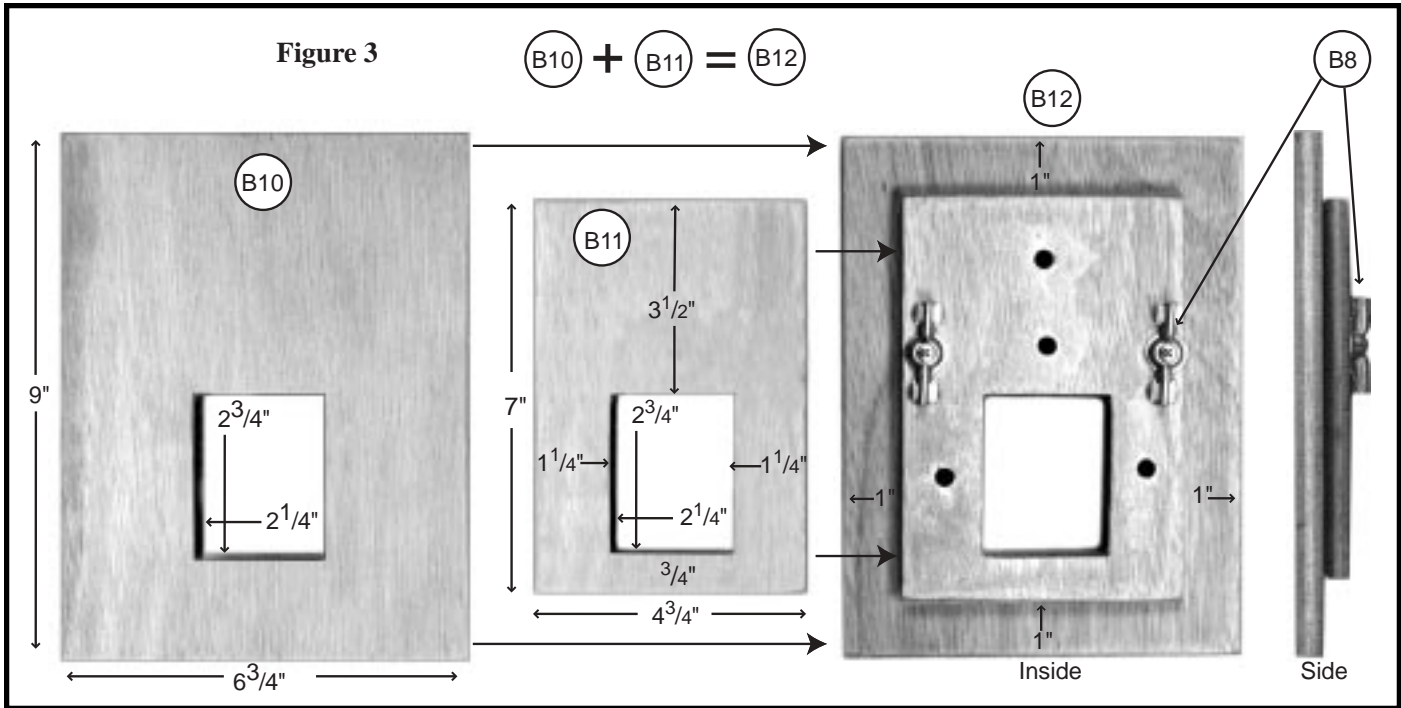
Figure 5

Now you are ready to mount the camera (B1) to the project box marked (B2a) on the camera unit assembly diagram.

- Center the camera in the enclosure (B2a) approximately 1/8" from the bottom.
- Mark the mounting holes in the camera circuit board on the back of the enclosure (B2a).
- Using a 1/8" bit, drill holes in the back of (B2a).
- Drill another hole, 1/4" in diameter, in the top center of (B2a) just above the camera (B1) for mounting the female RCA video plug (B5). These holes will be used as a pattern to mark the holes in the blank switch plate (B3).
- Before marking the blank switch plate (B3), insert the project box (B2a) into the cutout in the assembled primary and secondary camera plates (B12). This will ensure proper alignment of the blank switch plate (B3) to the primary camera plate (B10).
- Align the plate, mark, and drill the mounting holes using a 3/64" bit.
- Line up the holes in the blank switch plate (B3) with the holes in the (B2a) portion of the project box.
- Fasten them together with 2-56 x 3/16" (B4A) machine screws and stand offs 1/8" x 56 (B7).
- Insert and fasten the female RCA video plug (B5).
- Mount the camera (B1) to the stand offs using 2-56 x 1/8" machine screws (B4b).
- Wire up the camera power and signal.
- After completing the wiring, slide part (B2b) into (B2a), and insert the fully assembled unit through the opening in the camera plate (B12). Fasten the switch cover to the front of the primary camera plate (A1) using the butterfly latches.

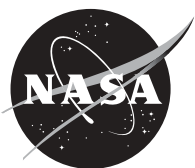
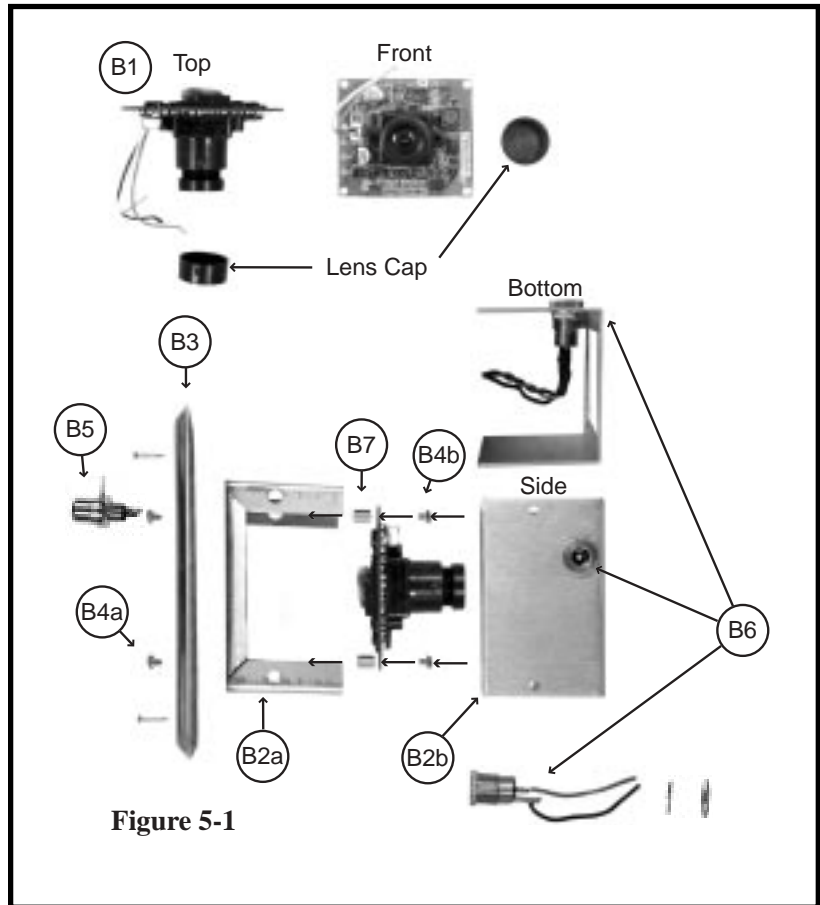


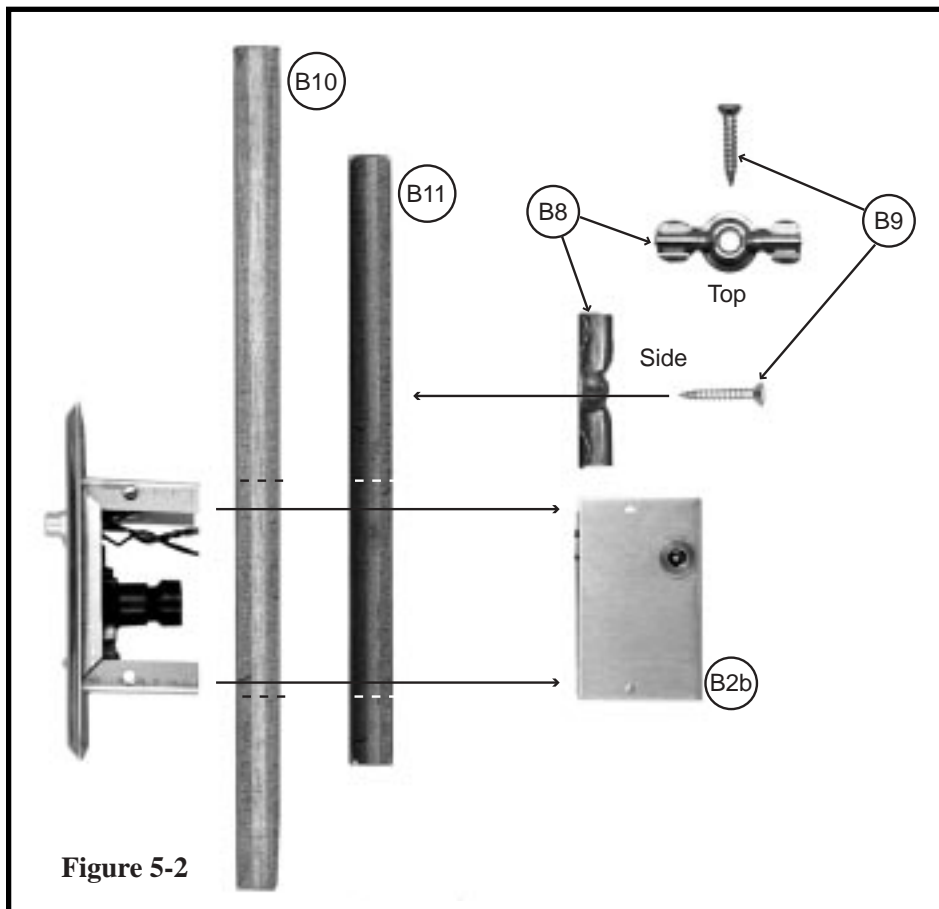
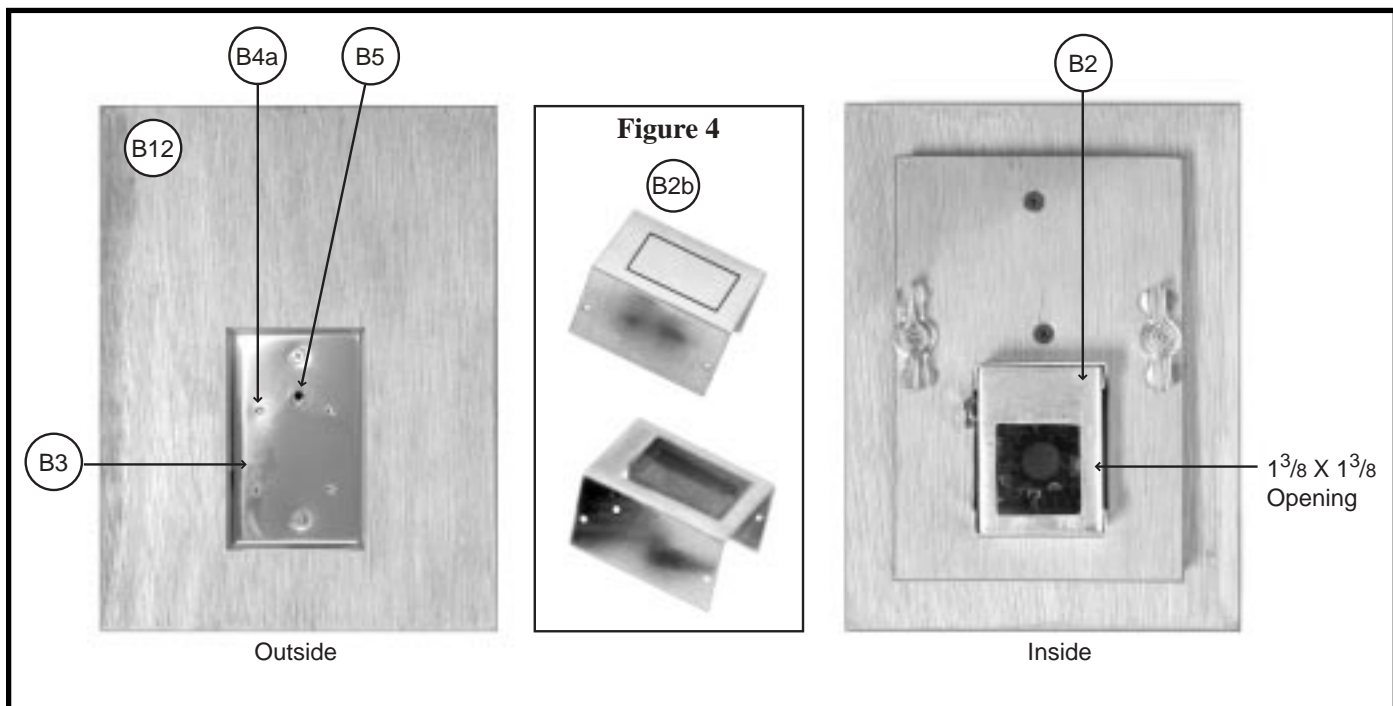
Camera Unit Assembly Diagram



Parts

- B1. Model #cvc-514bc 1/4" color board camera
- B2. Project box - 2 3/4" X 2 1/8" X 1 5/8"
- B3. Blank switch plate
- B4. Machine screws (a)#2-56 3/16" (b)#2-56 1/8"
- B5. Female RCA video plug
- B6. Coaxial DC power plug
- B7. Stand off (1/8" X 56)
- B8. 1" Butterfly latches (2 ea.)
- B9. #6 X 3/4" wood screws w/no shank
- B10. Primary front camera mount panel (1/2" birch plywood)
- B11. Secondary camera mount panel (1/2" birch plywood)
- B12. Plates aligned and screwed together





Tools / Materials Not Shown

- Table or circular saw, combination plywood blade
- Jigsaw, med. tooth wood blade, and metal cutting blade
- Sander
- Drill or drill press
- 1/2" paddle bit
- Metal bits, 1/8", 1/64", 1/4", 7/16"
- Philips screwdriver and #3 philips drill bit
- Flat screwdriver
- Metal file
- Wood rasp
- Solder work station
- Soldering iron
- Solder, .032" dia., 2.5 oz. rosin core
- Shrink tube, 1/8"
- 22 guage electrical wire
- Heat gun
- Wire strippers
- Needle nose pliers
- Tape measure
- Tri square
- 100 grit sand paper



Electrical Assembly Instructions

Skill requirement: basic electronics, metal smithing

Warning: Only attempt this under the supervision of a qualified electronics technician. There is a danger of electrical shock if not properly assembled under the supervision of qualified personnel familiar with electronic components. When using power and hand tools, please follow all safety guidelines stipulated in the user manuals that come with your tools.

Refer to the Electrical Assembly diagrams on pages 38-39 for dimensions and a list of parts. A list of tools and materials needed to build the electrical units is on page 37. The Electrical Assembly consists of several components. Build each of these components as completely as possible before installing them in the shell assembly.

Figure 6 - The Switch Assembly

- Lay out the hole pattern on the switch cover. With a punch, mark the center point of each hole. Use a drill press to drill the appropriate size holes in the plate.
- Mount the U-bolts (C2) and toggle switches (C3) to the plate. The wiring can be done before mounting the assembly to the shell. Refer to the Toggle Switch Schematic on page 41.
- Insert the switch assembly through hole (A11) cut into panel (A4) and screw to (A4) using 1/8" wood screws in each corner (see page 38).

Figure 7 - Lights

- Separate the light fixture (C24) from the battery pack by pulling the hinge pin that holds the two parts together. Discard the battery pack.
- Drill a 1/8" hole in both sides of the base of the lights.
- Solder a piece of wire to each side of the contacts in the base of the light fixtures: red to one side, black to the other. Make sure the wires are long enough to run from where the light will be mounted back to the toggle switch plate (C1).
- Pass a mounting screw through the holes and mount the fixture to the inside top wall of pieces (A3) of the shell assembly. These will light the activity field during demonstrations.
- Place LEDs (C20-22) into 10 mm holders (C23) and insert into holes (A12) beneath toggle plate (A11) in panel (A4). Install them from left to right – red, yellow, then green.

Hint: Use a piece of shrink tubing as a sheath for the portion of the screw that is inside the lamp head to prevent it from coming into contact with wires and causing a short circuit.

Figure 8 - Fan

- Place the fan (C5) over the back of the hole (A10) that is cut in panel (A4) so that when turned on the fan will pull air out of the glovebox.
- Place fan guards (C6) on both sides of the fan and attach entire unit to panel (A4) with machine screws.

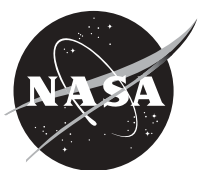


Figure 9 - Project Box

The project box contains all of the electronic components for the glovebox and provides the point of attachment to a power source. It will be necessary to cut an opening in the back of the box large enough to allow the wiring from the toggle assembly and the LEDs to protrude into the inside of the box where they will be connected to the breadboard.

- After the opening has been cut, use wood screws to attach the project box to the back of panel (A4).
- Run wires from field lights, fan, and LEDs to project box using plastic wire restraints (C19) to hold them in place in the shell assembly.
- Connect compatible wires (red to red, black to black) with wire nuts (C17 & C18). Wire into breadboard and power supply following the wiring diagram (Breadboard Schematic on page 40).
- Attach the breadboard to the side of the project box using standoffs to allow room for the wiring.

Figure 10 - Main Power Supply

The power supply is a 12-volt system that plugs into an outlet in the base of the project box.

- Insert Coaxial DC power jack (C16) into base of the project box (C14) using rubber grommet (C15) to hold in place.
- Wire to breadboard (C12) following the wiring diagram (Toggle Switch Schematic on page 41).
- Attach the cover to the project box, connect 12 volt DC transformer to coaxial power jack (C16), and you are ready to power up your classroom glovebox.

Electrical Assembly Tools / Materials Not Shown:

- | | |
|--|----------------------------|
| • Variable speed jigsaw and blades | • Solder work station |
| • Drill or drill press | • Heat gun |
| • Metal cutting bits | • Shrink tube |
| • 1/2" counter sink | • 18 guage electrical wire |
| • Open end wrenches: 3/8", 1/2", 9/16" | • Wire strippers |
| • Philips screw drive | • Needle nose pliers |
| • Flat screw driver | • Tape measure |
| • Soldering Iron | • Tri square |
| • Solder | |



Electrical Assembly

Figure 6

Parts

- C1. Plate - 1 guage stainless steel blank
- C2. 2" U bolts (3 ea.)
- C3. DPDT toggle switch - 3A@125V (3 ea.)
- C4. 500 ohm pc mount trim potentiometer
- C5. Philmore 4.25 in. fan
- C6. Philmore fan guard
- C7. LM317T voltage reg.
- C8. 7805 5V regulator
- C9. 7808 regulator
- C10. Resistor 240 ohm 1W (2 pk)
- C11. Resistor 22 k ohm 1/2 W (4 pk)
- C12. ICB88 PC board
- C13. Birnback nylon screws w/standoffs
- C14. Project Box - 7" X 5" X 3"
- C15. Rubber grommet
- C16. Coaxial DC power jack 5.5/2.5
- C17. Wire nuts # 20
- C18. Wire nuts # 18
- C19. Wire restraint
- C20. 10mm red LED
- C21. 10mm yellow LED
- C22. 10mm green LED
- C23. 10mm holder (3 ea.)
- C24. Clip-N-Lite AAA (discard battery container)
- C25. 12V power supply

