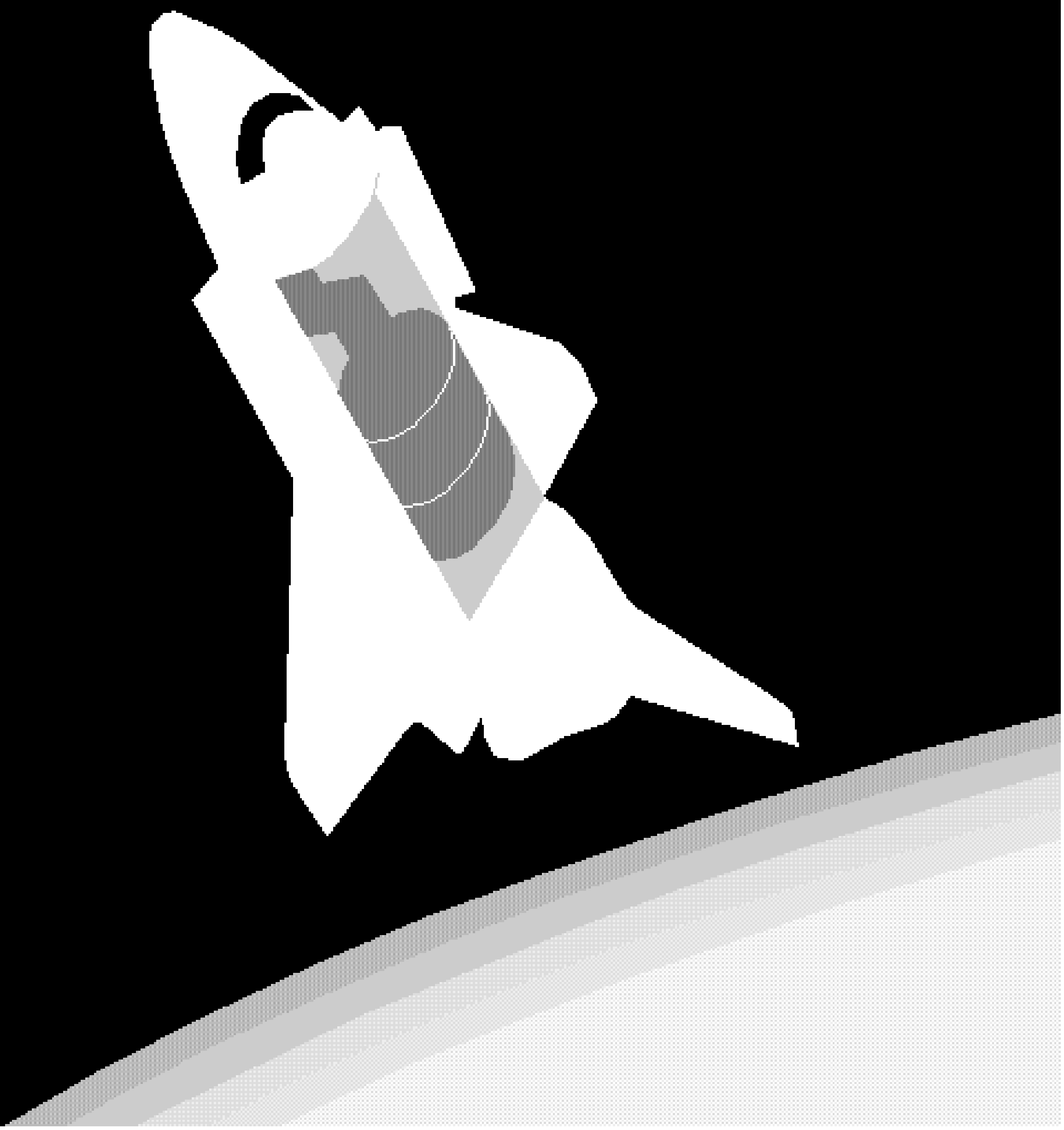
National Aeronautics and
Space Administration

Educational Product
Teachers | Grades 5-12

MICROGRAVITY

Teacher's Guide With Activities for Physical Science



The Cover

The National Aeronautics and Space Administration uses a variety of technologies to create microgravity environments for research. Pictured is the Space Shuttle Orbiter positioned with its tail pointed towards Earth to obtain the lowest possible gravity levels. In this orientation, called a gravity gradient attitude, the vehicle's position is maintained primarily by natural forces. This reduces the need for orbiter thruster firings that disturb acceleration-sensitive experiments.