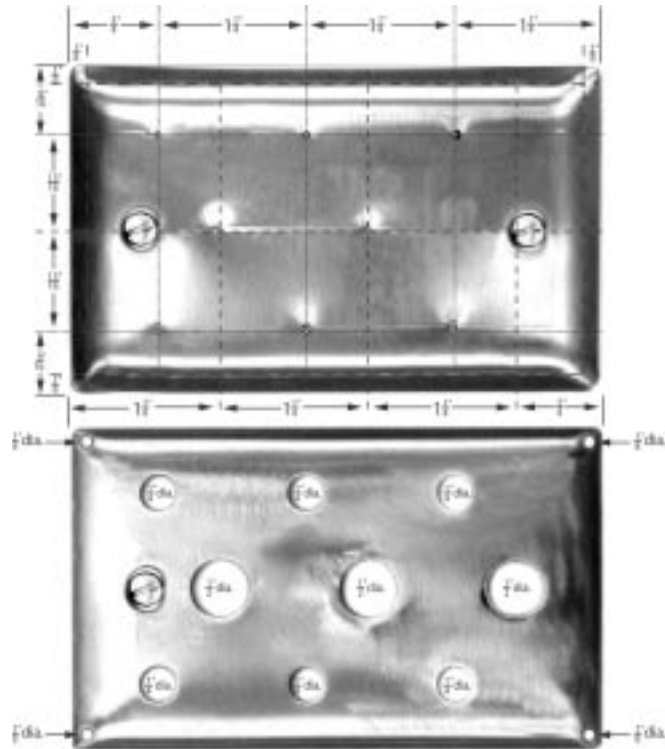
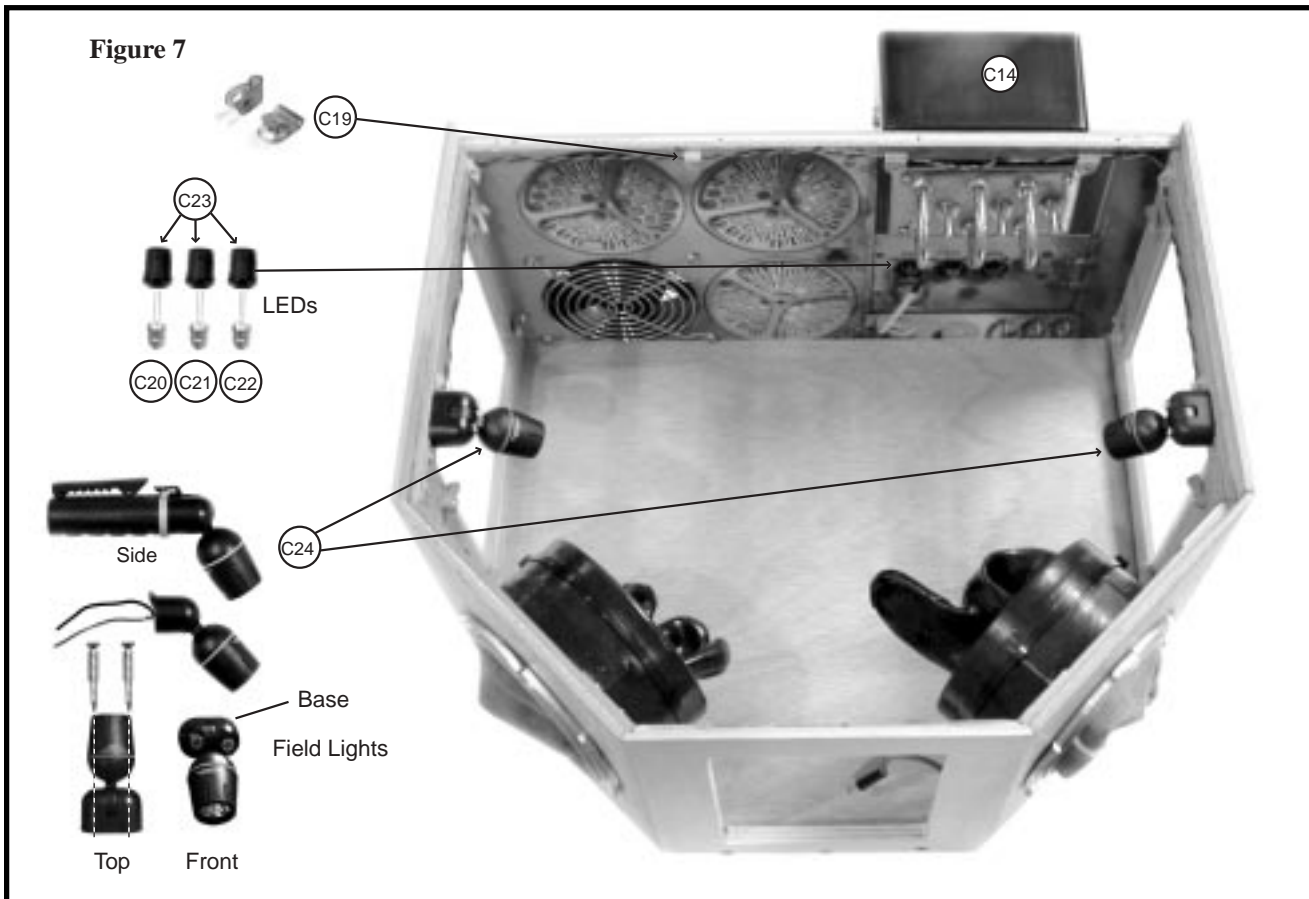
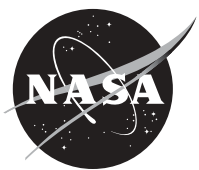
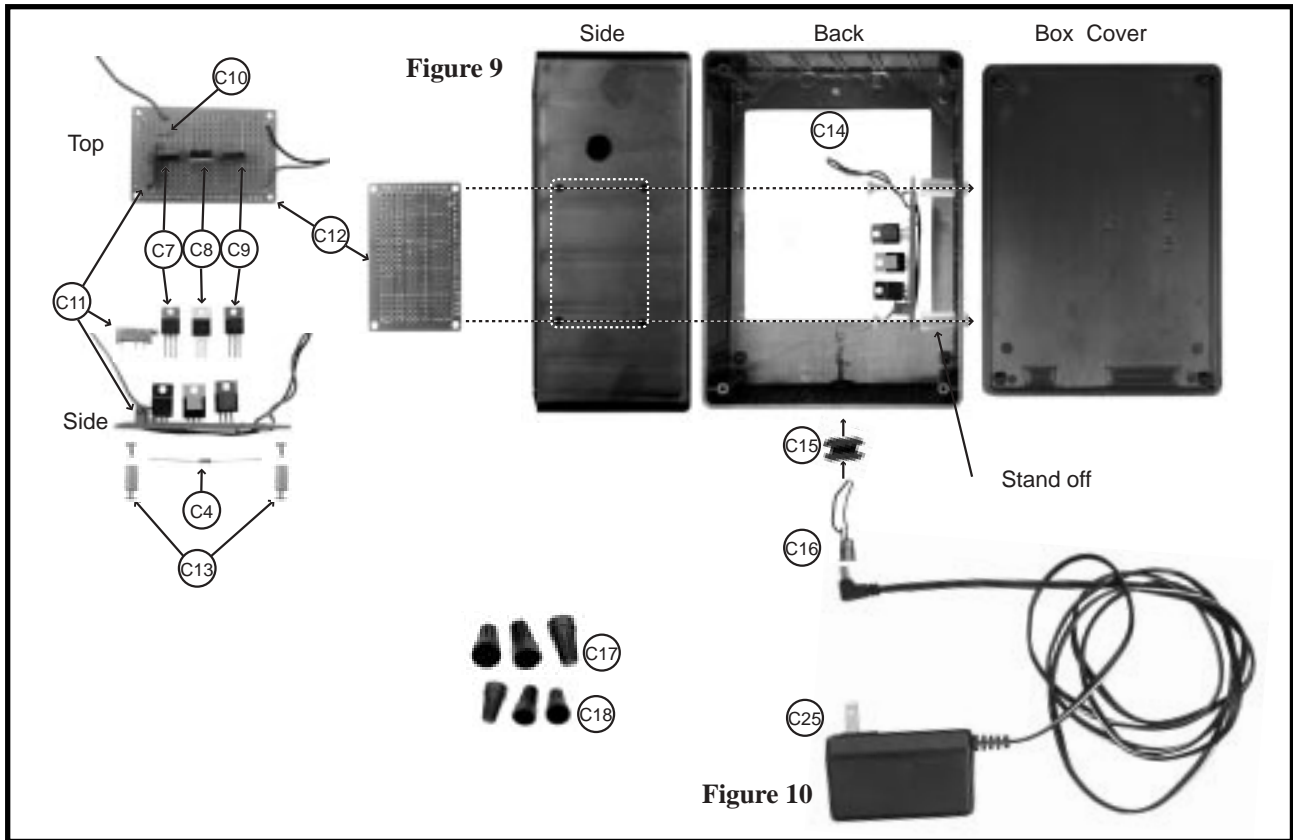
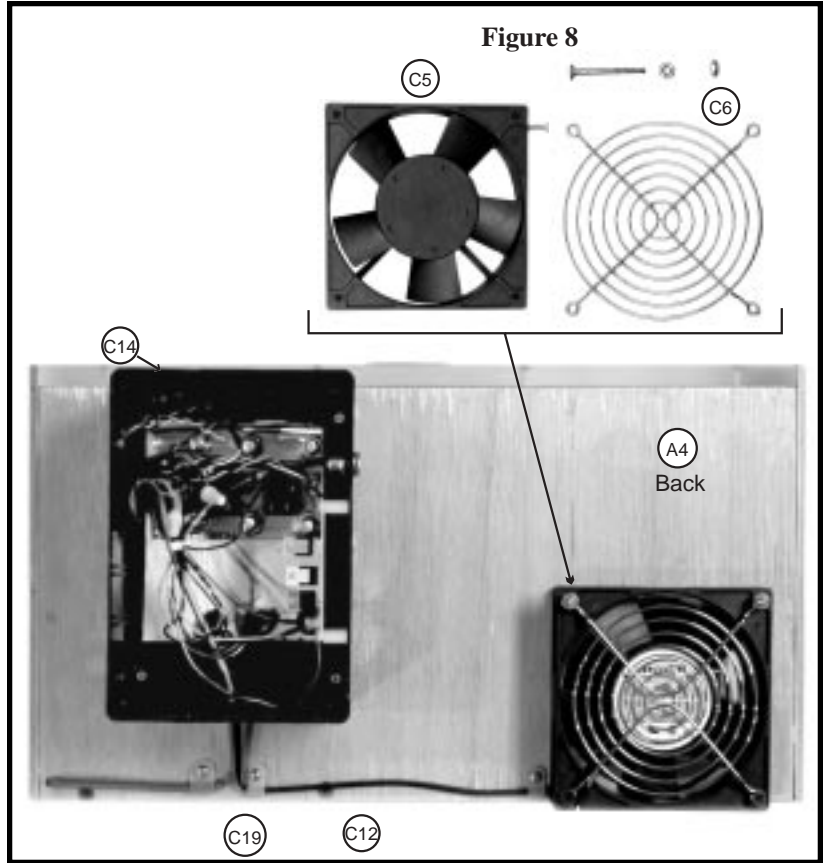
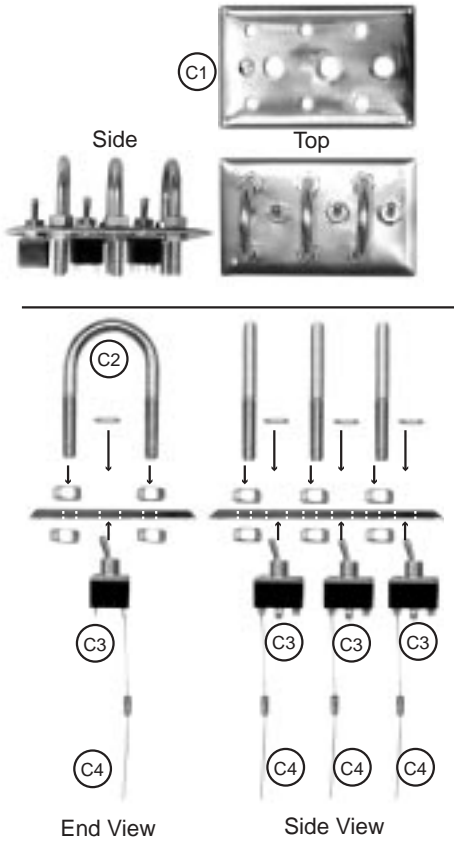
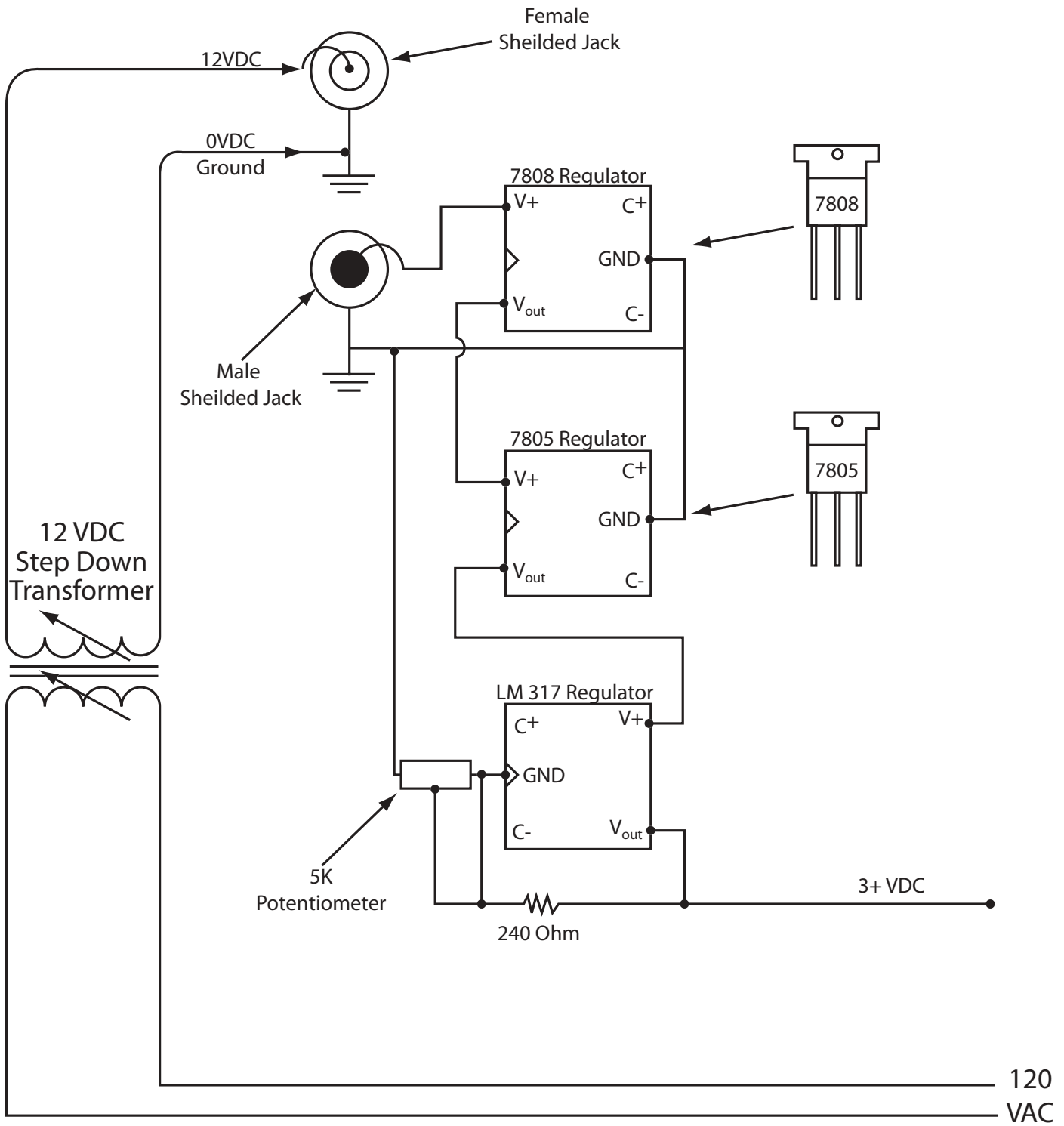


Figure 7

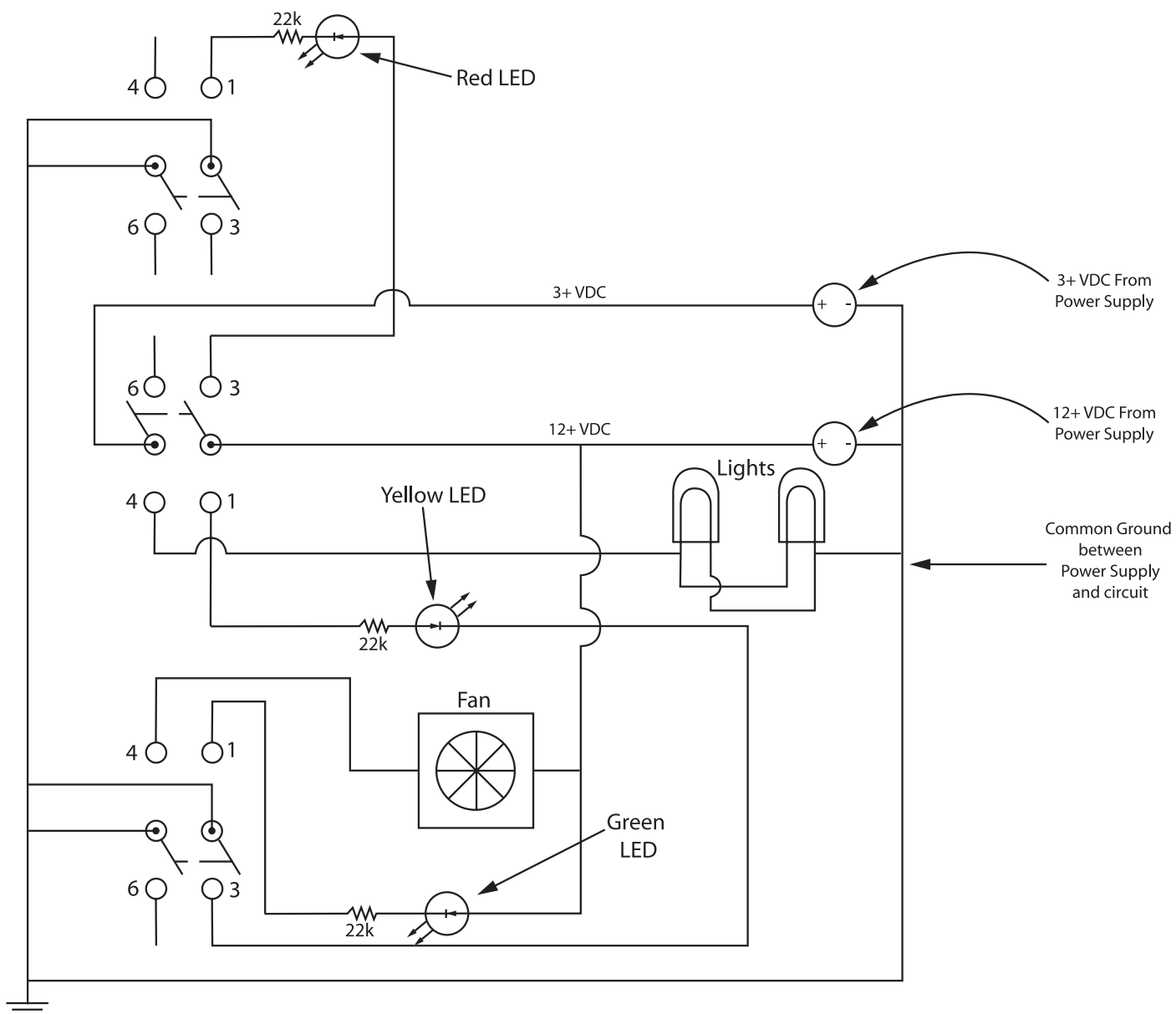




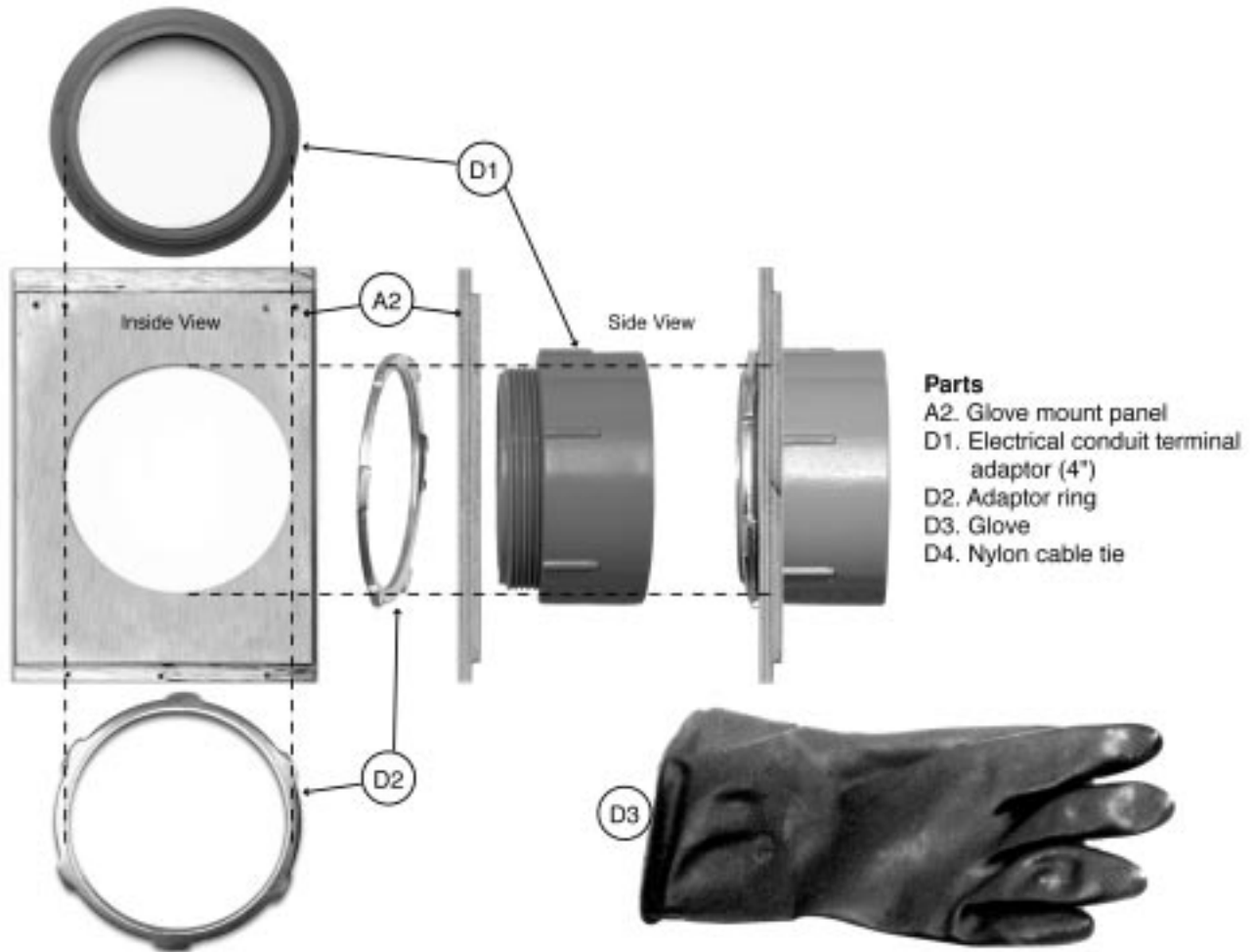
Breadboard Schematic



Toggle Switch Schematic



Glove Assembly Instructions

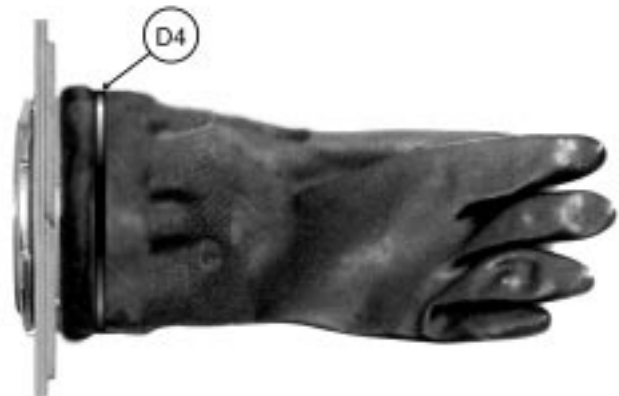


Parts

- A2. Glove mount panel
- D1. Electrical conduit terminal adaptor (4")
- D2. Adaptor ring
- D3. Glove
- D4. Nylon cable tie

To attach gloves to your Classroom Glovebox:

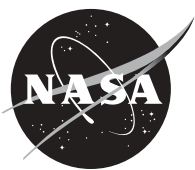
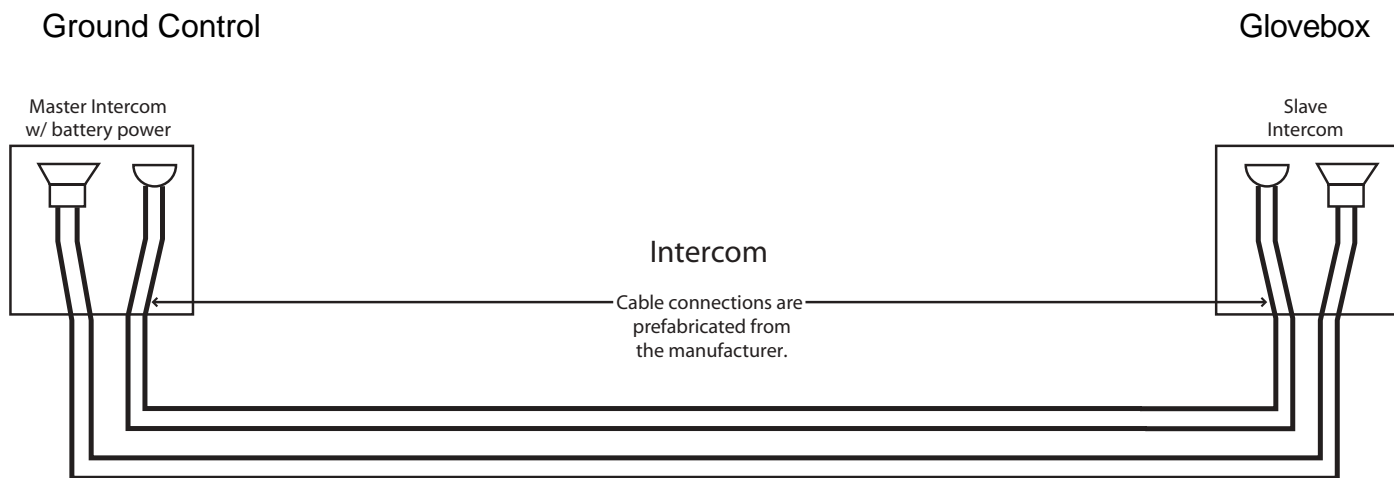
- Insert 4" electrical conduit terminal adaptor (D1) through hole in Glove mount panel (A2) from inside.
- From outside panel, screw the Adaptor ring (D2) snugly onto (D1).
- Stretch sleeve of the rubber glove (D3) over (D1).
- Secure in place with a nylon cable tie (D4), a heavy rubber band, or pipe clamp.