Microgravity

A Teacher's Guide With Activities
For Physical Science

National Aeronautics and Space Administration

Office of Life and Microgravity Sciences and Applications
Microgravity Science and Applications Division

Office of Human Resources and Education
Education Division

EG-103 January 1995

Acknowledgments

This publication was developed for the National Aeronautics and Space Administration with the assistance of the many educators of the Aerospace Education Services Program, Oklahoma State University.

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Introduction

There are many reasons for space flight. Space flight carries scientific instruments, and sometimes humans, high above the ground, permitting us to see Earth as a planet and to study the complex interactions of atmosphere, oceans, land, energy, and living things. Space flight lofts scientific instruments above the filtering effects of the atmosphere, making the entire electromagnetic spectrum available and allowing us to see more clearly the distant planets, stars, and galaxies. Space flight permits us to travel directly to other worlds to see them close up and sample their compositions. Finally, space flight allows scientists to investigate the fundamental states of matter—solids, liquids, and gases—and the forces that affect them in a microgravity environment. The study of the states of matter and their interactions in microgravity is an exciting opportunity to expand the frontiers of science. Investigations include materials science, combustion, fluids, and biotechnology. Microgravity is the subject of this teacher's guide.

What Is Microgravity?

The presence of Earth creates a gravitational field that acts to attract objects with a force inversely proportional to the square of the distance between the center of the object and the center of Earth. When measured on the surface of Earth, the acceleration of an object acted upon only by Earth's gravity is commonly referred to as one g or one Earth gravity. This acceleration is approximately 9.8 meters/second squared (m/s^2).

The term *microgravity* (μg) can be interpreted in a number of ways depending upon context. The prefix micro - (μ) is derived from the original Greek *mikros*, meaning "small." By this definition, a microgravity environment is one that will impart to an object a net acceleration small compared with that produced by Earth at its surface. In practice, such accelerations will range from about one percent of Earth's gravitational acceleration (aboard aircraft in parabolic flight) to better than one part in a million (for example, aboard Earth-orbiting free flyers).

Another common usage of micro- is found in quantitative systems of measurement, such as the metric system, where micro- means *one part in a million*. By this second definition, the acceleration imparted to an object in microgravity will be one-millionth (10^{-6}) of that measured at Earth's surface.

The use of the term microgravity in this guide will correspond to the first definition: small gravity levels or low gravity. As we describe how low-acceleration environments can be produced, you will find that the fidelity (quality) of the microgravity environment will depend on the mechanism used to create it. For illustrative purposes only, we will provide a few simple quantitative examples using the second definition. The examples attempt to provide insight into what might be expected if the local acceleration environment would be reduced by six orders of magnitude from 1g to 10^{-6}g.

If you stepped off a roof that was five meters high, it would take you just one second to reach the ground. In a microgravity environment equal to one percent of Earth's gravitational pull, the same drop would take 10 seconds. In a microgravity environment equal to one-millionth of Earth's gravitational pull, the same drop would take 1,000 seconds or about 17 minutes!

Microgravity can be created in two ways. Because gravitational pull diminishes with distance, one way to create a microgravity environment is to travel away from Earth. To reach a point where Earth's gravitational pull is reduced to one-millionth of that at the surface, you would have to travel into space a distance of 6.37 million kilometers from Earth (almost 17 times farther away than the Moon). This approach is impractical, except for automated spacecraft, since humans have yet to travel farther away from Earth than the distance to the Moon. However, a more practical microgravity environment can be created through the act of free fall.

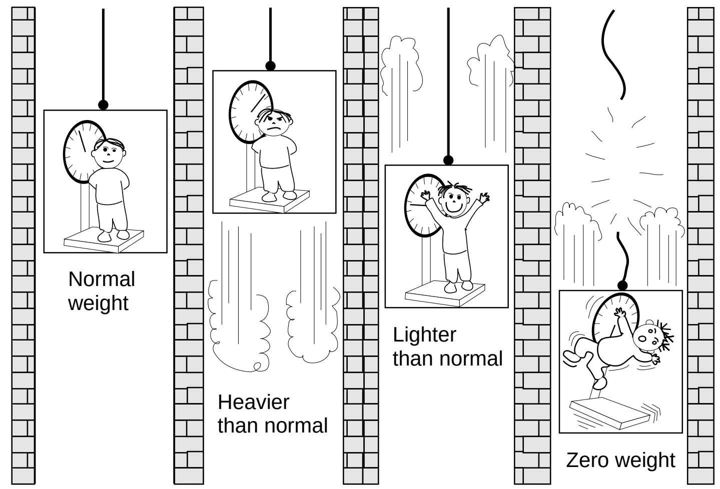

Figure 1. Acceleration and weight

The person in the stationary elevator car experiences normal weight. In the car immediately to the right, weight increases slightly because of the upward acceleration. Weight decreases slightly in the next car because of the downward acceleration. No weight is measured in the last car on the right because of free fall.