Intercom

An intercom is necessary to allow the ground control operator and the mission specialist at the glovebox to communicate. Any off-the-shelf battery powered intercom will suffice. To simplify glovebox operation, a hands-free unit can be attached to the outside of the front panel (A1) using Velcro®. This will allow the mission specialist more freedom.





Glovebox Parts List

Note- Check with a cabinet shop and plastics company before buying any plywood or plastic. They usually have drops that they will give away. The following parts are all the components necessary to build a basic glovebox mock up.

| <u>Part Description</u> | <u>Part #</u> | <u>Qty</u> | <u>Dimensions</u> | <u>Vendor</u> | <u>Unit Cost</u> | <u>Total Cost</u> |
|---------------------------------------|---------------|------------|-------------------|--------------------------|------------------|-------------------|
| Leuan Plywood | | 0.5 | 48"x48"x.5" | Local Lumber Yard | \$12.00 | \$12.00 |
| Clear Acrylic Plastic | | 1 | 8"x17"x.5" | Local Plastics Outlet | \$10.00 | \$10.00 |
| Clear Acrylic Plastic | | 2 | 7"x6.5"x.125" | Local Plastics Outlet | \$10.00 | \$10.00 |
| Piano Hinge (continuous hinge) | | 1 | 1"x.0625"x30" | Local Lumber Yard | \$10.95 | \$10.95 |
| Bugle head Screws per box | | 26 | # 6 x 1.25" | Local Lumber Yard | \$2.95 | \$2.95 |
| Corner Bracket 4/Pkt | | 4 | 1" | Local Lumber Yard | \$1.77 | \$1.77 |
| Terminal Adapter (TA) | | 2 | 4" | Electronics Supply Store | \$4.86 | \$9.72 |
| (TA) Locking Ring | | 2 | 4" | Electronics Supply Store | \$3.87 | \$7.74 |
| Rubber Gloves | | 1 | large | Home Improvement Store | \$3.21 | \$3.21 |
| Color Monitor: Samsung | TXH1372 | 1 | 13" | Electronics Supply Store | \$124.50 | \$124.50 |
| "Pro-Video" CCD (color) Board | | | | | | |
| Camera / with wide angle pinhole lens | | 1 | 1.25"x1.25" | Electronics Supply Store | \$169.00 | \$169.00 |
| 24' Audio Visual Cable | 2E+06 | 3 | 24' | Radio Supply Store | \$4.99 | \$14.97 |
| RCA Coupler | 3E+06 | 2 | .25" | Radio Supply Store | \$2.99 | \$5.98 |
| Coaxial Power Plug | | 2 | 2.5mm | Electronics Supply Store | \$1.79 | \$3.58 |
| Stand Offs | 9032 | 5 | 0.125" | Electronics Supply Store | \$0.26 | \$1.30 |
| Waldon F-591 Screws | | 1 | 2.56x.125" | Electronics Supply Store | \$3.29 | \$3.29 |
| Heat Shrink | | 1 | .25" | Electronics Supply Store | \$2.75 | \$2.75 |
| Intercom | | | | | | |
| (2) station - wired | 43-222b | 1 | | Radio Supply Store | \$14.99 | \$14.99 |
| Transformer- | | | | | | |
| 12V / DC-1000mA - AC | 273-1653b | 1 | | Radio Supply Store | \$21.99 | \$21.99 |
| Light Fixtures | | | | | | |
| "Clip 'N Light" | 61-2548 | 2 | | Radio Supply Store | \$9.99 | \$19.98 |
| Fan | 70-8415 | 1 | 4" | Electronics Supply Store | \$15.60 | \$15.60 |



| <u>Part Description</u> | <u>Part #</u> | <u>Qty</u> | <u>Dimensions</u> | <u>Vendor</u> | <u>Unit Cost</u> | <u>Total Cost</u> |
|-----------------------------------|---------------|------------|-------------------|--------------------------|------------------|-------------------|
| Fan Covers | 70-6415 | 2 | 4" | Electronics Supply Store | \$3.98 | \$7.96 |
| Box Cover | | 1 | 3" x 4" | Misc. Supply Store | \$0.77 | \$0.77 |
| "U" Bolts | | 3 | .25" x 5.5" | Home Improvement Store | \$1.34 | \$4.02 |
| LED - Pnl Mt. red / amber / green | 276-214 | 3 | Jumbo | Radio Supply Store | \$2.39 | \$7.17 |
| LED Holders - Pnl Mt. | 276-092 | 3 | 10mm | Radio Supply Store | \$0.33 | \$0.99 |
| Toggle Switches (dpdt) | | | | | | |
| 6A@250VAC | 275-652 | 3 | .25" | Radio Supply Store | \$2.79 | \$8.37 |
| Voltage Regulator (7805) | | 1 | 5V | Radio Supply Store | \$1.49 | \$1.49 |
| Voltage Regulator (LM317) | | 1 | 6V | Radio Supply Store | \$1.99 | \$1.99 |
| Voltage Regulator (7808) | | 1 | | Radio Supply Store | \$1.49 | \$1.49 |

MISCELLANEOUS MATERIALS

| <u>Part Description</u> | <u>Part #</u> | <u>Qty</u> | <u>Dimensions</u> | <u>Vendor</u> | <u>Unit Cost</u> | <u>Total Cost</u> |
|----------------------------|---------------|------------|-------------------|--------------------------|------------------|-------------------|
| Wire Ties | | 1 | 4" | Radio Supply Store | \$5.58 | \$5.58 |
| Assorted Fasteners | | | | Home Improvement Store | pr unit | \$14.86 |
| Jig Saw Blades | | 1 | | Home Improvement Store | \$2.49 | \$2.49 |
| Acrylic Saw Blade | | 1 | 7.25" | Home Improvement Store | \$9.88 | \$9.88 |
| Sand Paper | | 2 | | Home Improvement Store | \$2.19 | \$4.38 |
| Lamination | | 1 | | Photocopy Shop | \$7.15 | \$7.15 |
| Router Bit -.25" flush cut | | 1 | | Home Improvement Store | \$6.87 | \$6.87 |
| Blank Plate | | 1 | | Home Improvement Store | \$1.77 | \$1.77 |
| Coaxial Power Plug | | 1 | .125" | Electronics Supply Store | \$2.99 | \$2.99 |
| Box | | 1 | 3" x 4" | Electronics Supply Store | \$3.30 | \$3.30 |
| TOTAL | | | | | | \$559.79 |

Part 3. Classroom Activities



Fundamental Science Skills



Diffusion Activity with Data Analysis

| Grade Level | Subject |
|-------------|---------|
| 9-12 | Biology |

Introduction

Many of the most basic scientific processes are not completely understood. Scientists examine and study these processes in the hopes of determining how and why they work the way they do. Some of these basic processes can be more easily studied in a microgravity environment where some of the effects of gravity are reduced. The microgravity environment achieved on Earth through drop towers and the KC-135 airplane only provide a short period of microgravity. The microgravity environment created in space laboratories, such as Spacelab in the Space Shuttle, offer longer periods of microgravity. These long-term microgravity environments make it possible to perform detailed studies of basic scientific processes. One of the processes being studied is diffusion.

Diffusion is the most common form of passive transport, the movement of a substance across a cell membrane without the input of the cell's energy. Diffusion occurs when molecules randomly move from an area of higher concentration (more molecules) to an area of lower concentration (fewer molecules) to establish equilibrium. In this activity, you will observe the process of diffusion of a substance through a cell membrane. Dialysis tubing represents the cell membrane while the cell contents are represented by a sucrose solution.

The cell (dialysis tubing with sucrose solution) is placed in a container filled with distilled water. The molecules of sucrose are concentrated on the inside of the cell while the molecules of distilled water are concentrated on the outside of the cell. The sucrose molecules are too large to diffuse through the membrane of the dialysis tubing to exit the cell, but the distilled water molecules are small enough to diffuse through the tubing and into the cell. You will "observe" the diffusion process by comparing the weight of the tubing and the sucrose solution before and after the diffusion has occurred. This process will take about 15 - 20 minutes to initiate but will continue for some time due to the large sucrose molecules blocking the entry of the distilled water molecules. The total diffusion of the distilled water and the sucrose solution will not be necessary in order for you to note a weight change.

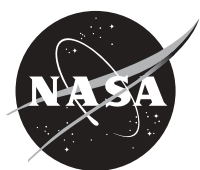
Because fluids behave differently in microgravity, experiments using fluids must be contained in some way to keep them from floating around in the Space Shuttle or the International Space Station (ISS). One means of achieving this containment is to use a glovebox. The glovebox you have built is not as complex as the one used in space, but it will provide you with an idea of what it is like to work in a glovebox.

Objective

- Students will observe the results of the diffusion process of a sucrose solution and distilled water.

Materials (per group)

- Glovebox
- Dialysis tubing (8-12" long, soaked in distilled water overnight); 6 pieces
- String
- Clear containers (such as beakers or drinking cups; 6 containers)



- Markers
- Funnel
- Distilled water
- Balance scale (electronic is recommended but a triple beam will work)
- Graphing calculator or graph paper
- 25-50 ml graduated cylinder

Materials (per class)

- 1 L of a 1.0-molar sucrose solution (342 g sucrose per liter of distilled water)
- 250 ml of a 0.8 molar sucrose solution (200 ml of a 1.0 molar solution + 50 ml of distilled water)
- 250 ml of a 0.6 molar sucrose solution (150 ml of a 1.0 molar solution + 100 ml of distilled water)
- 250 ml of a 0.4 molar sucrose solution (100 ml of a 1.0 molar solution + 150 ml of distilled water)
- 250 ml of a 0.2 molar sucrose solution (50 ml of a 1.0 molar solution + 200 ml of distilled water)
- 250 ml of a 0.0 molar sucrose solution (0 ml of a 1.0 molar solution + 250 ml of distilled water)

Procedure

1. Each group will need to obtain 15 – 20 ml of the sucrose solutions (6 different solutions). If preferred, have each group do one or two of the solutions. The groups will need the same number of dialysis tubing pieces as they have solutions, i.e., 6 solutions, 6 pieces of tubing.
2. Label a clear container for each molar solution being used. Fill each container about 3/4 full with distilled water.
3. Place all material, excluding the balance scale and the calculator, into the glovebox.
4. Tie off one end of each piece of dialysis tubing. Be careful not to tear the tubing. At the open end, funnel in about 15 ml of each of the 6 sucrose solutions. Place each filled tube in the appropriately labeled clear container.
5. Using an empty clear container, zero the balance. This will need to be done prior to each weighing. Remove the dialysis tubing from its container, blot the excess water from the tube, and weigh it. Immediately return the tubing to the appropriate clear container. (DO THIS QUICKLY!) Record the initial mass.
6. Let each solution stand in its container for a predetermined amount of time (15 – 30 minutes is recommended). Do your best to make sure each tube is in the distilled water for the same period of time.
7. At the end of the standing time, remove one tube at a time, blot off the excess water, and reweigh it. Record the final mass of each tube.
8. Calculate the percent change in mass of each tube.

$$\frac{\text{Final weight} - \text{Initial weight}}{(\text{Initial weight})} \times 100 = \text{Percent Change}$$



Record of Data

| Molarity | Initial Mass | Final Mass | Percent Change |
|----------|--------------|------------|----------------|
| 1.0 | | | |
| 0.8 | | | |
| 0.6 | | | |
| 0.4 | | | |
| 0.2 | | | |
| 0.0 | | | |

- Use a graphing calculator to plot Percent Change vs. Molarity of Sucrose. If a graphing calculator is not available, use graph paper to plot.

Data Analysis

Here are the basic instructions for creating a graph of the collected data using a TI-83+.

- Turn the calculator on. Press "STAT" key. Press "1" for "Edit". You will see columns labeled "L1", "L2", etc. These are the "lists" that you will use to insert data.
- Arrow the "cursor" up so that it darkens "L1" in the first list column. Clear each list by pressing CLEAR, then pressing ENTER. You are now ready to enter data from the lab activity.
- Cursor down to the 1st entry box under "L1", type 0 and press ENTER.
- Enter 0.2, 0.4, 0.6, 0.8, and 1.0 in Boxes 2 through 6 respectively.
- Insert your cursor to the first spot under "L2". Enter the respective percent changes for the sucrose dialysis bags in distilled water.
- Press "2nd", then press "Y=". This puts you into the "STAT PLOT" function. If "1:" is highlighted, press ENTER. Cursor left to select "On" and press ENTER. Cursor down to "Type" and choose the first one (scattergram), pressing ENTER to select it. Cursor down to "X list" and choose "L1". Cursor to "Y list", and select "L2".
- Cursor down to the "Mark" and choose the first one. Press "2nd" "Y=" again and make sure that the other plots are turned off. If any are on, simply cursor to the plots that are on, presenter, to turn it off.
- To see the graph, press "ZOOM" then press "9" for ZoomStat. This automatically takes the data in lists L1 and L2 and graphs them.
- To see what the data points are, press "TRACE", then use the right, left, up, and down arrows to view what each data points represents.
- If you want the points connected, go into STAT PLOT, press ENTER for Plot 1, and choose the second graph in "Type".
- A linear regression of the data can be produced as well. Press STAT and cursor right to CALC. Press 4 to select LinReg. At the flashing cursor, press ENTER. The equation for the line will appear. The "r =" value is how closely the line fits the data. Press the "Y=" key and clear any data that appears by putting the cursor right after the "=" sign and pressing CLEAR. With all of them cleared out, press VARS, then press 5 for "Statistics". Cursor to "EQ", then press 1 for the RegEQ. The equation appears next to the Y1= . Now press GRAPH and you will see your



original plot and a line that best fits the data.

12. Press 2nd then WINDOW. For TblStart, enter 0. For "DTbl," enter 0.1.
13. Press 2nd GRAPH and you will see a table that allows you to view the calculator's predictions of the percent changes for molarities that were not examined (extrapolation).

Questions

1. Write a paragraph explaining what happened to the distilled water in each container.
2. Predict what would happen if potassium iodide were placed in the cup with the distilled water. Make a statement that starts by saying, "If potassium iodide was added to the distilled water, I predict that...." Do you think that the weight change of the solution in the dialysis tubing would be more, less, or the same. Why?
3. How does this activity relate to that of a cell and a cell membrane?
4. List some advantages and disadvantages of using the glovebox for this activity.
5. If you were an astronaut in space performing this activity, what part(s) of the procedure would have to be changed?
6. Does the rate of diffusion increase, decrease, or stay the same in a microgravity environment? Explain.



| Grade Level | Subjects |
|-------------|-----------------------------------|
| 9-12 | Physical Science Algebra I, II |

Displacement-Time Graphs Using the Motion Detector

Introduction

When an object is in motion, it displaces or moves a distance in an amount of time. Displacement versus time graphs can be used to illustrate and analyze an object in motion.

This set of activities will use a motion detector attached to a graphing calculator to gather data on an object in motion. The motion detector works by sending out sound waves or sonar that bounce off an object and return to the detector. From this information, the program can determine whether the object is moving farther away or closer, and the time period. The graph of the object's motion will be displayed for further analysis, such as finding the best fit line and the slope of the line.

Objective

- Students will measure the displacement of an object using a motion detector.

Equipment (per group)

- Data collector (such as TI's CBL™ or Vernier's LabPro™)
- Graphing calculator
- Piece of cardboard or styrofoam plate
- Student glovebox
- Motion detector
- Data Mate Program*

Equipment Setup Procedure

1. Set up the experiment as shown in Figure 1.
2. Connect the data collector and the motion detector to the graphing calculator.
3. Turn on the graphing calculator and data collector.
4. Locate and begin MOTION program on the calculator. The calculator will store distance (in meters) in list L4, velocity values (meters per second) in list L5, and times (in seconds) in list L2.

Part 1. Making a Displacement vs. Time Graph

1. Hold the piece of cardboard or styrofoam plate approximately 0.5 meter above the motion detector.
2. Start the motion detector and slowly move the cardboard upward and away from the detector.
3. When your program stops retrieving data, graph the data on a distance vs. time graph.
4. Part of your graph should have a straight line sloping upward similar to Figure 2.
5. Since you will only be analyzing an object in motion, you will need to eliminate part of your graph. Using the tools on your calculator, remove any part of the graph that is not upward sloping (Figure 3).
6. Analyze the graph that remains, using a linear curve fit (dist. vs. time, if available). It will try to fit $Y = AX + B$ to the remaining data points (Figure 4).
7. The slope of this line (A) is distance / time, or the average velocity of the motion. This could be found another way, by locating two points on the line and using the slope formula.

* Data Mate comes installed on the CBL™ for the TI-83+. It is a generic program that will analyze the graphs from the data probes. Data Mate, CBL™, and TI-83+ are from Texas Instruments.



Equipment Setup

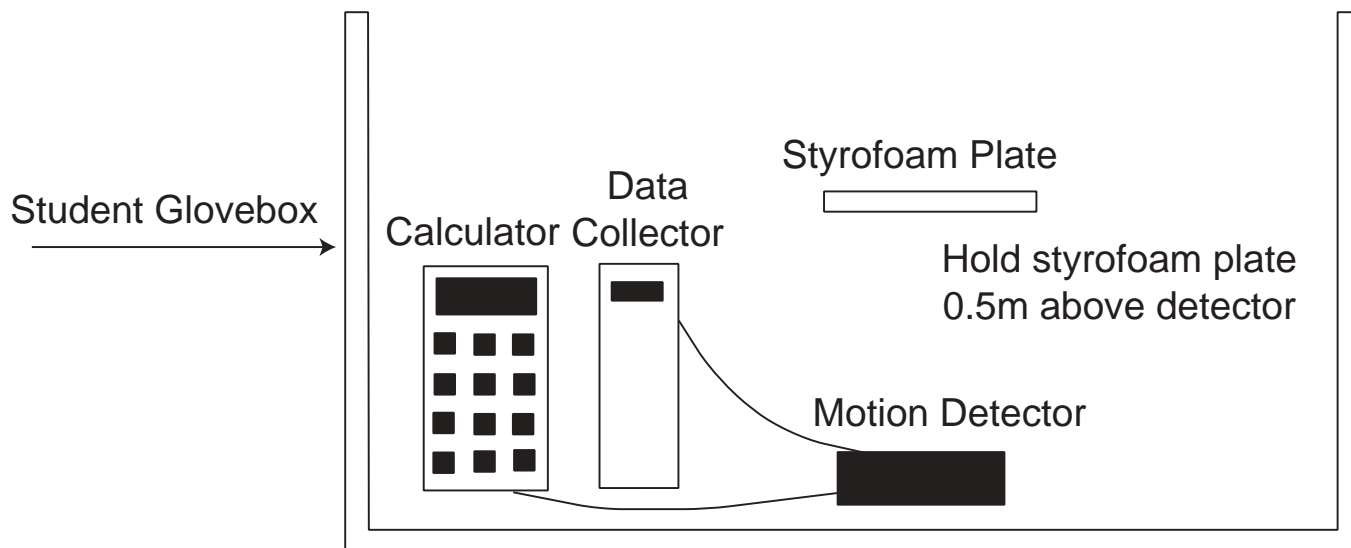


Figure 1.

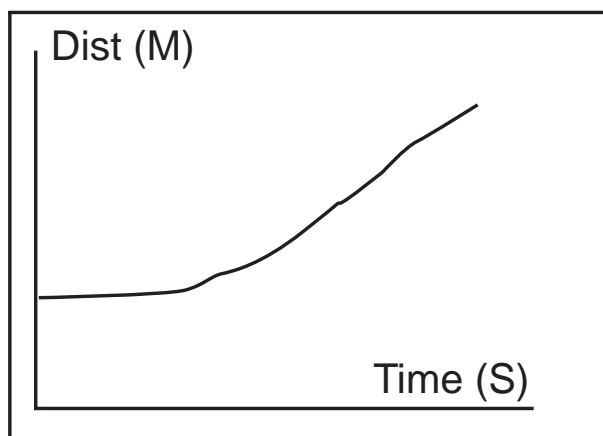


Figure 2.

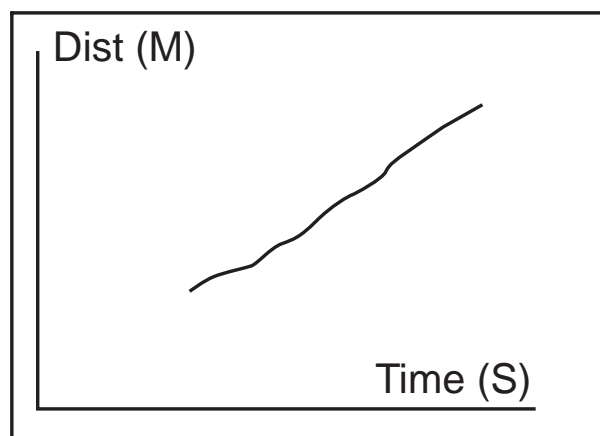


Figure 3.

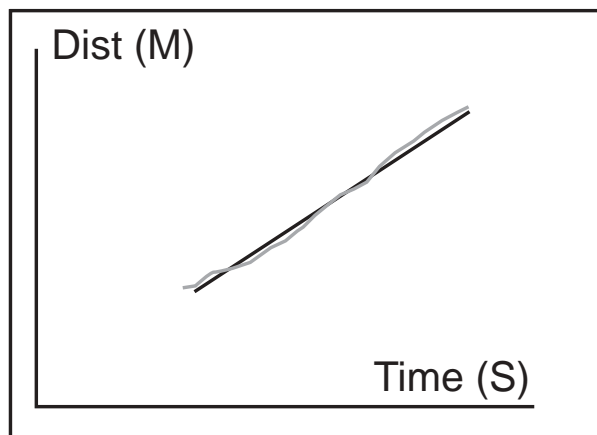
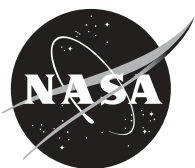


Figure 4.



Part 2. Predicting Displacement vs. Time Graphs

1. Draw 2 or 3 different displacement vs. time graphs on a piece of paper, and try to duplicate that motion with the motion detector.
2. Describe in written paragraph form, how you moved the cardboard to achieve these graphs.

Part 3. Matching Distance-Time Plots

1. If you have a program that randomly generates Distance-Time graphs, called DTMATCH, open the program and select a graph by pressing ENTER.
2. Try to duplicate the motion of the graphs. Press ENTER to show the motion of the cardboard displayed.
3. Take turns with others in your group.
4. Have each person describe what needs to be changed to improve the results.

Extensions (Use the MOTION Program)

Reset the calculator and create a graph:

1. in which the slope is steeper than the original.
2. in which the slope is negative, or downward sloping.
3. in which the slope is steeper than the previous graph.
4. that is curved upward.
5. that is curved downward.

Questions

1. If an object is stationary, how would the motion graph appear?
2. If an object is moving away quickly, how would the graph appear?
3. If an object is moving slowly closer, how would the graph appear?



| Grade Level | Subjects |
|-------------|---|
| 9-12 | Physical Science Algebra I, II Algebra-Trig |

Free Fall

Introduction

Gravity is such an accepted part of our lives that we rarely think about it even though it affects everything we do. Any time we drop or throw something and watch it fall to the ground, we see gravity in action. Gravitational attraction is a fundamental property of matter that exists throughout the known universe. Physicists identify the gravitational force as one of the four types of forces in the universe. The others are the strong and weak nuclear forces and electromagnetic forces.

When an object is falling without any other forces acting on it except gravity, the object is said to be in a state of free fall. Any object in free fall experiences microgravity conditions, which occur when the object falls toward the Earth with an acceleration equal to that due to gravity alone (approximately 9.8 m/s^2 or 32 ft/s^2 , or 1 g at the Earth's surface).

How would the graph of this motion appear on a Velocity-Time graph? Would it be a curve, a straight line, sloping upward, sloping downward, horizontal, or vertical? Since the force of gravity causes an acceleration on the object starting from rest, the graph would be a straight line, sloping upward, starting at zero. What would be the numerical value of slope of the line? The slope of the line would be equal to the acceleration of gravity, or 9.8 m/s^2 (32 ft/s^2). In this activity, you will use data you collect to find the slope of a Velocity vs. Time graph of an object in free fall and then compare your results to the value of g , 9.8 m/s^2 (32 ft/s^2).

Objective

- Students will measure the acceleration due to gravity of a ball in free fall.

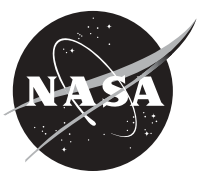
Materials (per group)

- Graphing calculator
- Data collector (such as TI's CBL™ or Vernier's LabPro™)
- Motion detector
- Racquetball
- Nylon cord (2-3 meters)
- Glovebox
- MOTION and PLOTS programs*

Procedure

1. Connect the calculator to the data collector and the motion detector in the correct ports (Figure1).
2. Turn on all devices.
3. Make two holes through a racquetball using a sharp object, such as a needle. Thread the nylon cord through the two holes, making a knot on one end. Attach the other end of the nylon cord to a support so that the ball hangs approximately 50 cm above the motion detector.

* MOTION and PLOTS are from the software contained in *Exploring Physics and Math with the CBL™*



Equipment Setup

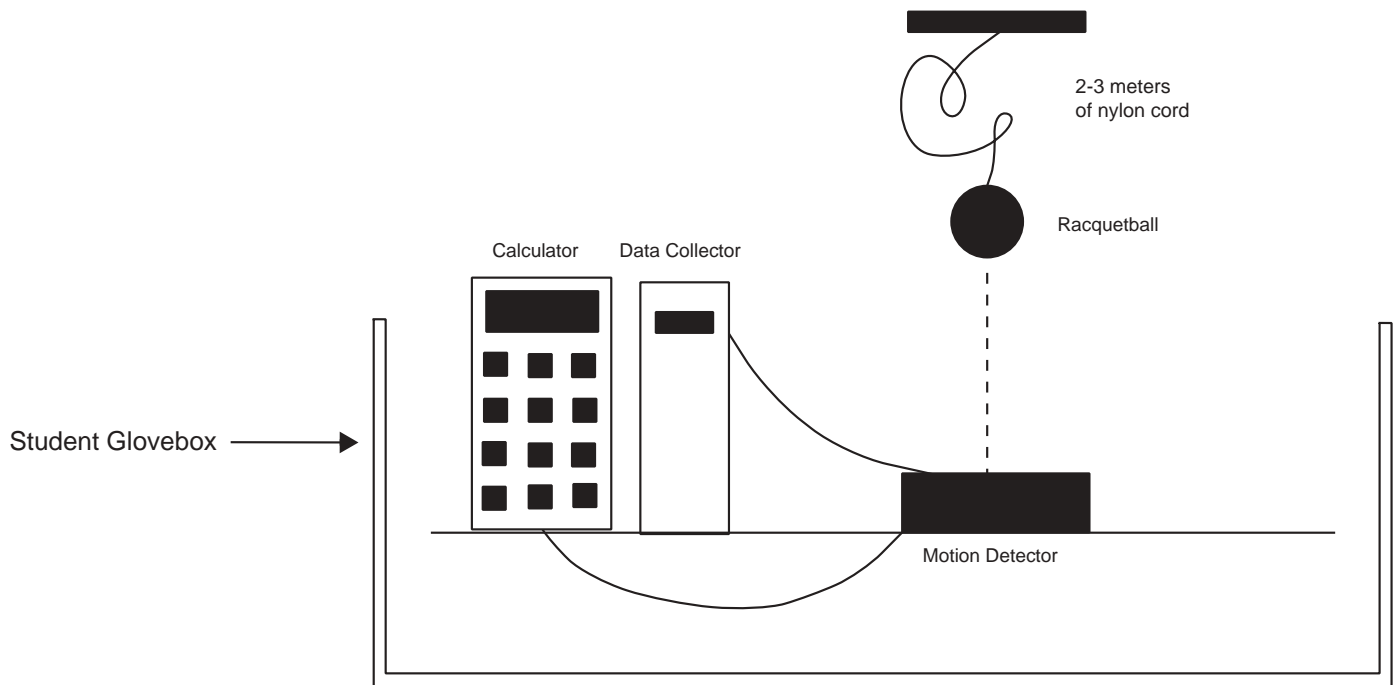
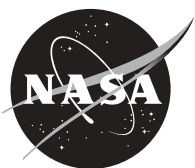


Figure 1

4. Select PROGRAM and then MOTION on the calculator. Press ENTER and ENTER again.
5. When prompted for zeroing the motion detector, place a styrofoam plate at a height 50 cm directly above the motion detector. Press ENTER. Enter 5 seconds when prompted for the collection time.
6. Have your partner stand on a chair or stool to hold the ball at least 2 meters above the motion detector with the excess nylon cord in their hand. Make sure that your partner is holding the ball high enough so that when the ball is released, it will not hit the detector and damage it.
7. When you are ready to start collecting data, press ENTER. Have your partner release the ball and the cord as soon as you hear the clicking sound of the detector. This sound indicates that it is collecting data. Note: If the ball does not fall in a straight line, you will have to recollect data.
8. After the detector is finished collecting data, select VELOCITY-TIME for a plot under the PLOT OPTIONS menu to see the graph of velocity vs. time for the racquetball.
9. To ZOOM into the graph, press ZOOM 1 to use the cursor to select opposite corners of the rectangular box around the straight line portion where the ball was in free fall. Press ENTER to zoom in on the boxed-in portion of the graph. Use the cursor to locate an opposite vertex of the rectangular box, then press ENTER. When you have found the portion of the graph from time zero to 3 seconds, sketch the graph on the worksheet. Be sure to label and scale the axes properly. Note: If you have difficulty with the ZOOM feature, try setting your WINDOW for these values: $X_{\min} = 0$, $X_{\max} = 5$, $X_{\text{scl}} = 0.1$, $Y_{\min} = 0$, $Y_{\max} = 30$, $Y_{\text{scl}} = 0.1$.



10. The velocity vs. time graph that you obtain should be a straight line, which means it has a constant slope (Figure 2). Using the trace function, find the slope of the line by locating two points on the line and finding their coordinates. Record the coordinates of these two points on your worksheet.
11. Using the slope formula, find the slope of the line [$m = (y_2 - y_1) / (x_2 - x_1)$]. Record the value of the slope on your worksheet.
12. Repeat the above procedure two more times, and take the average of the three slope values. You might also try giving the ball an initial push downward, instead of just dropping it.
13. Percent of Error is calculated by the following formula:

$$\text{Percent of Error} = \frac{(\text{Accepted Value} - \text{Experimental Value})}{\text{Accepted Value}} \times 100$$

Use your average value of g for the experimental value and 9.8 m/s^2 for the accepted value.

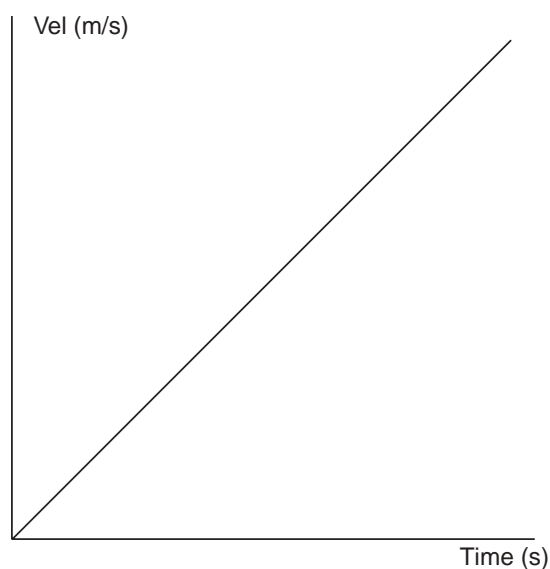


Figure 2



Worksheet

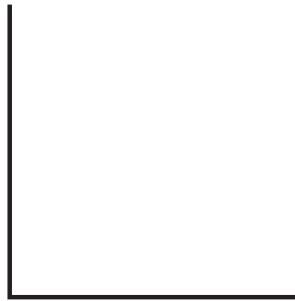
| Trial | Coordinates of point 1 x_1, y_1 | Coordinates of point 2 x_2, y_2 | Slope $(y_2 - y_1) / (x_2 - x_1)$ |
|-------|-----------------------------------|-----------------------------------|-----------------------------------|
| 1 | | | |
| 2 | | | |
| 3 | | | |

Average Slope _____ Percent of error _____

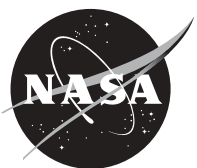
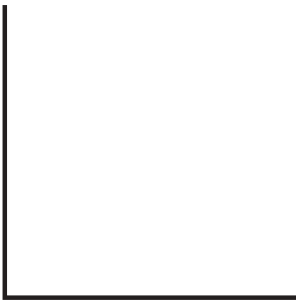
Graph of Trial 1:
Velocity vs. Time of Free Fall



Graph of Trial 2:
Velocity vs. Time of Free Fall



Graph of Trial 3:
Velocity vs. Time of Free Fall



| Grade Level | Subjects |
|-------------|---|
| 10-12 | Physical Science Algebra I, II Algebra-Trig |

Finding the Value of “g” on an Incline

Introduction

Galileo Galilei was an Italian scientist and mathematician who did research that contributed to our understanding of gravity. Before his investigations in the late 1500’s, the scientific community accepted the beliefs of Aristotle. Aristotle (384-322, B.C.), who did not perform any scientific research, as we know it, made his conjectures based on close observations. It seemed to Aristotle that the heavier an object was, “the more eagerly it would strive to achieve its proper place,” since the “heaviness was the manifestation of its eagerness to return to this place.” Therefore, a heavier object would fall more rapidly than a lighter one. It was not until Galileo that this problem was reconsidered.

Galileo had a laboratory where he took measurements and recorded data. Although he had timing instruments, they were not precise enough to measure free fall, so he used an inclined plane instead. When the ramp angle is increased, the acceleration also increases. There is a direct proportion between acceleration and the sine of an angle. In this activity, you will use a motion detector to measure the acceleration of an object rolling down an incline at various angles. From this data, you will be able to extrapolate the acceleration due to gravity as a function of the incline angle increased to 90° . A drop of 90° is the same as free fall, so you will be determining the value of g.

Objectives

- Students will determine the value of acceleration of objects rolling down an inclined plane.
- Students will determine the relationship of acceleration and the angle of incline.
- Students will determine the value of g from a set of acceleration values.

Materials (per group)

- Graphing calculator
- Data collector (such as TI’s CBL™ or Vernier’s LabPro™)
- Motion detector
- Inclined plane (1-2 meters long)
- Small car or ball
- Meter stick
- Books
- MOTION and PLOTS programs*

Procedure

1. Place one book under the end of a ramp that is between 1 and 2 meters in length.
2. Place the motion detector at the top of the ramp, facing down the incline (Figure 1).
3. Connect the graphing calculator to the data collector and the motion detector.
4. Turn on all devices.
5. Find the calculator program MOTION, and start the program.
6. Release the cart or the ball, trying not to place your hand in the path of the detector.

* MOTION and PLOTS are from the software contained in *Exploring Physics and Math with the CBL™ System*, 1984, from Texas Instruments.



Equipment Setup

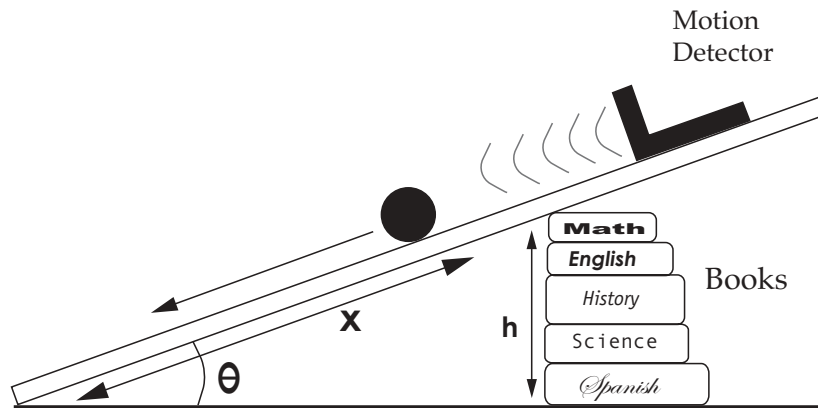


Figure 1.

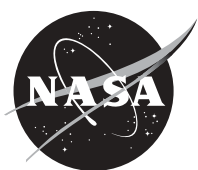
7. To see your graph, select the Distance-Time graph and decide which portion of the graph is relevant to rolling down the incline. Eliminate the portion from the graph that you believe is extraneous.
8. Select the Velocity-Time graph to analyze, performing a best-fit curve on the graph.
9. Record the slope of this line as the acceleration of the motion.
10. Measure the height and length of the ramp, and write the slope of the Velocity-Time graph in the chart below.
11. Find the sine of the angle by dividing the height, h , by the length, x , and record this value.
12. Repeat this four more times, increasing the height each time.

Analysis

To find the value of acceleration due to gravity (g), you will use the values that you found on the inclined plane, and extrapolate the value for a 90° angle. You will need to plot the above values in an Acceleration vs. $\sin \theta$ graph. Then using the graphed data, extend the line to find the acceleration when θ equals 90° .

Data Table

| Number of Books | Height h (m) | Length of incline x (m) | Slope | $\sin \theta$ | Acceleration (m/s^2) |
|-----------------|----------------|---------------------------|-------|---------------|--------------------------|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |



| Grade Level | Subjects |
|-------------|---|
| 10-12 | Physical Science Algebra I, II Algebra-Trig |

Spectroscopy

Introduction

The purpose of spectroscopy is to identify materials with minimal disturbance. For example, if one is observing a clear liquid inside a cell, spectroscopy can be used to identify the material, instead of destroying the cell itself. Spectroscopy can also be used to identify substances of remote objects, such as stars or what elements make up the minerals on Mars. Spectroscopy measures the interaction of light (visible or not) with the substances that make up the material. When light hits any object, some of it gets absorbed, some of it gets scattered, and some of it passes through. Depending on the characteristics of the substance, this amount varies. For example, if you have grape gelatin in a glass dish, the amount of red and blue light that passes through or gets scattered is high (producing the color purple), while the green will have high absorption.

The formula for transmittance, T , of a given wavelength of light through a solution is the ratio of the intensity of light transmitted through a substance, I_t , to the intensity of light striking the substance, I_o . It can be expressed mathematically as $T = I_t / I_o$

To express it as a percent, change the fraction to a decimal, multiply by 100 and attach the percent symbol. For example, $T = 3/4 = 0.75 = 75\%$

In the grape gelatin example, the **absorption** of green light was high, while the absorption of red and blue light was low (since most was transmitted or reflected). What we will be measuring in this activity is the relationship of the absorbed light with the transmitted light. The relationship of the absorbed light's wavelength is the logarithm inverse of the transmitted light's wavelength. If A is the wavelength of absorbed light, and T is the wavelength of transmitted light, then $A = \log(1/T)$ or $A = \log(100/\%T)$

In this activity, you will use a colorimeter to measure the transmittance of different colored solutions as they are illuminated with either blue (470 nm), green (565 nm), or red (635 nm) light. The solutions you will use have been formed by diluting regular food coloring (red and blue) with water. Given these two solutions of red and blue food coloring, which will most weakly transmit red light? _____ Will this solution strongly or weakly absorb red light? _____ (yes or no)

Objective

- Students will use a colorimeter to measure the amount of transmitted light in different colored solutions.

Materials (per group)

- Data collector (such as TI's CBL™ or Vernier's LabPro™)
- Graphing calculator
- Colorimeter*
- Red and blue food coloring stock solution (use 3 drops of food coloring per 500 ml of distilled water for each color)

* The colorimeter used for this experiment was a Vernier with a DBL DIN adapter from Vernier Software & Technology.



| Wavelength (nm) | Color |
|-----------------|--------------|
| 650-800 | red |
| 595-640 | orange |
| 580-595 | yellow |
| 560-580 | yellow-green |
| 500-530 | green |
| 490-500 | blue-green |
| 460-480 | blue |
| 440-450 | violet-blue |
| 390-430 | violet |

Source: S. Eskinazi, [Numerical Modeling of Color](#).

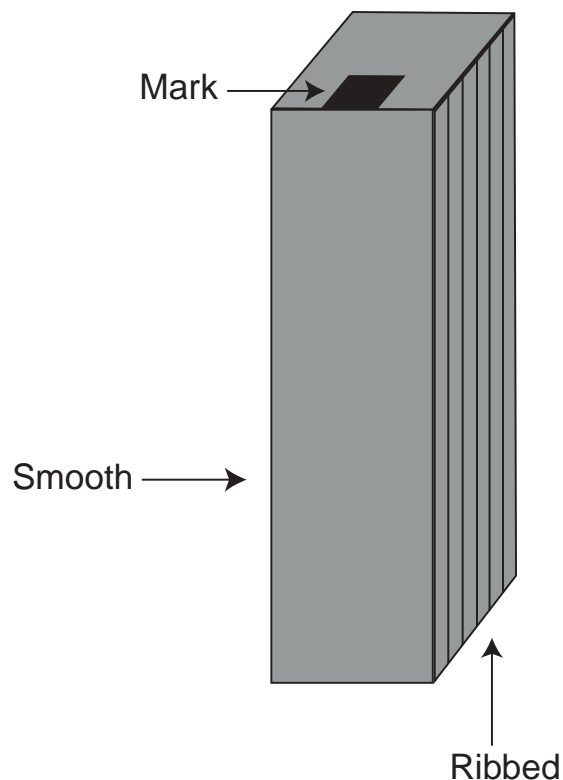


Figure 1.

Procedure

1. Connect the calculator to the data collector and to the colorimeter.
2. Fill one of the cuvettes 3/4 full with distilled water and cap it. This is the blank cuvette.
3. Fill one of the remaining cuvettes 3/4 full with the blue solution and cap it. Fill the last cuvette 3/4 full with the red solution and cap it.
4. Using the waterproof marker, mark the edge of each cap above one of the smooth sides of the cuvette (Figure 1).
5. Turn on the calculator and the data collector, press PROGRAM on the calculator and choose COLOR.
6. The program will prompt you to insert either the blank, the blue, or the red cuvette into the colorimeter. Make sure the cuvette is clean and dry. Make sure that there are no bubbles in the solution. **Do not** touch the smooth sides of the cuvette.
7. Make sure when you insert the cuvette, the mark on the cap is next to the white reference mark on the top of the colorimeter.
8. Make sure the colorimeter lid is closed before pressing TRIGGER.
9. Your calculator should show a scatter plot of the wavelengths (Figure 2).

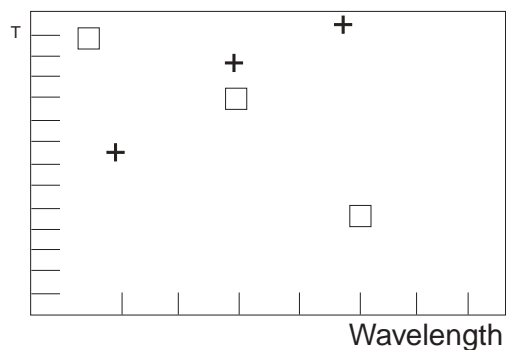
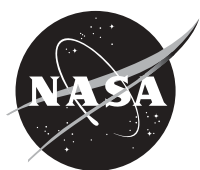


Figure 2.



Recording the Data

- The data recorded in the experiment is stored in lists L1, L2, and L3. The wavelengths of the light used are stored in L1, in nanometers. The percent transmittance of the blue solution at each wavelength is stored in L2, and the percent transmittance of the red solution at each wavelength is stored in L3. The scatter plot represents percent transmittance with respect to wavelength for the blue solution, indicated by a \square , and the red solution, indicated by a $+$. In the box below, sketch your scatter plot.

- Write a sentence or two describing how the percent transmittance of the red and blue solutions changed as the wavelength of the light increased.

Analyzing the Results

- Use the data from your scatter plot to complete the following table.
 - How did your results compare with your prediction?

| Wavelength (nm) | Color of Solution With Lowest %T | Color of Solution With Highest %T |
|-----------------|----------------------------------|-----------------------------------|
| 470 | | |
| 565 | | |
| 635 | | |



2. Explain any differences in the results that you obtained with what you predicted. What physical limitations may have affected your experiment? (Possible sources of error)
-
-

3. Use the following keystrokes on your calculator to convert the percent transmittances in lists L2 and L3 to absorbances:

```
LOG ( 100 / 2nd L2 ) STO 2nd L4 ENTER  
LOG ( 100 / 2nd L3 ) STO 2nd L5 ENTER
```

This stores the absorbances of the blue and red solutions in L4 and L5, respectively.

4. A plot of the absorbance of a solution at different wavelengths of light is called an absorption spectrum. Although you have only three data points for each solution, you can still construct a very simplified absorption spectrum for each solution. To do this, construct two scatter plots. The scatter plots should represent the absorbances in L4 and L5 with respect to the wavelengths in L1. Graph the scatter plots on the same viewing screen. Sketch the results in the space below.



5. Using the scatter plot you drew, describe in a sentence or two how the absorbance of the blue and red solutions changed as the wavelength of the light increased.
-
-
-



6. Using the same scatter plots, complete the following table. How do your results compare with your predictions? Explain below.

| Wavelength (nm) | Color of Solution With Lowest A | Color of Solution With Highest A |
|-----------------|---------------------------------|----------------------------------|
| 470 | | |
| 565 | | |
| 635 | | |

7. Use the relationship between percent transmittance (%T) and absorbance to compare your first scatter plot (Recording the Results) and the graph you made in #4 (Analyzing the Results).

8. Use the relationship that you determined between percent transmittance (%T) and absorbance to complete the following table. Can you determine the color of the solution from the given information? Explain your reasoning.

Color _____



| Wavelength (nm) | % Transmitted | Absorbance |
|-----------------|---------------|------------|
| 470 | 85 | 0.07 |
| 565 | 57 | |
| 635 | | 0.54 |



| Grade Level | Subjects |
|-------------|-----------------------------------|
| 9-12 | Physical Science Algebra I, II |

Velocity-Time Graphs Using the Motion Detector

Introduction

When an object is in motion, it moves with a certain speed or velocity. Velocity is defined as an object's total displacement divided by time. Velocity-Time graphs can be used to illustrate and analyze an object's motion.