We will use a simple example to illustrate how free fall can achieve microgravity. Imagine riding in an elevator to the top floor of a very tall building. At the top, the cables supporting the car break, causing the car and you to fall to the ground. (In this example, we discount the effects of air friction on the falling car.) Since you and the elevator car are falling together, you will float inside the car. In other words, you and the elevator car are accelerating downward at the same rate. If a scale were present, your weight would not register because the scale would be falling too (Figure 1).

Gravity

Gravitational attraction is a fundamental property of matter that exists throughout the known universe. Physicists identify gravity as one of the four types of forces in the universe. The others are the strong and weak nuclear forces and the electromagnetic force.

More than 300 years ago the great English scientist Sir Isaac Newton published the important generalization that mathematically describes this universal force of gravity. Newton was the first to realize that gravity extends well beyond the domain of Earth. This realization was based on the first of three laws he had formulated to describe the motion of objects. Part of Newton's first law, the law of inertia, states that objects in motion travel in a straight line at a constant velocity unless acted upon by a net force. According to this law, the planets in space should travel in straight lines. However, as early as the time of Aristotle, the planets were known to travel on curved paths. Newton reasoned that the circular motions of the planets are the result of a net force acting upon each of them. That force, he concluded, is the same force that causes an apple to fall to the ground—gravity.

Newton's experimental research into the force of gravity resulted in his elegant mathematical statement that is known today as the **Law of Universal Gravitation**. According to Newton, every mass in the universe attracts every other mass. The attractive force between any two objects is directly proportional to the product of the two masses being measured and inversely proportional to the square of the distance separating them. If we let *F* represent this force, *r* the distance between the centers of the masses, and m_1 and m_2 the magnitude of the two masses, the relationship stated can be written symbolically as:

$$F \propto \frac{m_1 m_2}{r^2}$$

($\propto$ is defined mathematically to mean "is proportional to.") From this relationship, we can see that the greater the masses of the attracting objects, the greater the force of attraction between them. We can also see that the farther apart the objects are from each other, the less the attraction. It is important to note the inverse square relationship with respect to distance. In other words, if the distance between the objects is doubled, the attraction between them is diminished by a factor of four, and if the distance is tripled, the attraction is only one-ninth as much.

Newton's Law of Universal Gravitation was later quantified by eighteenth-century English physicist Henry Cavendish who actually measured the gravitational force between two one-kilogram masses separated by a distance of one meter. This attraction was an extremely weak force, but its determination permitted the proportional relationship of Newton's law to be converted into an equation. This measurement yielded the *universal gravitational constant* or *G.*

Deep In Space

The inverse square relationship, with respect to distance, of the Law of Gravitation can be used to determine how far to move a microgravity laboratory from Earth to achieve a 10^{-6}g environment. Distance (*r*) is measured between the centers of mass of the laboratory and of Earth. While the laboratory is still on Earth, the distance between their centers is 6,370 kilometers (equal to the approximate radius of Earth, r_e). To achieve 10^{-6}g, the laboratory has to be moved to a distance of 1,000 Earth radii. In the equation, r then becomes 1,000 r_e or r= 6.37×10^6km.

Cavendish determined that the value of *G* is 0.0000000000667 newton m^2/kg^2 or 6.67×10^{-11} Nm^2/kg^2. With G added to the equation, the Universal Law of Gravitation becomes:

$$F = G\frac{m_1 m_2}{r^2}$$

Creating Microgravity

Drop Towers and Tubes

In a practical sense, microgravity can be achieved with a number of technologies, each depending upon the act of free fall. Drop towers and drop tubes are high-tech versions of the elevator analogy presented in a previous section. The large version of these facilities is essentially a hole in the ground.

Drop towers accommodate large experiment packages, generally using a drop shield to contain the package and isolate the experiment from aerodynamic drag during free fall in the open environment.

NASA's Lewis Research Center in Cleveland, Ohio has a 145-meter drop tower facility that begins on the surface and descends into Earth like a mine shaft. The test section of the facility is 6.1 meters in diameter and 132 meters deep. Beneath the test section is a catch basin filled with polystyrene beads. The 132-meter drop creates a microgravity environment for a period of 5.2 seconds.