This set of activities will use a motion detector attached to a graphing calculator to gather data on an object's velocity. The motion detector works by sending out sound waves or sonar that bounce off an object and return to the detector as the object moves in a straight path. From this information, the program can determine the speed of the object, and whether the movement is moving closer or farther away. Since velocity is a vector quantity, both values of size or magnitude and direction are required. The graph of the object's velocity will be displayed for further analysis, such as finding the best-fit line and the slope.

Objective

- Students will measure an object's velocity using a motion detector.

Equipment

- Data collector (such as TI's CBL™ or Vernier's LabPro™)
- Graphing calculator
- Student glovebox
- Data Mate Program
- Piece of cardboard or styrofoam plate
- Motion detector

Equipment Setup Procedure

1. Set up the experiment as shown in Figure 1.
2. Connect the data collector and the motion detector to the graphing calculator.
3. Turn on the graphing calculator and data collector.
4. Locate and begin the Data Mate* program on the calculator.
5. Zero the motion detector at a distance farther than 0.4 meters. Enter a collection time period for 5 seconds, if prompted.
6. The calculator will store distance (in meters) in list L4, velocity values (meters per second) in list L5, and times (in seconds) in list L2.

* Data Mate comes with the CBL™ for the TI-83+. It is a generic program that will analyze the graphs from the data probes. The Data Mate, CBL™, and TI-83+ are from Texas Instruments.



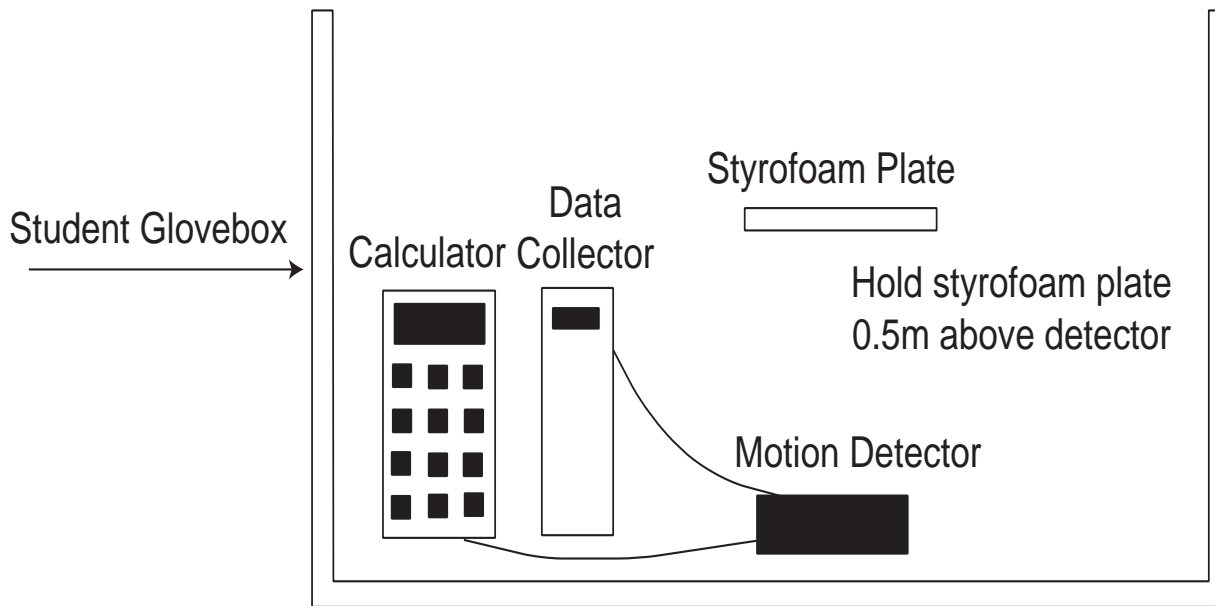


Figure 1.

Procedure: Making a Velocity vs. Time Graph of Constant Motion

1. Hold the piece of cardboard or styrofoam plate approximately 0.5 meter above the motion detector.
2. Start the motion detector and slowly move the cardboard upward and away from the detector.
3. When your program stops retrieving data, graph the data on a velocity vs. time graph.
4. Part of your graph may have a graph similar to Figure 2.
5. Since you will only be analyzing an object in constant motion, you will need to eliminate part of your graph. Using the tools on your calculator, remove any part of the graph that is not wanted. Eliminate extraneous data in the graph, such as what might occur in the very beginning or the end. Figure 3 shows the graph with extraneous data removed.
6. Analyze the graph that remains, using a linear curve fit (use velocity vs. time, if available). It will try to fit $Y = AX + B$ to the remaining data points. Figure 4 shows a best-fit line for the data.
7. The slope of this line (A) is the **change in velocity/change in time**, or the acceleration of the motion. This could be found another way, by locating two points on the line and using the slope formula, $(Y_2 - Y_1) / (X_2 - X_1)$. If you moved the cardboard in a constant motion away from the detector, what value should your best-fit line approximate?

Part 2. Predicting Velocity vs. Time Graphs

1. Draw two or three different velocity vs. time graphs on a piece of paper and try to describe in a paragraph how to move the cardboard to achieve each type of motion with the motion detector.
2. Test your prediction by moving the cardboard as described.

Part 3. Identifying Velocity-Time Plots

Using the motion detector as a point of origin, describe how you would move the cardboard, relative to the detector, to have a graph that starts on the positive Y-axis and:



1. slopes upward at a steep angle.
2. slopes downward at a steep angle.
3. stays parallel to the positive X axis.
4. slopes downward to the X axis, intersects the X axis, then moves back up at an angle, forming a V.

Extensions

Reset the calculator and try to create a graph:

1. in which the slope is steeper than the first graph in the lab activity.
2. in which the slope is negative or downward sloping.
3. in which the slope is steeper than the graph in the previous graph.
4. that is curved upward.
5. that is curved downward.

Questions

Draw a sketch of each of these types of motion on a Velocity-Time graph and a Distance-Time graph if an object is:

1. moving away at a constant and slow rate.
2. moving away quickly at a constant rate.
3. moving away at an accelerated rate.
4. free-falling from a ledge high above the observer, who is located on the ground below.

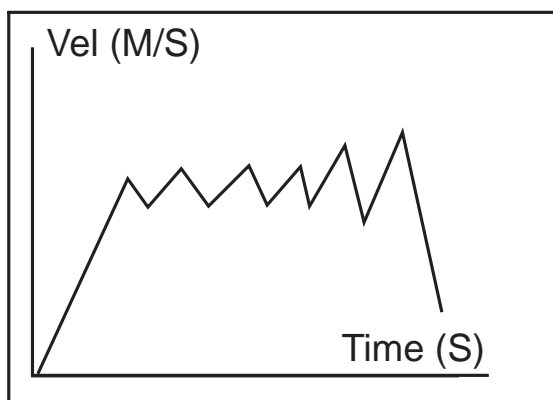


Figure 2.

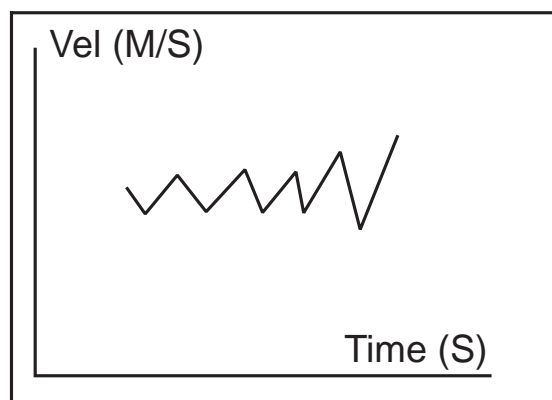


Figure 3.

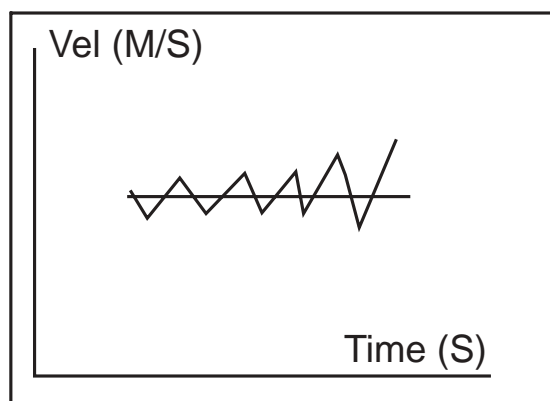


Figure 4.



Glovebox Activities



| | |
|-------------|------------------|
| Grade Level | Subjects |
| 9-12 | Physical Science |

Capillary-Driven Heat Transfer

Introduction

Capillary Pumped Loops (CPLs) are devices used to transfer heat from one location to another using capillary action. In low-gravity applications such as satellites (and possibly the International Space Station), CPLs may be used to keep electronic devices from overheating by transferring heat to space radiators. The transfer of heat with a CPL is accomplished by evaporating one liquid surface at the hot side and condensing the vapor produced onto another liquid surface at the cold side. Capillary action, the phenomenon that causes paper towels to absorb spilled liquids, is used to “pump” the liquid back to the evaporating liquid surface (hot side) to complete the “loop.”

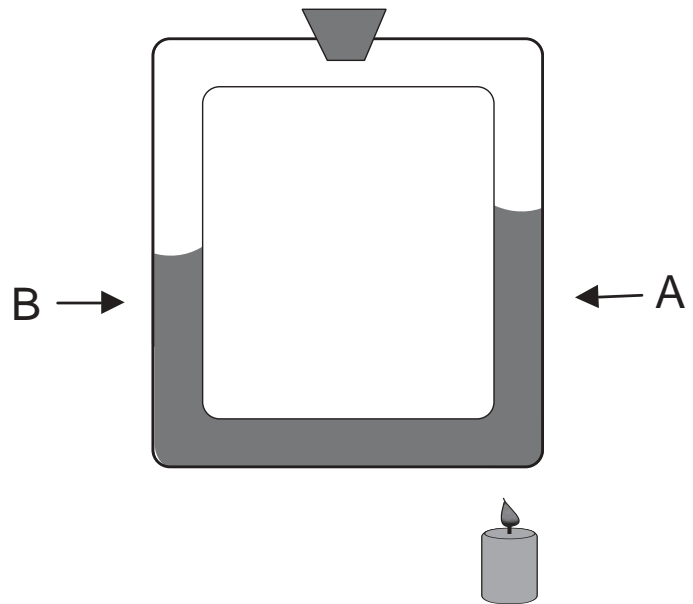


Figure 1. Heat Driven Capillary Apparatus Used on Earth

The advantages of CPLs are that they require no power to operate and they can transfer heat 30 feet or more. Their reliance upon evaporation and condensation to transfer heat makes them much more economical in terms of weight than conventional heat transfer systems. The disadvantage of CPLs is that they have proven to be unreliable in space operations and the explanation for this reliability problem is a subject of study.

The Capillary-Driven Heat Transfer (CHT) investigation was conceived to study the fundamental fluid physics phenomena thought to be responsible for the failure of CPLs in low-gravity operations. CHT was conducted in the Microgravity Glovebox (MGBX) facility in Shuttle Columbia’s *Spacelab* during the first Microgravity Science Laboratory (MSL-1) mission in July 1997.

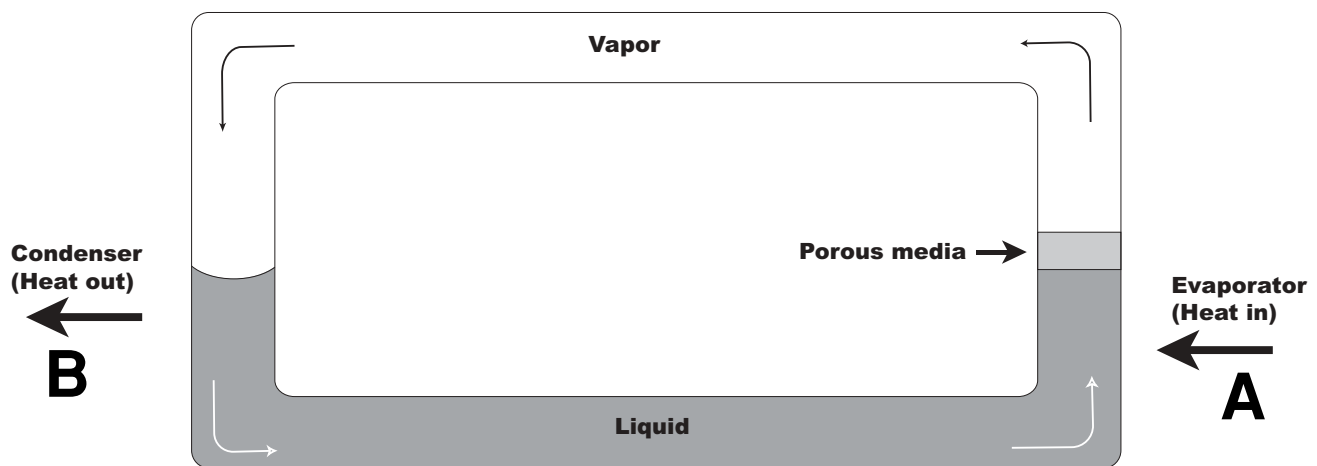


Figure 2. Capillary-Driven Heat Transfer Apparatus Used in Microgravity



Objective

- Students will observe the transfer of heat by a convection driven capillary loop.

Materials (per group)

- Glass convection loop, able to withstand high temperatures
- Hot flame
- Food coloring
- Clamp
- Stand
- Water

Procedure

1. Fill the convection loop half full with colored water.
2. Lightly close off the opening of the loop.
3. Clamp the loop to a stand.
4. Heat a bottom corner of the loop.
5. Observe the motion of the water in the loop.

Questions

1. How does the heat affect the water?
2. As the water expands, how is the density affected - does it get lighter or heavier?
3. What are examples of some naturally occurring convection currents?
4. How would you expect this experiment to perform in microgravity?

Explanation

The heat from the flame heats the water on one side of the loop, which makes the water expand at that spot (Point A-Figure 1). The expanding water is less dense than it was before heating and it rises. The water on the other side of the loop (Point B-Figure 1) is comparatively cooler and more dense, causing it to sink. This rising and sinking creates a convection current within the loop.

In the CHT Glovebox investigation, the water did not rise when heated. Instead, when it changed to vapor at point A (Figure 2), it traveled through the loop and recondensed at the other side of the column at point B (Figure 2). A condenser was placed at this location (B) to transfer the heat away to another location. Originally, it was thought that capillary action would cause the return of the liquid to the original point.

What Was the Outcome?

Scientists observed the formation of a continuous liquid film over the entire length of the return tube. Immediately after applying heat, a liquid film could be seen advancing along the wall of the return portion due to the condensation of vapor on the cooler walls of the loop. At the elbows of the tube, the liquid pooled on the outer radius of the tube, forming slugs. This pool of liquid collected into a lobe that would eventually bridge or block the vapor line, causing it to fail.



References

Capillary pumped heat transfer (CHT) experiment. Hallinan, K. P., University of Dayton, Dayton, Ohio, & Allen, J. S., National Center for Microgravity Research, Cleveland, Ohio.



| Grade Level | Subjects |
|-------------|--|
| 9-12 | Physical Science Biology Chemistry |

Colloidal Suspensions

Introduction

Everything in the universe is made from the same building blocks — atoms. All physical properties of matter, such as weight, hardness, and color, are determined by the combination of atoms present in a substance, the way atoms interact with each other, and the type of arrangements they form. The size of atoms and the complex ways groups of atoms organize themselves to form various states of matter make them very difficult to study. One way to overcome these problems is by studying systems of simple, larger particles that behave in similar ways. On the STS-95 mission, which launched October 29, 1989, the second Colloidal Disorder-Order Transition (CDOT-2) experiment tested the fundamental theories of matter that describe atomic behavior. Researchers used colloids to learn more about how the organization of atoms changed as they form into orderly solid structures. They used colloidal hard spheres suspended in liquid in varying concentration to model this behavior. In samples with a certain level of concentration of hard spheres, crystal-like structures form. The behavior of these systems is similar to the changes in atomic structure that take place in the transition from liquid to solid, such as when water freezes. Initially, atoms in the water are randomly distributed, but as the water freezes, atoms organize into crystalline arrangements.

Colloids are systems of fine particles suspended in a fluid. Milk, orange juice, and paint are some common examples. CDOT-2 used colloidal suspensions of uniformly sized microscopic solid plastic spheres as a model of atomic interactions. On Earth, gravity causes the denser particles in a colloidal suspension to settle to the bottom, which is why some colloids, like orange juice and paint, must be shaken or stirred before use. This settling makes it difficult to study colloids in ground-based laboratories. In microgravity, the effects of density differences between particles and their surrounding fluids are decreased; thus, the particles disperse evenly within the fluid.

Objectives

- Students will observe two different density fluids in the same container.
- Students will observe the effects of an emulsifier on two liquids.

Materials (per group)

- 500 ml clear glass jar or beaker
- Graduated cylinder
- Stirrer
- Water
- Cooking oil
- Liquid detergent

Procedure

1. Fill the beaker with 250 ml of water.
2. Add 125 ml of oil on top of the water.
3. Stir the two liquids. Allow the liquids to sit for a while and then observe.
4. Squirt some liquid detergent on top of the oil and stir thoroughly.
5. Let the liquids stand for a while and observe. (You may need to add more detergent, stir more vigorously, or both.)



Questions

1. After the first stirring, what did you observe?
2. How did the liquids behave after adding the detergent?
3. Why? Explain.
4. How do you think this experiment would behave in microgravity?

Extension

The detergent acts as an “emulsifier” and allows the small drops of oil to stay dispersed in the water. This suspension of different density substances is called a colloid. Some other examples of a colloid are paint, mayonnaise, salad dressing, milk, foam, smoke, smog, gelatin, and muddy water. Gelatin is an example of a solid dispersed in a liquid, while smoke is an example of a solid dispersed in a gas (air). Can you think of some other types of colloids and identify what types of matter they are?

References

CDOT-2: A new approach to uncovering atomic behavior, Paul Chaikin, Principal Investigator, Princeton University. National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, AL.



Damping

| Grade Level | Subjects |
|-------------|---|
| 10-12 | Physical Science Algebra I, II Algebra-Trig |

Introduction

The Microgravity Science Glovebox (MSG) is located in the U.S. *Destiny* Lab onboard the International Space Station (ISS). This enclosed laboratory will be used by researchers and scientists to perform research and investigations that require a long term microgravity environment. One of the difficulties on the ISS, and on the Space Shuttle, is the effects of vibrations, such as those caused by closing or opening drawers, crew members exercising, normal operating vibrations, and so on. This is a problem because the vibrations can affect the results of an experiment. To solve this problem, NASA scientists have developed hardware that is inserted into the MSG to stop vibrations from reaching the experiment. The system is called a vibration isolator.

The vibration isolator uses the phenomenon called damping to reduce or eliminate the vibration. Damping occurs when frictional forces stop an object from vibrating, such as a swing or pendulum. If a swing or pendulum does not have any other forces acting on it, other than gravity and friction, it slowly begins to decrease and finally stop. The distance from the middle of the swing to its outermost point of vibration is called the amplitude. Damping causes the amplitude of a vibration to decrease with time. This experiment will use a spring and a graphing calculator with a data collection device to graph a damped vibration.

The equation for the motion of a damped vibration is $A = A_I e^{-t/C}$, where A_I is the initial amplitude, e is the natural logarithm base, t is the time in seconds, and C is the damping constant, measured in seconds. The damping constant depends on the physical characteristics of the oscillator or spring.

Objective

- Students will graph and measure the damping function of a spring using various sized weights on a spring.

Materials (per group)

- Graphing calculator
- 1 data collector (such as TI's CBL™ or Vernier's LabPro™)
- Motion detector
- Hanging masses & hanger
- Styrofoam plate or cardboard
- Ruler
- MOTION and PLOTS* Programs
- Support rod
- Student glovebox
- Coiled spring
- Ring stand
- Masking tape

* MOTION and PLOTS are from the software contained in *Exploring Physics and Math with the CBL System*, 1984, from Texas Instruments.



Equipment Setup

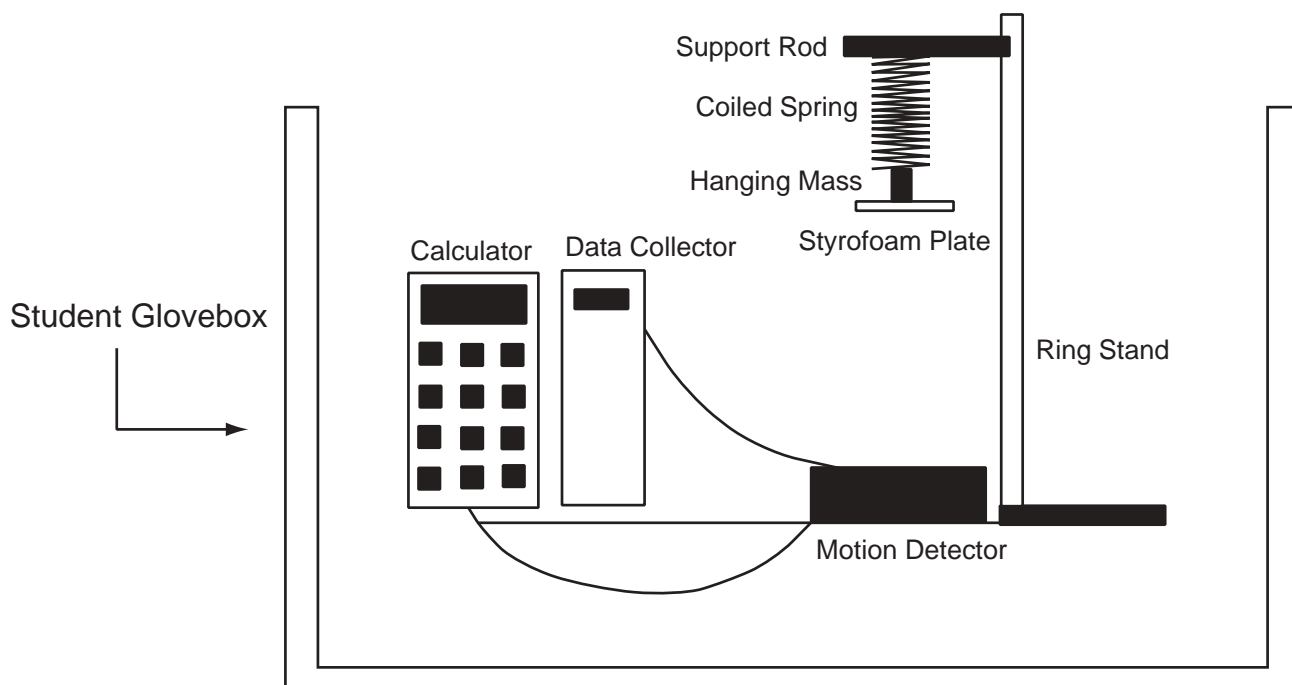


Figure 1

Procedure

1. Using the equipment setup shown in Figure 1, place materials in the glovebox. Because the equipment height is too tall to close the lid, leave it open but still use the gloves for all the work.
2. Connect the data collector to the graphing calculator and to the motion detector as shown in Figure 1.
3. Turn on the data collector and calculator.
4. Hang the coiled spring from the support arm on the ring stand. Tape a mass hanger to the styrofoam plate or piece of cardboard. Add a slotted weight to the hanger. Attach the hanging mass and plate to the end of the coiled spring. Place the motion detector face up on a flat, level surface below the styrofoam plate holding the hanging masses.
5. On the calculator, select the PROGRAM key then select MOTION from the menu list. Press ENTER. When prompted to zero the motion detector, place the styrofoam plate, with the hanging mass attached, where you want the X-axis to be located (stretch the coiled spring to a position somewhere between the natural hang location of the weighted plate and the motion detector). Hold the plate in this position while the calculator zeros the motion detector. When prompted for collection time, enter 10 seconds.
6. Adjust the height of the support so that the plate comes no closer than 50 cm to the motion detector. Press ENTER on the calculator when you are ready to start collecting data. Pull the weighted plate straight down 20 cm then let it go.