To begin a drop experiment, the experiment apparatus is placed in either a cylindrical or rectangular test vehicle that can carry experiment loads of up to 450 kilograms. The vehicle is suspended from a cap that encloses the upper end of the facility. Air is pumped out of the facility until a vacuum of 10^{-2} torr is achieved. (Atmospheric pressure is 760 torr.) By doing so, the acceleration effects caused by aerodynamic drag on the vehicle are reduced to less than 10^{-5} g. During the drop, cameras within the vehicle record the action and data is telemetered to recorders.

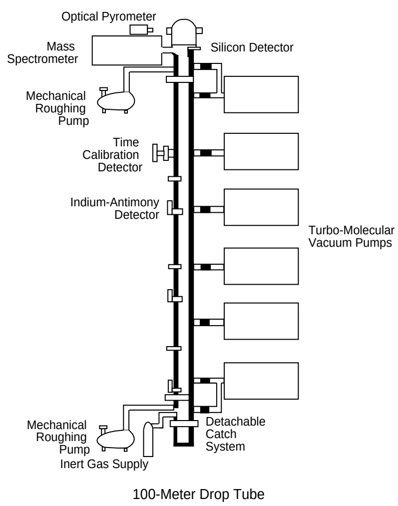

Figure 2. 100-Meter Drop Tube at the NASA Marshall Space Flight Center.

A smaller facility for microgravity research is located at the NASA Marshall Space Flight Center in Huntsville, Alabama. It is a 100-meter-high, 25.4-centimeter-diameter evacuated drop tube that can achieve microgravity for periods of as long as 4.5 seconds. The upper end of the tube is fitted with a stainless steel bell jar. For solidification experiments, an electron bombardment or an electromagnetic levitator furnace is mounted inside the jar to melt the test samples. After the sample melts, drops are formed and fall through the tube to a detachable catch fixture at the bottom of the tube (Figure 2).

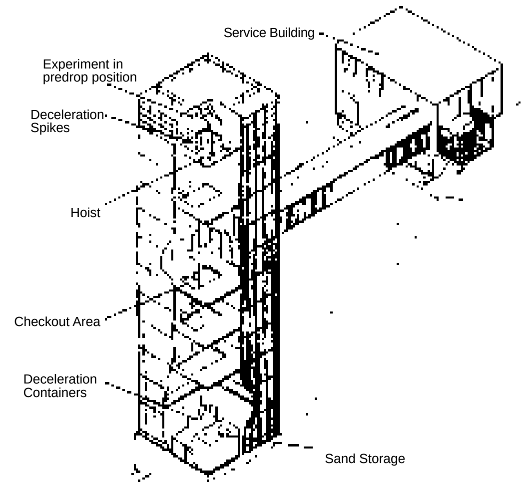

Figure 3. 30-Meter Drop Tower at the NASA Lewis Research Center.

Additional drop facilities of different sizes and for different purposes are located at the NASA Field Centers and in other countries. A 490-meter-deep vertical mine shaft in Japan has been converted to a drop facility that can achieve a 10^{-5}g environment for up to 11.7 seconds.

Aircraft

Airplanes can achieve low-gravity for periods of about 25 seconds or longer. The NASA Johnson Space Center in Houston, Texas operates a KC-135 aircraft for astronaut training and conducting experiments. The plane is a commercial-sized transport jet (Boeing 707) with most of its passenger seats removed. The walls are padded for protection of the people inside. Although airplanes cannot achieve microgravity conditions of as high quality as those produced in drop towers and drop tubes (since they are never completely in free fall and their drag forces are quite high), they do offer an important advantage over drop facilities—experimenters can ride along with their experiments.

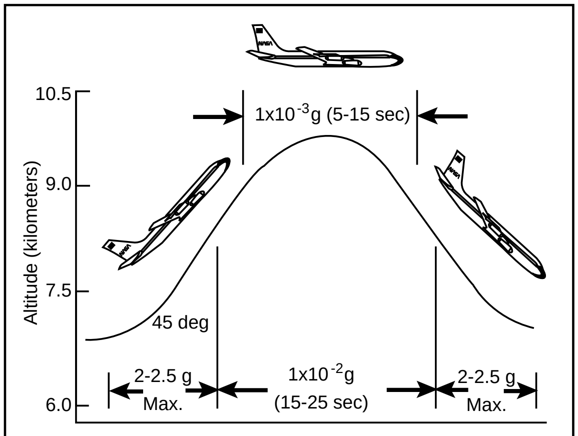

Figure 4. Parabolic Flight Characteristics.