7. After the data collector has finished collecting data, select DISTANCE-TIME at the PLOT OPTIONS menu of the calculator to see a graph of distance vs. time for the oscillating mass.
8. Press TRACE to move along the position-versus-time plot. Determine the oscillator's initial amplitude (the highest Y coordinate closest to the Y-axis) and record this value as A_I on your worksheet.
9. Quit the program temporarily by hitting 2nd and QUIT.

Analysis

1. Store your recorded initial amplitude value for A_I as A. (On the home screen of the calculator, type the value for A_I , press STORE, press ALPHA, press A, which is the math key, and then press ENTER.) Also, store 0.1 as C.
2. Press Y= and move the cursor to the first available function register. Enter the damping equation, $Y = A e^{(-X/C)}$. If Plot 1 is not selected, place the cursor over Plot 1 and hit ENTER. Press GRAPH. Your graph should resemble Figure 2 below.

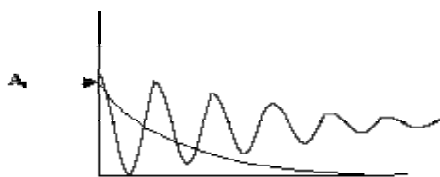


Figure 2

3. Try storing different values for C, increasing it by 0.1 each time, until the Y= graph passes through all the displayed amplitude positions. Sketch the graph that passes through all the displayed amplitude positions on your worksheet, along with the numerical value used for C. Note: You may have to change your window settings to see the graph better.
4. Repeat the process using a different hanging mass. Write a statement on your worksheet predicting how the value of C will be affected if you use a lighter or heavier mass. See if you can predict the value of C after performing several trials.



Worksheet

| Trial | Mass (grams) | A_1 | C |
|-------|--------------|-------|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

If I increase the mass on the vibrating/oscillating object, the value of C will _____.

My predicted value of C is _____, using a mass of _____. (trial 2)

My predicted value of C is _____, using a mass of _____. (trial 3)

Graph of Trial 1



$A_1 =$ _____

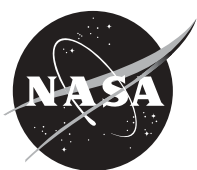
C = _____

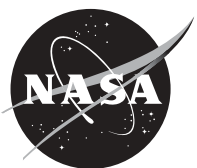
Graph of Trial 2



$A_1 =$ _____

C = _____



Graph of Trial 3 $A_1 =$ _____ $C =$ _____

| Grade Level | Subjects |
|-------------|------------------|
| 9-12 | Physical Science |

Floating Solids Between Liquids

Introduction

On June 25, 1992, the United States Microgravity Laboratory-1 (USML-1) *Spacelab* payload was launched aboard Space Shuttle *Columbia* as part of the STS-50 mission. *Spacelab* was a modular research laboratory flown within the Space Shuttle orbiter's cargo bay. The laboratory module was pressurized so astronauts could work in a laboratory environment in their shirtsleeves rather than bulky spacesuits. During the USML-1 mission, 31 experiments were conducted in four broad areas—materials science, fluid science, combustion science, and biotechnology. Of these 31 experiments, 16 were conducted in the USML-1 Glovebox (GBX).

One of the experiments conducted in the GBX was called “Stability of a Double Float Zone” or DFZ. The objective of the experiment was to determine if a solid cylinder can be supported by two liquid columns and remain stable in microgravity. It was theorized that it might be possible to increase the purity and efficiency of glass materials with a patented technique that relies on a solid column of material supported by two liquid columns, in which the solid and liquid were of the same substance. This technique was simulated using a variety of double float zone configurations. The concept was tested using Lexan® rods of different sizes and with different end geometries. A center rod was supported between two other rods by a float zone made of dyed water. The dyed water simulated the liquid portion of the float zone.

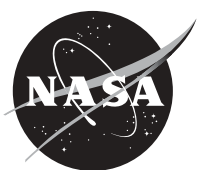
Although you cannot duplicate this experiment or a microgravity environment in your classroom, it is possible to study the floating of solids between two liquids. This activity requires the use of solids and liquids of varying densities. None of the substances are corrosive or harmful. However, always use caution when working with liquids.

Objective

- Students will compare the densities of different substances.
- Students will observe the positioning of solids floating between two liquids.

Materials (per group)

- 20 ml of corn syrup
- 20 ml of glycerin
- 20 ml of water
- 20 ml of alcohol
- 20 ml of water with 2 tsp. salt added
- 20 ml of corn oil
- String (One piece for each solid used, each piece needs to be longer than the height of the cylinder)
- Paraffin
- Steel bolt
- Styrofoam
- Cork
- Student glovebox
- Graduated cylinder (at least 150 ml)



Procedure

1. Place all materials in the glovebox. If the graduated cylinder is too tall to close the lid, leave it open but use the gloves for all the work.
2. Pour approximately 20 ml of each liquid into the graduated cylinder in the order given below. Try not to get any liquid on the interior walls of the cylinder (especially the thicker liquids). Do not stir or agitate the liquids. Allow time for each liquid to settle down (become still) before pouring on the next liquid. The order for pouring liquids is: corn syrup, glycerin, salt water, water, corn oil, alcohol.
3. Tie a piece of string around each of the solids. One-by-one, carefully drop each of them into the graduated cylinder. Allow time between each insertion for the liquids to settle down.

Questions

1. How does the density of steel compare with the density of glycerin?
2. Which substance is the least dense? Which substance is the densest?
3. Where did the paraffin end up?
4. What positions did each of the solids take? How do you account for this positioning?
5. Which substances have a density greater than one, equal to one, and less than one?
6. How do you think these substances would behave in microgravity?

Extension

Try other solids (buttons, glass rods, oil, wood, nylon, celluloid, etc.) and liquids (motor oil, molasses, sewing machine oil, etc.). Try to predict where each of these will float. Try to approximate the density of each (use the densities of known substances as a reference).

For the Teacher

Approximate Densities of Some
Common Substances

| Substance | Density (g/cm ³) |
|---------------|------------------------------|
| Alcohol | 0.78 |
| Celluloid | 1.24 |
| Cork | 0.2 |
| Corn Oil | 0.93 |
| Corn Syrup | 1.38 |
| Glycerin | 1.26 |
| Nylon | 1.1 |
| Paraffin | 0.9 |
| Polystyrene | 1.04 |
| Rubber Washer | 1.34 |
| Salt Water | 1.2 |
| Steel | 7.8 |
| Water | 1.0 |
| Wood | 0.7 |

Experiment Setup

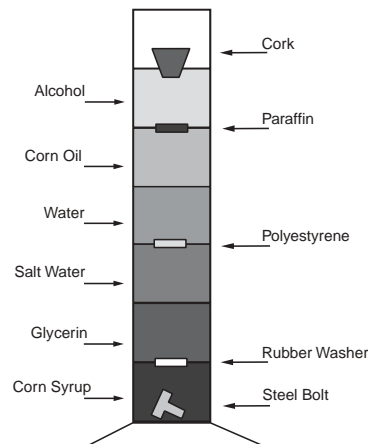


Figure 1.



| Grade Level | Subjects |
|-------------|-----------------------------|
| 9-10 | Physical Science Biology |

Nucleation of Crystals from Solution

Introduction

On June 25, 1992, the United States Microgravity Laboratory-1 (USML-1) *Spacelab* payload was launched aboard Space Shuttle *Columbia* as part of the STS-50 mission. *Spacelab* was a 23-foot long modular research laboratory flown within the Shuttle orbiter's cargo bay. The laboratory module was pressurized so astronauts could work in a laboratory environment in their shirtsleeves rather than bulky spacesuits. During the USML-1 mission, 31 experiments were conducted in four broad areas—materials science, fluid physics, combustion science, and biotechnology. Of these 31 experiments, 16 were conducted in the USML-1 Glovebox (GBX).

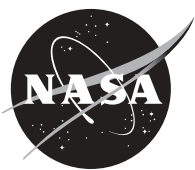
One of the experiments conducted in the GBX was called “Nucleation of Crystals from Solutions in a Low-g Environment” or NCS. The objective of the experiment was to test a new technique for initiating and controlling the nucleation of crystals from solutions in reduced gravity. Improvements in the ability to control the location and time of the onset of nucleation of crystals in a solution have the potential to increase the flexibility of all space experiments involving solution crystal growth. Researchers injected a small quantity of highly concentrated, heated solution into the interior of a lightly supersaturated, cooler solution containing molecules for crystal growth. (On Earth, the warmer solution would rise to the top, but in space it remains suspended.) With this procedure, the injected solution quickly cooled in the presence of the cooler, lightly saturated host solution. This caused a zone to be formed in the host solution for the beginnings (nucleation) of crystal formation. Once the crystallites formed, they grew in the favorable concentration and temperature environment provided by the host solution.

By understanding the structure of proteins in the human body, scientists can learn how these proteins fit into the overall biology of humans, and how the proteins work in the body. Studies of protein crystals could also lead to the development of food with higher protein content, highly disease-resistant crops, and more effective drugs.

The usual procedure for growing crystals in a 1-g environment is to cool the walls of a container of solution to drive the solution into supersaturation. (This is the procedure used in this activity.) Because of the absence of convection in microgravity, cooling the walls of the container only rapidly cooled the adjacent solution and not the interior solution. The molecules in the interior of the solution cooled very slowly. The crystallites tended to cool and form on the walls of the container and did not form in the interior until a much later time when the interior solution was cooled down. As a result, there was not enough control over the formation and growth rates of crystals to produce large and high quality formations.

Objective

- Students will grow naphthalene crystals to see how they are affected by temperature change.



Materials (per group)

- Beaker
- Erlenmeyer flask or beaker with a larger base than the beaker
- Burner and stand
- Mothballs (Naphthalene)
- Spark lighter
- Student glovebox

Procedure

1. Using the equipment setup shown in Figure 1, place materials in the glovebox. If the equipment height is too tall to close the lid, leave it open but still try to use the gloves for all the work.
2. Place 4 or 5 mothballs in the beaker.
3. Fill the flask halfway with cold water and stack the flask on top of the beaker holding the mothballs.
4. Heat slowly over a small flame. Leave the burner on until all the mothballs are melted, then turn off the flame, leaving the flask on top of the beaker for 5 to 10 minutes.
5. Lift the flask carefully and slant the bottom facing you to see the crystals.

Questions

1. What is the process called when a solid changes into a liquid?
2. What is the process called when a solid changes into a gas?
3. What purpose does the cold water have in the flask?
4. What other substances change from solid to gas without a liquid phase?
5. How would this experiment behave in microgravity conditions?

References

Nucleation of crystals from solution in microgravity (USML-1 glovebox (GBX) investigation). Kroes, R.L., Reiss, D.A., & Lehoczky, S.L., Marshall Space Flight Center, Huntsville, Alabama.

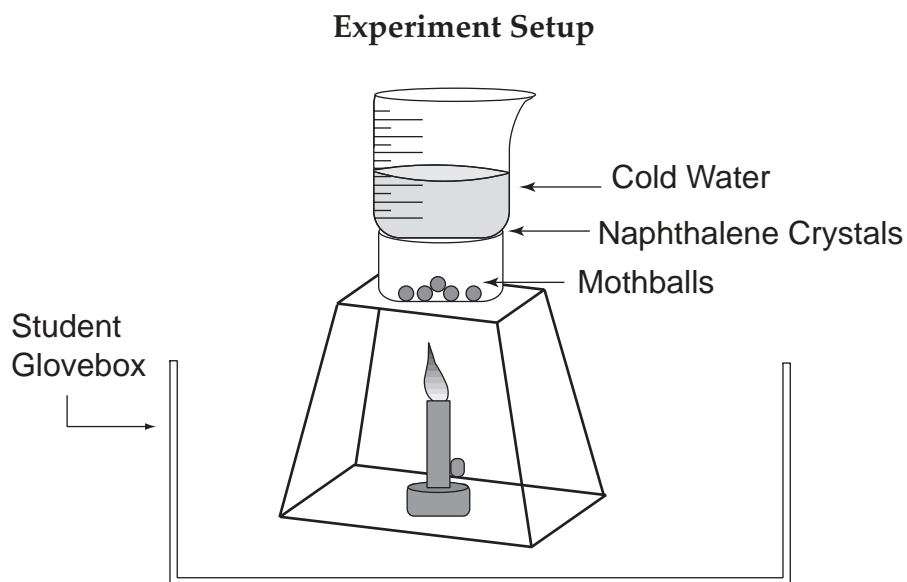


Figure 1.



Oscillatory Heat Flow Experiment

Introduction

On June 25, 1992, the United States Microgravity Laboratory-1 (USML-1) *Spacelab* payload was launched aboard Space Shuttle *Columbia* as part of the STS-50 mission. *Spacelab* was a 23-foot long modular research laboratory flown within the Shuttle orbiter's cargo bay. The laboratory module was pressurized so astronauts could work in a laboratory environment in their shirtsleeves rather than bulky spacesuits. During the USML-1 mission, 31 experiments were conducted in four broad areas—materials science, fluid physics, combustion science, and biotechnology. Of these 31 experiments, 16 were conducted in the USML-1 Glovebox (GBX).

One of the experiments conducted in the GBX was called “Oscillatory Thermocapillary Flow Experiment” or OTFE. The objective was to determine the conditions for the onset of oscillations in thermocapillary flows in silicone oils. On Earth, when a flowing liquid contained within a small tube (capillary tube) is heated (the prefix thermo- means heat), the fluid begins to vibrate, or oscillate. Researchers examined the oscillations of the fluids in microgravity and compared them to those experienced on Earth.

Objective

- Students will observe the motion of liquids and solids when the liquid is heated.

Materials (per group)

- Immersion heater (such as one used in aquariums)
- Large glass container or beaker
- Glitter or food coloring
- Cooking oil
- Student glovebox
- Water

Experiment Setup

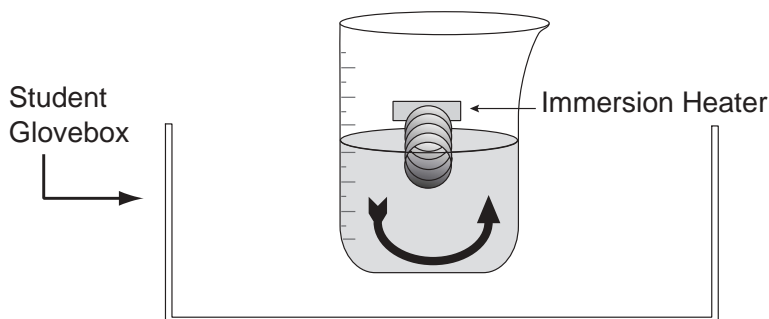


Figure 1.



Procedure

1. Using the equipment setup shown in Figure 1, place materials in the glovebox and close the lid.
2. Fill the glass container with water and attach the immersion heater to the side, making sure the coils are immersed in water.
3. Sprinkle a small amount of solid particles, such as glitter, into the water.
4. Add a few drops of food coloring or oil to the water and observe the motion.

Questions

1. How does the heater affect the water?
2. When the fluid becomes hotter, what happens?
3. How did the liquid that was very close to the coils behave? Why?
4. Do you think that the results would be different for other fluids?

Extension

Try other types of fluids, such as carbonated water, mouthwash, vinegar, etc., to see how they behave under the same circumstances.

References

Oscillatory thermocapillary flow experiment (OTFE). Y. Kamotani, Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, Ohio, Simon Ostrach, Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, Ohio, A. Pline, NASA Glenn Research Center, Cleveland, Ohio.



| | |
|-------------|-------------------------------|
| Grade Level | Subjects |
| 9-12 | Physical Science Chemistry |

Oscillatory Dynamics of Single Bubbles

Introduction

On June 25, 1992, the United States Microgravity Laboratory-1 (USML-1) *Spacelab* payload was launched aboard Space Shuttle *Columbia* as part of the STS-50 mission. *Spacelab* was a 23-foot long modular research laboratory flown within the Shuttle orbiter's cargo bay. The laboratory module was pressurized so astronauts could work in a laboratory environment in their shirtsleeves rather than bulky spacesuits. During the USML-1 mission, 31 experiments were conducted in four broad areas-materials science, fluid physics, combustion science, and biotechnology. Of these 31 experiments, 16 were conducted in the USML-1 Glovebox (GBX).

One of the experiments conducted in the GBX was called "Oscillatory Dynamics of Single Bubbles and Agglomeration in an Ultrasonic Sound Field in Microgravity" or ODBA. The objective was to explore how large and small bubbles behave in space in response to an ultrasound stimulus. By understanding how the shape and behavior of bubbles in a liquid change in response to ultrasound, it may be possible to develop techniques that eliminate or counteract the complications that small bubbles cause during materials processing on Earth. With the elimination of some of the effects of gravity, researchers were able to concentrate on the dynamics of the effects of surface tension on the shape of the bubble.

In this activity, you will observe the motion of floating bubbles in a closed container. To make the bubbles float, you will be using a mixture of chemicals that give off a harmless gas (carbon dioxide). Carbon dioxide is heavier than normal air, so it sinks, providing a cushion of air for the bubbles, and allowing them to float.

Objective

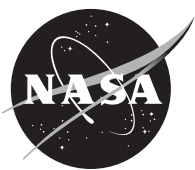
- Students will observe the motion of soap bubbles floating in a closed container.

Materials (per group)

- Soap solution (1 cup liquid dish soap, 3 tbsp of glycerin, 1 gallon of water)
- 1/2 cup of calcium carbonate or sodium bicarbonate (baking soda)
- 1 cup of dilute HCl or vinegar
- Large plastic drinking straw
- Large beaker
- Small cup
- Electronic tuning fork (optional)
- Student glovebox

Procedure

1. Using the equipment setup shown in Figure 1., place materials in the glovebox and leave the lid open for escaping gas.
2. Place a small amount (2 or 3 tsp) of soap solution in the small cup.
3. Put a teaspoon of the baking soda with the vinegar or calcium carbonate with the dilute HCl in the large beaker.
4. Dip the end of the plastic straw into the soap solution and blow bubbles of smaller diameter than the large glass beaker into the beaker, carefully guiding them with the straw. Observe the motion of the soap bubbles inside the glass beaker.



5. (Optional) If you have an electronic tuning fork available, try placing that in various locations below and around the bubbles.

Floating Soap Bubbles

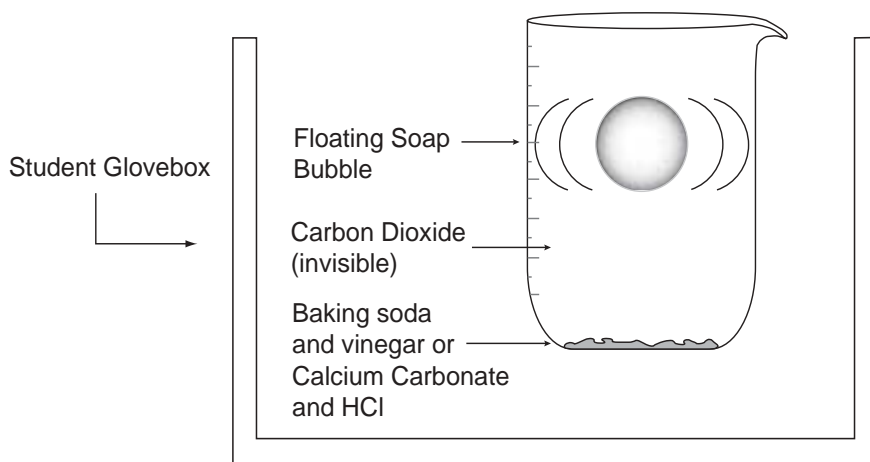


Figure 1.

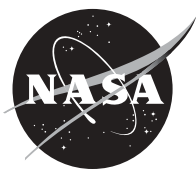
Questions

1. Do the sizes of the bubbles change as they move around? (Up and down, sideways?)
2. What colors can you see on the bubbles? Do the colors change?
3. Do the bubbles stay at the same relative height when inside the container?
4. What other gas could be used to get the same result as CO_2 ?
5. (Optional) How did the bubbles react to the sound of the tuning fork? Why do you think this happens?

Explanation

The baking soda and vinegar or the calcium carbonate and the HCl give off carbon dioxide, a gas that is heavier than air. This gas sinks to the bottom of the container and provides a layer of air for the bubbles to float on, preventing the bubbles from instantly sinking. As the bubbles stay on top of the CO_2 , the gas begins to enter the membranes of the bubbles by diffusion, causing the bubbles to expand and eventually sink, as it gets heavier (Figure 1).

The colors of the soap bubbles come from reflections of the white light that falls on the surface of the bubbles. This white light, either from the sun or a light bulb, contains all the colors in the visible spectrum. As waves of light hit the bubble, some reflect off the outer surface and some pass through and reflect off the inner side of the sphere. These waves of light can be at different phases and interfere with each other as they both reflect back. If the crest of one wave meets the crest of another, a brighter light is formed, but if a crest meets a trough, then a dimmer light or no light is produced. The waves that meet are not at the same phase, and they either add (reinforce) or cancel each other.



If you tried to use an electronic tuning fork around the soap bubbles, you should have seen them vibrate or oscillate. This is because the sound waves are a form of energy that travels through the air. This energy causes the air molecules, or whatever material they are traveling through, to vibrate back and forth. This vibration eventually reaches the walls of the bubble and causes them to move or “dance.” The louder the sound, the more energy is transferred and the greater the vibration.

References

Oscillatory dynamics of single bubbles and agglomeration in a sound field in microgravity. Marston, P.L., Washington State University, Pullman, Washington Trinh, E.H., Depew, J., NASA Jet Propulsion Laboratory, Pasadena, California, Asaki, T.J., Los Alamos National Laboratory, Los Alamos, New Mexico.



Wetting Characteristics

| Grade Level | Subjects |
|-------------|-----------------------------|
| 9-10 | Physical Science Biology |

Introduction

The United States Microgravity Payload-4 (USMP-4) was launched November 19, 1997 as part of mission STS-87. One of the experiments conducted in the Microgravity Glovebox (MGBX) as part of USML-4 was titled “Wetting Characteristics of Immiscibles” or WCI. WCI is an advanced study of the way immiscible liquids behave. Special metal alloys—known as immiscibles—contain components that do not mix in the liquid melt before solidification (similar to oil and water). Previous microgravity experiments with these alloys revealed unexpected separation of their components into layers, even though gravity’s effects were reduced. The WCI experiment investigated one possible cause for this segregation—droplet wetting, or coating, along the container walls. The investigation was designed to study ways to control this wetting behavior and ultimately result in improved materials processing on Earth for this potentially important class of alloys.

The experiment was performed inside a thermal chamber in the MGBX. The mixed alloys were heated until they melted. They were then observed through an external microscope during the cooling phase for any wetting phenomena.

In this activity, you will observe the wetting characteristics of water in different sized tubes. Although the water and tubes are in a 1-g environment, the adhesion of the water to the sides of the tubes of glass is similar to the WCI investigation.

Objectives

- Students will observe the adhesion of water to glass.
- Students will observe the effect of diameter on the height of water in a tube.

Materials (per group)

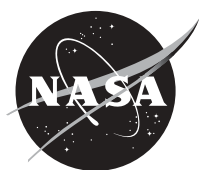
- Glass capillary tubes of different diameters
- Glass beaker
- Student glovebox
- Food coloring
- Water

Procedure

1. Using the equipment setup shown in Figure 1, place the materials in the glovebox.
2. Fill the beaker with water. Add a few drops of food coloring.
3. Hold the capillary tubes in the beaker of colored water. Each tube should be held at approximately the same depth. Observe the water level in each tube.

Questions

1. How does the height of the water change, if at all, when the tubes are raised or lowered in the beaker?
2. Why is the water level in the tubes higher than the water in the beaker?
3. Why is the water level highest in the tube with the smallest diameter?



Experiment Setup

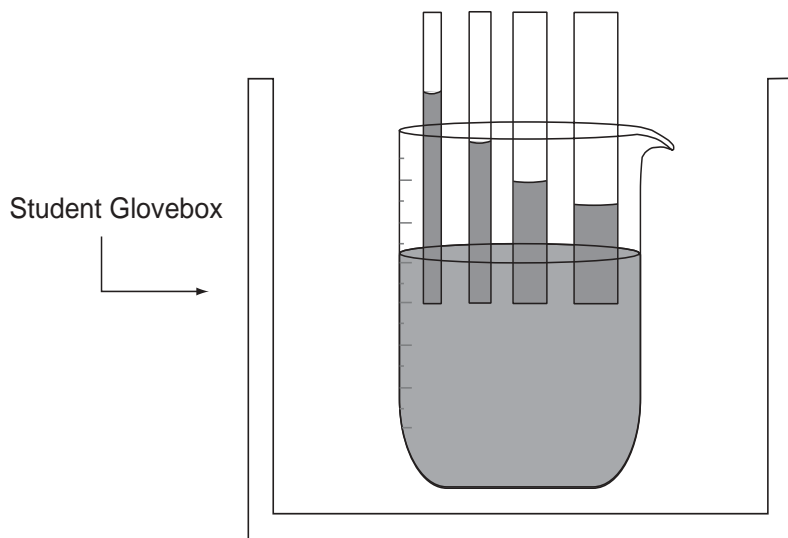


Figure 1.

Extension Activity

Find out how very tall trees, such as the redwoods, get water from their roots to their leaves at the tops of the trees.

Explanation of Wetting Characteristics

Water tends to adhere to glass, causing a meniscus in a glass tube. Also, the top surface of the water has surface tension, which acts like a film, keeping the water molecules together. This surface tension allows the water surface to behave as though it has an elastic property. The water molecules that are adjacent to the glass will “cling” to the glass because of adhesion, but the molecules that are not next to the glass do not have this support. In gravity conditions, the inner part “sags,” but because of the surface tension, the upper most layer of water molecules stay together, sort of like a trampoline sheet with hooks to the frame.

The smaller the diameter of the tube, the higher the ratio of “support” molecules to “sagging” molecules (in other words, the ratio of the length of circumference to the cross section area is greater for smaller circles), so this acts as a force that partially offsets the effects of gravity. That’s why water will go higher in smaller diameter tubes. In microgravity conditions, water and other fluids cling to the sides of the container.



Space Related Activities



Growing Protein Crystals

Introduction

Many hours of scientific study and investigation have been invested in the growing of protein crystals. The information they reveal about a protein's molecular structure makes them very important to science. Proteins, or macromolecules, are involved in everyday functions of the body, such as transporting oxygen and chemicals in blood, forming major components of muscle and skin, and fighting disease. Active sites on molecules of proteins, when inappropriately triggered or absent, can cause disease or an unwanted function. Scientists seek to locate these active sites so drug designers can understand their function and then, in some cases, work to block them or render them inactive.

Protein crystals are difficult to grow on Earth because of convection and sedimentation. Convection takes place during crystal growth on Earth as protein molecules move from the surrounding solution and assemble in an orderly way to become a part of the growing crystal lattice. As protein molecules in the solution move toward a crystal and become a part of the crystal, the solution bordering the crystal then contains a lower protein concentration than the remainder of the solution, and therefore, it has a lower density. This less dense solution tends to rise, and the denser solution sinks under the influence of gravity, creating fluid flows, or convection. These fluid flows can have a negative effect on the quality of the crystal being formed.

Sedimentation occurs when crystals drift to the bottom of a drop of the solution when they have grown to a mass larger than can be supported by the suspension in the drop. When this happens, partially formed crystals fall on top of one another and continue to grow into each other. Because the analysis done by scientists requires single crystals, sedimentation renders potentially high-quality crystals unusable for data collection.

In this activity, you will extract Excelsin, a seed storage protein, from ground Brazil nuts. The Brazil nuts will be ground and mixed with a salt-water solution. This mixture will be filtered and then dialyzed with distilled water to obtain crystals. The crystals will then be examined under a microscope to determine their size and morphology (shape).

Objectives

- Students will extract and crystallize Excelsin from Brazil nuts.
- Students will determine the size and morphology of Excelsin crystals.

Materials (per group)

- Funnel
- Thermometer
- Table salt
- Styrofoam
- Small clamps
- Centrifuge tubes
- Heating plate
- Distilled water
- Glass rod
- Balance
- Small centrifuge (optional, 1 per class)
- Blender or coffee grinder



- Pipette or medicine dropper
- Brazil nuts (raw, organically grown)
- 50 ml graduated cylinder
- Dialysis membrane (approx. 20 cm in length)
- Gloves, if using glass wool
- Cheesecloth, glass wool or filter paper
- Beakers, 500 ml and 150 ml

Procedure

Part 1: Isolation of Excelsin (the extracted protein substance)

1. Record the mass of 8 or 9 raw Brazil nuts. Grind the nuts to granular size. One nut has a mass of approximately 2.8 grams.
2. Prepare a 5% sodium chloride (NaCl) solution by dissolving 10 grams of solid NaCl in 200 ml. of distilled water. Measure 25 ml. of 5% NaCl solution into a graduated cylinder and then pour into a 150 ml beaker. Record the volume of NaCl solution in the beaker. Reserve the remaining portion for making the 1% solution in Part 2.
3. Create a water bath by placing a flat piece of styrofoam (can be cut from the bottom of a styrofoam cup) into the bottom of a 500 ml beaker. Pour approximately 50 ml of water into the 500 ml beaker. Place the smaller 150 ml beaker (that contains the NaCl solution) in the larger 500 ml beaker (that contains the water). Place the beaker assembly on the heating plate and heat until the water is at 50° C. Measure the final temperature and record.
4. Add the ground nuts to the NaCl solution in the 150 ml beaker and stir with a glass rod to mix. Continue heating the water bath to maintain the temperature of the NaCl solution and ground nut mixture at 50° to 70° C for 20 minutes, stirring occasionally. (Be careful not to stir vigorously or to heat above the designated temperature range because this may cause the protein structure to break down or denature).
5. **Caution: Glass wool should only be handled when wearing gloves.** Place 1-2 layers of glass wool (or 10 layers of cheesecloth or filter paper) in a funnel and place over a beaker. Pour the NaCl/nut mixture through the glass wool. Measure and record the volume of the filtrate. (Note: The filtrate should be opaque.)
6. For classrooms without a centrifuge: Skip steps 7-9 and go directly to the Crystallization of Excelsin.
7. For classrooms with a centrifuge: Pour the filtrate into two centrifuge tubes and weigh to make sure the tubes are of equal weight. Record the mass of each centrifuge tube.
8. Centrifuge for 20 minutes at 3000 rpm. Pipette off the oil (top layer) and discard it. Carefully push the pipette through the nut meat layer (the next layer) into the water layer and pour off and save the water portion (located above the pellet and just below the oil). See Figure 1. Discard the pellet, nut meat, and the oil. The water portion contains the protein in solution, which is what you want to keep.
9. Centrifuge the water portion to clarify the solution. This watery portion is called a supernatant. The supernatant should be a fairly clear brown or brownish-yellow solution after centrifuging it. Measure and record the volume of this extracted protein solution.

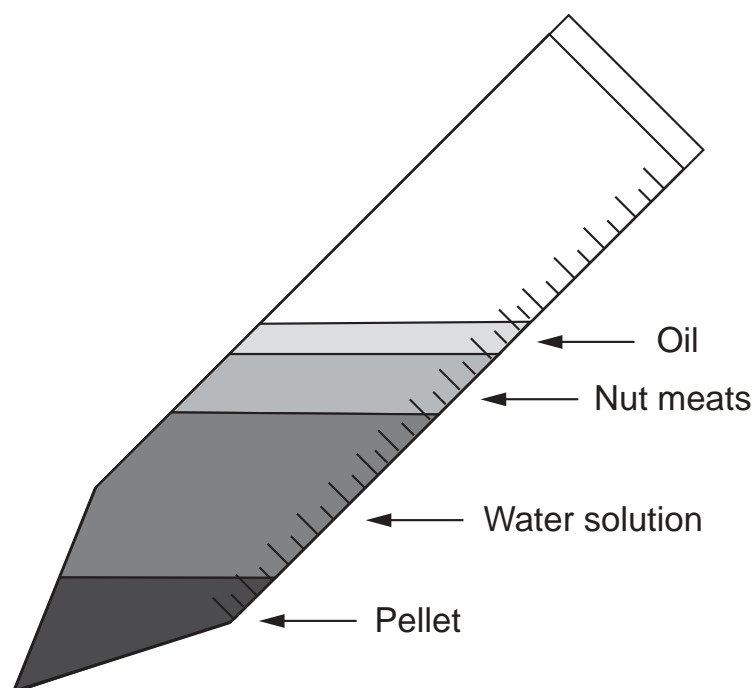
Part 2: Crystallization of Excelsin

1. Soak the dialysis membrane in room temperature water for 5 minutes or longer. Take the membrane out of the water and tie a knot in one end. Do not touch the area that will contain the protein solution. Touching the tubing may increase the pore size of the tubing and result in loss of protein.



2. Pour the extracted protein/ filtrate solution into the dialysis membrane/ tubing and tie the other end of the membrane. Leave a small air pocket in the bag so that it will float.
3. Prepare 500 ml of 1% NaCl solution by combining 100 ml of 5% NaCl solution and 400 ml of distilled water. Pour the prepared 500 ml solution into a large beaker. Carefully add the dialysis membrane containing the protein solution. Record the volume of both the 1% solution and the protein filtrate solution. Crystals should appear 4 – 10 hours later as white powder in the bottom of the bag. If crystals do not appear, lower the NaCl concentration to 0%.
4. When the white powder appears, view it under a microscope while the solution is still in the bag.

Layers Formed After Centrifuging the Brazil Nut



Part 3: Recrystallization and Purification of Excelsin

1. Cut one end of the dialysis membrane bag and pour off the solution from the crystals.
2. Pour a small amount of 5% NaCl solution (1-3 ml) into the bag to get the crystals to go back into solution. Retie or clamp the open bag. Place the bag into a beaker containing a fresh solution of 1% NaCl. Allow to soak overnight, or until crystals appear. Record information about the crystals, such as size, number, and structure (see chart below).
3. By repeating this process of soaking in NaCl solution (dialysis), a protein can usually be rendered essentially pure. To obtain larger crystals, slowly decrease the concentration of NaCl in solution. For example, instead of going directly to a 1% NaCl, start with 4.5% and decrease in increments of 0.5%.



| Step | Procedure | Record |
|------|---|--------|
| 1(1) | Brazil nut mass (grams) | g |
| 1(2) | Volume of NaCl sol. (ml) | ml |
| 1(3) | Temperature of water bath (°C) | °C |
| 1(4) | Temperature of NaCl/nut sol. (°C)-1st recording | °C |
| 1(4) | Temperature of NaCl/nut sol. (°C)-2nd recording | °C |
| 1(4) | Temperature of NaCl/nut sol. (°C)-3rd recording | °C |
| 1(4) | Temperature of NaCl/nut sol. (°C)-4th recording | °C |
| 1(4) | Temperature of NaCl/nut sol. (°C)-5th recording | °C |
| 1(5) | Volume of protein filtrate (ml) | ml |
| 1(6) | Centrifuge tube #1 mass | g |
| 1(6) | Centrifuge tube #2 mass | g |
| 1(8) | Volume of extracted protein sol. (ml) | ml |
| 2(3) | Volume of protein filtrate (ml) | ml |
| 2(3) | Volume of 1% NaCl sol. (ml) | ml |
| 2(3) | Volume of 0% NaCl sol. (ml) | ml |
| 3(2) | Volume of 5% NaCl sol. added to bag (ml) | ml |
| 3(2) | Volume of 1% NaCl sol. added for dialysis (ml) | ml |
| 3(3) | Volume of 5% NaCl sol. added to bag (ml) | ml |
| 3(3) | Volume of 1% NaCl sol. added for dialysis (ml) | ml |

Record the size, number and shape (morphology) of the final Excelsin crystals produced.

| Crystal | Shape (check which box applies.) | Number | Size (mm) |
|----------|----------------------------------|--------|-----------|
| Excelsin | Spherical | | |
| | Platelike | | |
| | Hexagonal | | |
| | Needles | | |
| | Other | | |

References

A NASA Recipe for Protein Crystallography, EB-2000-10-183-MSFC. National Aeronautics and Space Administration Education Brief.



| Grade Level | Subjects |
|-------------|----------|
| 9-12 | Biology |

Plant Growth in Microgravity

Introduction

The relationship between plants and humans has always been a close and interdependent one. Research about basic plant processes helps in understanding and augmenting this interdependence. Ground-based investigations yield information vital to this understanding; however, the knowledge gained from plant research in space is exciting and extends the potential for new discoveries beneficial to humans. There is abundant evidence that microgravity affects virtually every aspect of plant growth. Space flight provides the only known environment in which fundamental biological processes and mechanisms can be studied in the absence of the sometimes-overriding effects of gravity. Removal of the effects of gravity for long periods of time allows new perspectives in the study of plants.

Answers to important questions about the basics of plant growth and development lie in understanding the role gravity has on plant processes and responses in the environment. For example, gravitropism is the bending response of plants to the force of gravity with the roots growing downward and the shoots growing upward. Charles Darwin began experiments on plant gravitropism during the nineteenth century, yet the mechanisms of this process are still not clear. The more knowledge generated about how plants function, the more likely we can adapt that information into practical, useful new applications and products enhancing life on Earth and in space.

Extended duration human exploration missions, such as a lunar or Martian outpost, will require life support capabilities beyond those now available. A solution is to develop technologies that integrate physical and chemical processes into a dynamic, recycling life support system. Studying plants in space will provide the scientific information necessary for development of such a life support system. Plants will be a primary component of atmospheric regeneration: carbon dioxide exhaled by humans will be taken up by plants and used in photosynthesis, in the process returning oxygen and food to the crew. Plants are also important in water regeneration. To achieve a controlled life support system, ground-based research in growth chamber facilities must be conducted along with plant investigations in the microgravity environment of space flight.

In this activity, students will compare the differences in the germination, growth, flowering, pollination, and seed formation between the experimental plants grown in a simulated microgravity environment and the control group of plants grown in Earth's gravity. This activity is based on a series of experiments conducted on the Russian space station *Mir* during the fifth increment of the Shuttle/*Mir* program in 1997. The plants used were *Brassica rapa*, a close relative of broccoli, cauliflower, and Brussel sprout plants. The *Brassica rapa* seeds were planted in a specially designed, well-ventilated plant growth chamber. When the seeds grew and produced flowers, they were pollinated by hand using a "bee stick" (the body of a dried bee glued to a toothpick). The pollinated plants produced seedpods. When the pods matured and dried, they were collected and replanted. These seeds produced a second generation of plants. This was the first time seeds planted in space produced seeds that subsequently germinated.



Objective

- Students will investigate the problems of plant cultivation in space by growing plants in a simulated microgravity environment.

Materials (per group)

- Paper clips (medium)
- Bamboo skewers and thread
- Clinostat* (see information at end of activity)
- Small plastic cup (4 oz)
- Soft foam or paper towels
- Plant light (if no sunlight from windows)
- Plant seeds from any small, quick-growing, flowering plant*
- Plastic tray
- Rubber bands
- Ruler
- Peat pellet
- Cotton swabs
- Warm water

Procedure

Part 1: Earth Conditions (Control Group)

1. Place the peat pellet on the plastic tray. Cover with warm water and wait about 5 minutes for the pellets to expand to 4-5 cm in diameter. (Peat pellets are pot and soil all in one.) Drain excess water with paper towels.
2. Wrap the newly formed peat pots with soft foam or paper towels so they will fit snugly inside the plastic cup. This prevents the pots from moving around in the cup.
3. Plant 5 seeds per cup. Press each seed approximately 0.5 cm into the soil. Be sure the seed is covered with soil. (Figure 1)
4. Place the cups near a window or under a plant light.
5. Water the pellets according to the directions given for each variety of plant.

Planting Seeds in Peat Pellet for Earth Conditions

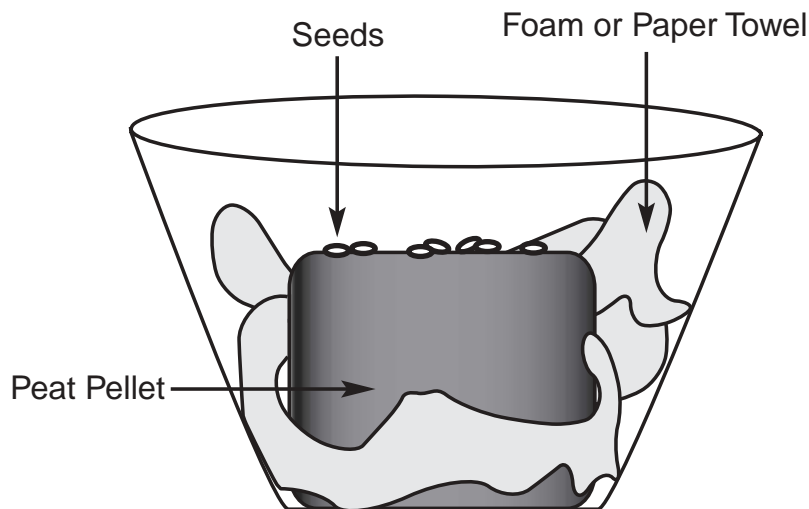


Figure 1.



Planting Seeds in Peat Pellet for Microgravity Conditions

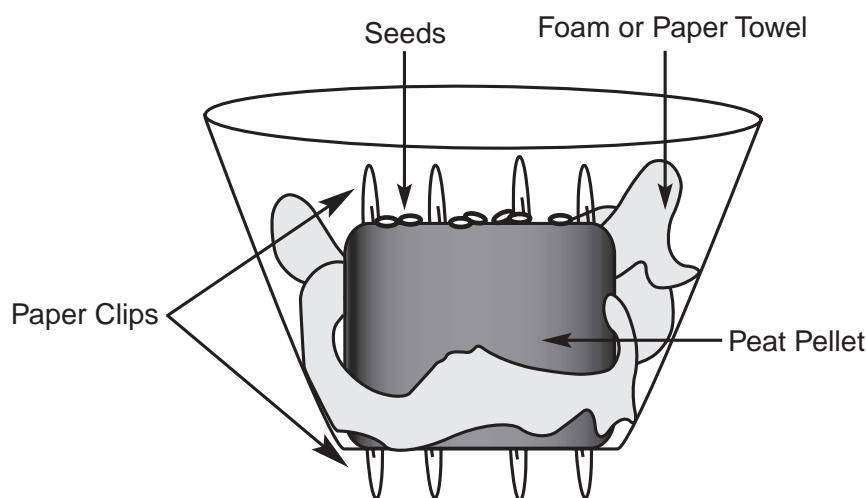


Figure 2.

Part 2: Microgravity Conditions (Clinostat Group)

1. Prepare peat pellets in the plastic cups as in steps 1 and 2 in Part 1.
2. Secure the pellets to the plastic cup by pushing straightened paper clips completely through the cup and the pellet. (Figure 2)
3. Attach the plastic cup to the clinostat using rubber bands and paper clips (Figure 3). The rubber bands go through the perforations found at the base of the rotating wheel of the clinostat.
4. Plant 5 seeds as described in step 3 in Part 1.
5. Before turning on the clinostat, make sure the cup and pellets are centered on the rotating wheel.
6. Place the clinostat and pellets near a window or under a plant light.
7. Water the pellets according to the directions given for each variety of plant.

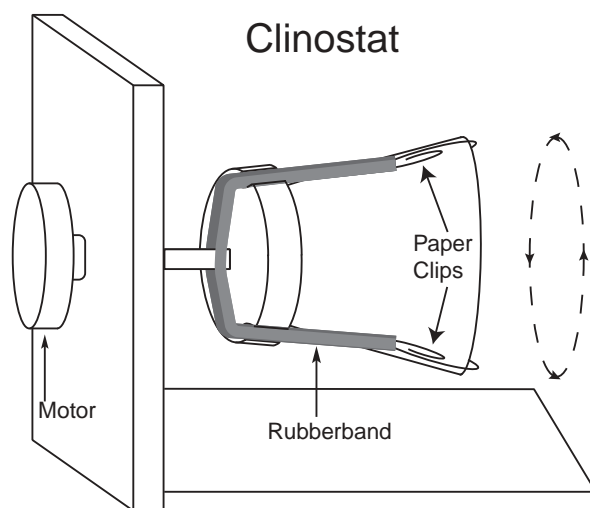


Figure 3.



Observing and Recording

1. Germination: Observe the Control Group and the Clinostat Group daily for Week One. Record the total number of seeds germinating.
2. Measurements and Observations: Once a week, starting with Week Two, measure the length of each growing plant (in centimeters). As the plants mature, other data should be collected: number of leaves on each plant, stem orientation with respect to the pot, health problems, different leaf color, etc.
3. Data Analysis: If you are collecting data from more than one plant, calculate and record the mathematical mean of all measurements.
4. Stake the Plants: When the Control Group plants reach a length of 3 cm, stake each plant with a skewer and thread to prevent the plants from flopping over (this can cause the plant to be injured or broken).
5. Flowers/Buds, and Cross-pollination: When the plants start to flower, record the date and number of flowers (buds or open flowers). If a cross-pollinating plant such as *Brassica rapa* is used, pollination should be done every other day by using cotton swabs. If a self-pollinating plant is used, such as *Arabidopsis thaliana*, no intervention is needed.
6. Fruits: When fruits start to develop, record the date and number of fruits. If using mustard plants, record the length of the siliques (the mustard fruits).
7. End of Experiment: The experiment ends when most plants have developed mature fruits. Plants should be kept alive until the fruits are ripe. Seeds can be collected and used for future experiments.

Questions

1. How does microgravity effect the different stages of plant development?
2. How can microgravity be simulated on Earth?
3. Is it practical to grow crops in space? What are some of the difficulties of growing plants inside spacecraft?
4. Graph each of the quantitative variables (plant length, number of leaves, number of flowers, number of fruits) using the average found for their data (Earth pot), as well as for the microgravity pot. There should be separate graphs for each variable. For example, the plant length (plant length, in cm) would be graphed on the vertical axis as the dependent variable, and each numbered day of the experiment length (time period, in days) would be graphed on the horizontal axis as the independent variable.
5. How can adverse effects of microgravity on plants be overcome?

Information about materials

- Clinostats can be made if any of the students have an inclination to build things. A variety of motors may be purchased at electronics surplus stores, hardware stores, or Edmund's Scientific. One example of a motor type is HP E25571, 120 v, 60 HZ, 3W RH, 2 RPM, HP1052, A3279, CSA, LR 14686. The motor must turn the plastic cup very slowly—less than four revolutions per minute. There is an accurate description and picture with details on how to make a clinostat in the February issue of *Scientific American*, 1996, pages 122-123. The clinostat described in the article uses a bicycle wheel and 2 DC motors.
- Order quick growing “fast plants” from a biological supply company. These genetic varieties of seeds complete their entire life cycle in about 6 weeks.



- Identify a window where student projects can be left safely for up to 6 weeks. Plant lights can also be used. Leave the lights on continuously for both the Earth pot and Microgravity pot to simulate the 24-hour plant light that is used on the ISS.
- An inexpensive and easy option for building a clinostat is to use a rotisserie oven skewer with attached motor. Use a large plastic container, such as the type used for molded packaging for potato chips (like Tarengos® or Pringles®), for the rotating part. Glue or Velcro™ film canister lids to the outside of the potato chip container. Thread the rod of the rotisserie through the base and lid of the potato chip container, so that the container is oriented horizontally. Place the plant pellets in the base of the film canister and attach the film canister base to the lid (Figure 4).



Figure 4. A clinostat made from a rotisserie.



The Inertial Balance

| Grade Level | Subjects |
|-------------|-----------------------------|
| 9-12 | Physical Science Algebra |

Introduction

The microgravity environment of an orbiting space shuttle or space station presents many research problems for scientists. On Earth, mass measurement is simple. Samples, such as a crystal, or subjects, such as laboratory animals, are measured on a scale or beam balance. In a scale, the object being measured compresses the springs. The amount of compression indicates what the object weighs. (On Earth, weight is related to mass.) Beam balances, like a seesaw, measure an unknown mass by comparison to known masses. With both of these devices, the force produced by Earth's gravitational attraction enables them to function.

In microgravity, scales and beam balances do not work. Setting a sample on the pan of a scale will not cause the scale springs to compress. Placing a subject on one side of a beam balance will not affect the other side. This causes problems for researchers. For example, a life science study on the nutrition of astronauts in orbit may require daily monitoring of an astronaut's mass.

Mass is measured in microgravity by employing inertia. Inertia is the property of matter that causes it to resist a change in motion. If you have ever tried to push anything that is heavy, you have experienced inertia. Imagine trying to push a truck. You will quickly realize that the amount of inertia or resistance to motion an object has is directly proportional to the object's mass. The more mass, the more inertia. By directly measuring an object's inertia in microgravity, you are indirectly measuring its mass.

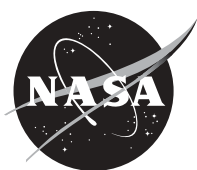
The inertial balance is a device used to measure the inertia of an object. As a result of finding the object's inertia, the mass can also be found. The inertial balance is a spring device that vibrates the subject or sample being measured. The object to be measured is placed in the sample tray or seat and anchored. The frequency of the vibration will vary with the mass of the object and the stiffness of the spring (in this activity, a hacksaw blade or a yardstick). An object with greater mass will vibrate more slowly than an object with less mass. The time needed to complete a given number of cycles is measured and the mass of the object is calculated by comparing the time to that of other known quantities.

Objective

- Students will demonstrate how mass can be measured in microgravity.

Materials (per group)

- 10 pennies
- 4 light-weight objects to be measured
- Graph paper
- Glue
- Velcro™ or tape
- Tissue paper or small piece of foam
- Hacksaw blade (12 in) or yardstick (cut down to 10 in)
- C-clamp
- Stopwatch
- Ruler
- Small wooden block
- Metal washers (2 or 3)
- Plastic 35 mm film canisters



Procedure

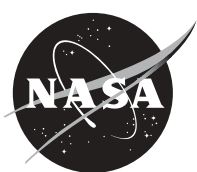
Part 1: Preparing the Inertial Balance

Before beginning the activity, the inertial balances must be constructed. The dimensions of the block of wood are not critical and you may be able to use a piece of scrap lumber. The wooden block needs to have a notch cut into one end. The notch should be just large enough for the hacksaw or yardstick to slide into. Before inserting the hacksaw blade or yardstick, apply a small amount of glue to both sides of one end and slip it into the notch. Make sure the hacksaw blade or yardstick is slightly above and parallel to the bottom flat side of the block. Set aside to allow the glue to dry.

Once the balance has dried, you need to attach the film canister. Using Velcro™ or tape, secure the canister to the end of the hacksaw blade or yardstick. Glue the metal washers to the inside of the canister. The washer provides needed extra mass to the canister end of the inertial balance so that the vibrations can be easily counted. Do not include this washer in your calculations or data.

Part 2: Calibrating the Inertial Balance

1. Clamp the wooden block that contains the spring (hacksaw blade or yardstick) to a table or counter, as shown. The spring (blade or hacksaw) should be free to swing back and forth (Figure 1).
2. Pick one member of your team to be timekeeper, another to record data (recorder), and another to count the cycles (counter).
3. Begin calibration by inserting a wad of tissue paper or piece of foam into the canister. Pull back on the blade or yardstick. When the timekeeper says START, start the stopwatch. The blade should be released and the counter should start to count the 25 cycles. One cycle is one back and forth motion of the spring. The counter will say STOP after 25 cycles and the time keeper should stop the watch. Enter the time for zero pennies in the Calibration Table. To improve accuracy, repeat the measurements two more times and average the results.
4. Insert 1 penny in the canister next to the tissue paper wad and measure the time it takes for 25 cycles. Repeat two more times and average the results. Record the average time on the graph for 1 penny.
5. Repeat this procedure for 2 through 10 pennies. Record the average time for each in the table.
6. Graph the data on the Calibration Graph, located on the **Measuring Mass with Inertia Worksheet**. Draw a line that goes through all or close to all of the points on the graph, using the **Sample Graph** (Figure 2) as a guide. This calibrates your inertial balance.



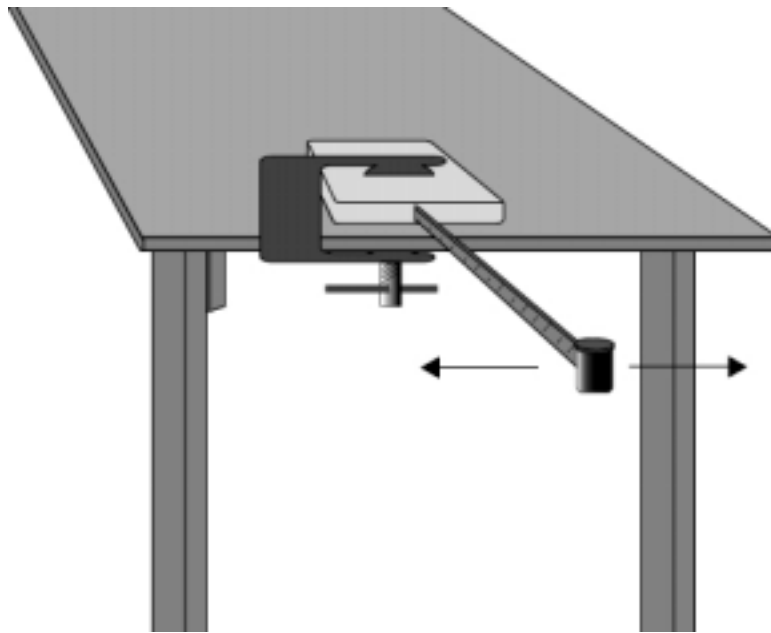


Figure 1

Part 3: Using the Inertial Balance

1. Place an unknown object in the canister. Use the same tissue paper or foam used previously. Cover and measure the time to complete 25 cycles. Do this 2 more times and average the times. Record the average values in the **Unknown Object Table**.

Unknown Object Table

| Unknown Object | Trial 1 Time for 25 Cycles (seconds) | Trial 2 Time for 25 Cycles (seconds) | Trial 3 Time for 25 Cycles (seconds) | Average Time for 25 Cycles (seconds) |
|----------------|--|--|--|--|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |



Calibration Table

| Number of Pennies | Trial 1 Time for 25 Cycles (seconds) | Trial 2 Time for 25 Cycles (seconds) | Trial 3 Time for 25 Cycles (seconds) | Average (seconds) |
|-------------------|--|--|--|----------------------|
| 0 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |

2. Graph your data on the same **Calibration Graph** located on the **Measuring Mass with Inertia Worksheet**. For each unknown, start in the left side of the graph (Y-axis) and find the average number of seconds you found in Step 1. Move straight over to the right of the graph until you reach the graph line that you drew in the calibration activity. From this point of intersection, move directly down to the penny line (X-axis). This gives you the mass of the unknown object in penny weights (pw).

Sample Graph

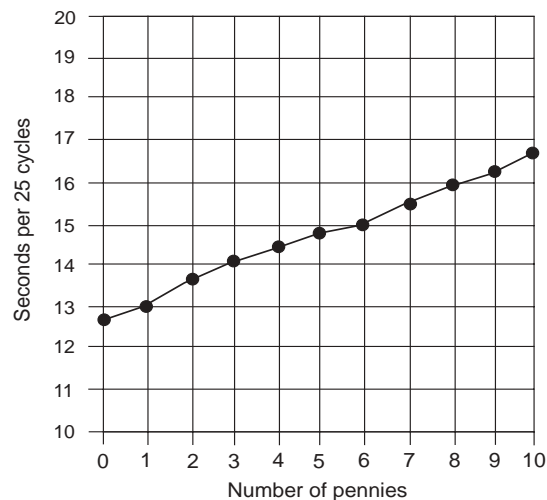


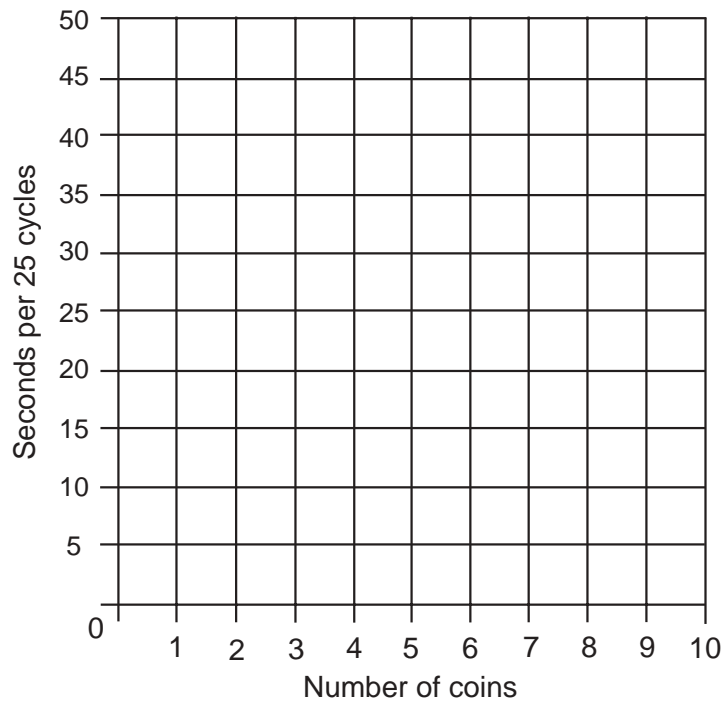
Figure 2



Measuring Mass with Inertia Worksheet

Measurement Team:

Calibration Graph



Unknown Object 1:

Mass: _____ pw

Unknown Object 3:

Mass: _____ pw

Unknown Object 2:

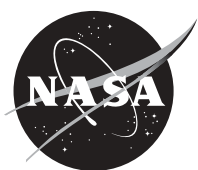
Mass: _____ pw

Unknown Object 4:

Mass: _____ pw

References

Microgravity—A Teacher's Guide with Activities in Science, Mathematics, and Technology, EG-1997-08-110-HQ.Educator Guide.



Viscosity of a Fluid

Introduction

Fluids consist of both liquids and gases. The study of fluids is an important part of physics, which involves the way fluids flow and their interactions with other types of fluids and solids.

This activity will concentrate on a particular physical characteristic of fluids, viscosity. Viscosity is the amount of internal friction within the fluid, or the measure of resistance to flow when acted on by a shearing force. The viscous friction force is always opposite the direction of motion and proportional to its speed. The units of viscosity are pascal-seconds, or joule-seconds/m³. Another unit, poise, equals 0.10 pascal-seconds. The chart shows the viscosity of some common fluids.

Approximate Viscosity of Some Common Fluids

| Fluid | Viscosity (Pascal-sec.) |
|--------------------|-------------------------|
| Air (18° C) | 1.9x10 ⁻⁵ |
| Water (20° C) | 0.001 |
| Blood (37° C) | 0.005 |
| Canola Oil (20° C) | 0.01 |
| Motor Oil (20° C) | 1 |
| Corn Syrup | 8 |
| Shampoo | 1 |

Stokes' Law applies to spheres moving through a viscous fluid that is non-turbulent. The equation is

$$\eta = \frac{2 R^2 g (\rho_s - \rho_f)}{9 (v)}$$

where η represents the viscosity of the fluid; R is the radius of the sphere in meters; g is acceleration due to gravity in m/s²; ρ_s is the density of the sphere in kg/m³; ρ_f is the density of the fluid in kg/m³; and v is the velocity of the object in m/s.

Objective

- Students will find the viscosity of a fluid using Stokes' Law.

Materials (per group)

- Small spherical object, such as a ball bearing
- Long, wide, clear tube, such as a glass vase
- Timer
- Marker pens
- Various clear fluids, such as motor oil, canola oil, corn syrup, or shampoo
- Micrometer
- Graduated cylinder
- Clamps
- Balance scale
- Ring stand



Equipment Setup

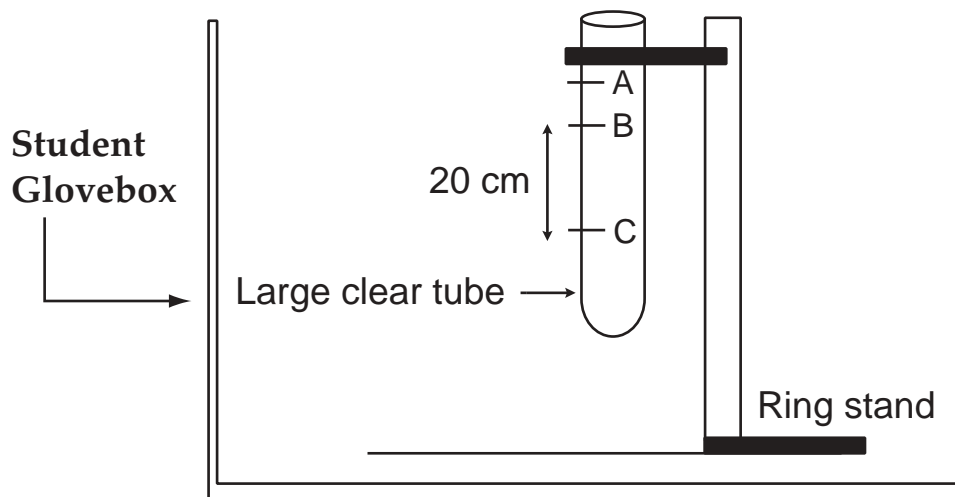


Figure 1

Procedure

1. Measure the mass of the long tube.
2. Clamp the long tube to the ring stand, as shown in Figure 1.
3. On the outside of the tube, make two marks, B and C, 20 cm apart.
4. If the tube is not calibrated, find the volume of the tube at a distance of 1 or more centimeters above the first mark. Place a mark on the outside of the long tube so that you can measure the volume of the tube at that position. Label it A.
5. Add water to the clear tube, filling it to the mark you made (A) in the previous step.
6. Pour this water into a graduated cylinder to measure the volume of the water.
7. Fill the tube to the top mark with a fluid, such as canola oil or corn syrup.
8. Weigh the tube containing the fluid. Determine the mass of the fluid by subtracting the mass of the tube.
9. Using the micrometer, measure the diameter of the sphere. Determine the radius of the sphere & record this value.
10. Using the balance scale, measure the mass of the sphere. Record this value.
11. Find the volume of the sphere and record.
12. Find the density of the sphere by dividing the mass by the volume. Record this value.
13. Carefully place the sphere in the surface of the fluid. Do not push on it.
14. When the sphere reaches the beginning distance mark, B, begin the timer.
15. Stop the timer when the sphere passes mark C. Make sure that you use the same relative position of the sphere with respect to the marks.
16. Take several measurements and average the times.
17. Record all information in the table on the **Viscosity Worksheet**.
18. Calculate the viscosity of the fluid using the information in the table above and Stokes' law .



Analysis

1. Find the relative error for each fluid viscosity, by the following formula:

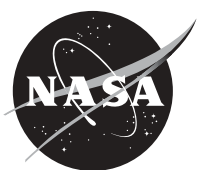
$$\text{Relative Error} = \frac{(\text{Viscosity accepted} - \text{Viscosity calculated}) \times 100}{\text{Viscosity Accepted}}$$

2. Try to account for any discrepancies or errors in your data. List them below.
 - a.
 - b.
 - c.
3. All other things being equal, how would the velocity of a sphere of diameter 0.10 cm compare with a sphere of diameter 0.20 cm?

Extension

A plastic sphere (density = 0.95 g/cm³, R= 1 cm) is dropped into a beaker of shampoo (density = 0.80 g/cm³) and sinks at a rate of 10 cm per minute.

What is the viscosity of the shampoo?



Viscosity Worksheet

Volume of Sphere = $\frac{4}{3} \pi r^3$

| Fluid | Radius of sphere R (m) | Volume of sphere (kg/m ³) | Mass of sphere P _s | Mass of fluid (kg) | Volume of fluid (m ³) | Density of fluid (kg/m ³) P _f | Time for sphere to fall (s) | Velocity of sphere in fluid (m/s) v |
|-------|------------------------|---------------------------------------|-------------------------------|--------------------|-----------------------------------|--|-----------------------------|-------------------------------------|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

| Measurement # | Viscosity of fluid, calculated | Viscosity of fluid, accepted | Relative error |
|---------------|--------------------------------|------------------------------|----------------|
| | | | |
| | | | |
| | | | |



Glossary

absorbance: the ability of a substance to absorb radiation, expressed mathematically as the negative common logarithm of transmittance.

absorption: the interception of radiant energy or sound waves.

acceleration: the rate of change of velocity.

adhesion: the molecular attraction exerted between the surfaces of bodies in contact.

amplitude: the distance that a vibrating object moves from the equilibrium position to a maximum displacement position.

Capillary Pumped Loops (CPL's): devices that are used to transfer heat from one location to another using capillary action.

capillary action: the tendency of liquids, when in contact with a surface, to be elevated or depressed depending on the relative attraction of the molecules of the liquid for each other and for those of the surface.

capillary tube: a small diameter tube.

clinostat: an instrument that rotates at a regular rate.

colloid: a substance that consists of particles dispersed throughout another substance which are too small for resolution with an ordinary light microscope but are incapable of passing through a semipermeable membrane.

colorimeter: an instrument or device for determining and specifying colors; used for chemical analysis by comparison of a liquid's color with standard colors.

convection: the circulatory motion that occurs in a fluid at a nonuniform temperature due to the variation of its density and the action of gravity.

condensation: the conversion of a substance from the vapor state to a denser liquid or solid state.

condenser: a device in which the molecules of a vapor convert to a liquid.

crystals: a body that is formed by the solidification of a chemical element, a compound, or a mixture and has a regularly repeating internal arrangement of its atoms.

cuvette: a small transparent container used to hold liquids in a colorimeter.

damping: to eliminate the amount of vibration or oscillation.



density: the ratio of an object's mass to its volume.

diffusion: movement of substances from a region of higher concentration to a region of lower concentration.

displacement: the distance between an object's first position and any later position

drop tower: a long vertical shaft used for dropping experiment packages, enabling them to achieve microgravity conditions through free-fall.

emulsifier: a substance that causes tiny droplets of one liquid to coagulate in another liquid.

evaporation: to convert from a liquid state into a vapor.

evaporator: an instrument that provides energy (usually heat) to convert a liquid to a vapor.

germination: the process of sprouting from a seed or bud.

glovebox: a container that physically isolates an experiment from the laboratory environment; a research tool used to protect the experiment from outside contamination and/or the researcher from hazardous situations or substances.

gravitation: the force of attraction between two objects that is proportional to their masses; especially the attraction of the Earth's mass for bodies near its surface.

inertia: the tendency of a body to remain at rest or stay in motion in a straight line unless acted upon by an external force.

macromolecules: very large molecules, as of a protein or rubber.

mean (mathematical): a value that is computed by dividing the sum of two or more terms by the number of terms; to average two numbers.

microgravity: an environment in which the apparent weight of a system is small compared to its actual weight due to gravity.

Microgravity Glovebox (MGBX): a small tightly sealed box with gloves attached for handling the microgravity experiments inside; the MGBX consists of a glovebox work area, a video drawer for audio and video, and an interface frame that attaches to the Shuttle cabin so that it can provide electrical power, control, and data collection.

Microgravity Science Glovebox (MSG): a larger volume glovebox specially developed for the International Space Station with more capabilities than previous gloveboxes, having larger ports, increased power, increased thermal removal, increased illumination, and a significantly advanced data system with real-time downlinking and uplinking.



molarity: method of expressing concentrations of solutions defined as the number of moles per solute per liter.

nucleation: to form into a cluster or nucleus.

oscillation: to vibrate from one extreme to the other.

recondense: to change back into a liquid.

scattered: reflected irregularly; diffused.

sedimentation: the action of particles settling to the bottom of a container; caused by gravity.

Spacelab: a scientific laboratory developed by the European Space Agency that was carried into Earth orbit in the Space Shuttle's payload bay.

sublimation: the conversion of molecules from a solid state to a vapor state without passing through the liquid state.

supersaturation: the state of having more solute within a solution that is beyond the 100% level of saturation.

transmittance: the fraction of radiant energy that having entered a layer of absorbing matter reaches its farther boundary.

transmit: to cause a light or force to pass through a medium.

velocity: the rate of change of position along a straight line with respect to time.

viscosity: the amount of internal friction within the fluid, or the measure of resistance to flow when acted on by a shearing force.

viscous: having a relatively high resistance to flow.



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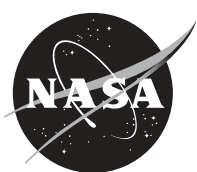
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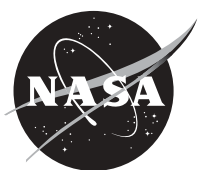
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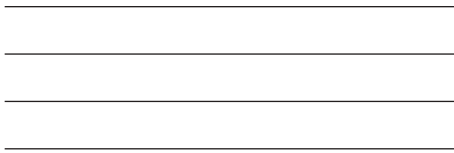
9. How can we make this educator guide more effective for you?

10. Additional comments:

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