A typical flight lasts 2 to 3 hours and carries experiments and crewmembers to a beginning altitude about 7 km above sea level. The plane climbs rapidly at a 45-degree angle (pull up), traces a parabola (pushover), and then descends at a 45-degree angle (pull out) (Figure 4). During the pull up and pull out segments, crew and experiments experience between 2g and 2.5g. During the parabola, at altitudes ranging from 7.3 to 10.4 kilometers, net acceleration drops as low as 10^{-3} g. On a typical flight, 40 parabolic trajectories are flown. The gut-wrenching sensations produced on the flight have earned the plane the nickname of "vomit comet." NASA also operates a Learjet for low-gravity research out of the NASA Lewis Research Center. Flying on a trajectory similar to the one followed by the KC-135, the Learjet provides a low-acceleration environment of $5x10^{-2}$g to $75x10^{-2}$ g for up to 20 seconds.

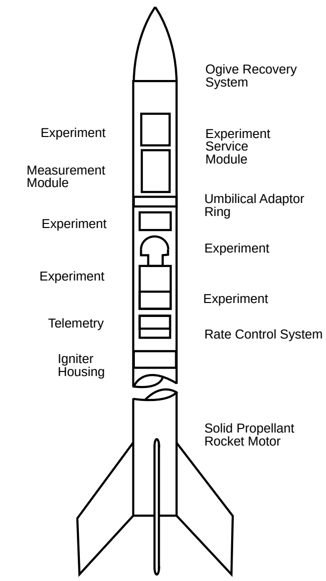

Figure 6. Small Rocket for Microgravity Experiments.

Rockets

Small rockets provide a third technology for creating microgravity. A sounding rocket follows a suborbital trajectory and can produce several minutes of free fall. The period of free fall exists during its coast, after burn out, and before entering the atmosphere. Acceleration levels are usually at or below 10^{-5}g. NASA has employed many different sounding rockets for microgravity experiments. The most comprehensive series of launches used SPAR (Space Processing Application Rocket) rockets for fluid physics, capillarity, liquid diffusion, containerless processing, and electrolysis experiments from 1975 to 1981. The SPAR could lift 300 kg payloads into free-fall parabolic trajectories lasting four to six minutes (Figures 5, 6).

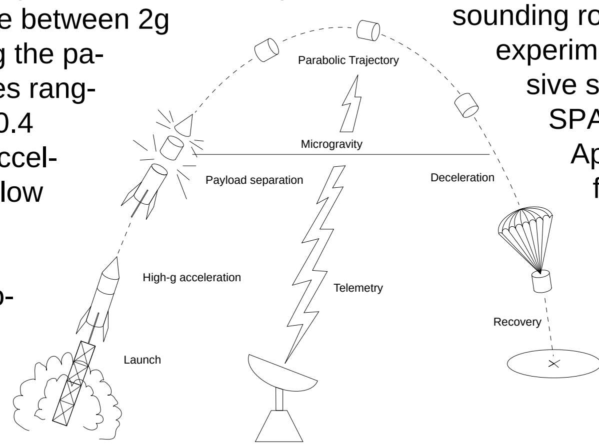

Figure 5. Rocket Parabolic Flight Profile.

Orbiting Spacecraft

Although airplanes, drop facilities, and small rockets can be used to establish a microgravity environment, all of these laboratories share a common problem. After a few seconds or minutes of low-g, Earth gets in the way and the free fall stops. In spite of this limitation, much can be learned about fluid dynamics and mixing, liquid-gas surface interactions, and crystallization and macromolecular structure. But to conduct longer term experiments (days, weeks, months, and years), it is necessary to travel into space and orbit Earth. Having more time available for experiments means that slower processes and more subtle effects can be investigated.

To see how it is possible to establish microgravity conditions for long periods of time, it is first necessary to understand what keeps a spacecraft in orbit. Ask any group of students or adults what keeps satellites and Space Shuttles in orbit and you will probably get a variety of answers. Two common answers are: “The rocket engines keep firing to hold it up.” and “There is no gravity in space.”

Although the first answer is theoretically possible, the path followed by the spacecraft would technically not be an orbit. Other than the altitude involved and the specific means of exerting an upward force, there would be little difference between a spacecraft with its engines constantly firing and an airplane flying around the world. In the case of the satellite, it would just not be possible to provide it with enough fuel to maintain its altitude for more than a few minutes.

The second answer is also wrong. In a previous section, we discussed that Isaac Newton proved that the circular paths of the planets through space was due to gravity’s presence, not its absence.

Newton expanded on his conclusions 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 friction with the air would not be a factor. He then imagined a cannon at the top of that mountain firing cannonballs parallel to the ground. As each cannonball was fired, it was acted upon by two forces. One force, the explosion of the black powder, propelled the cannonball straight outward. If no other force were to act on the cannon ball, the shot would travel in a straight line and at a constant velocity. But Newton knew that a second force would act on the cannonball:

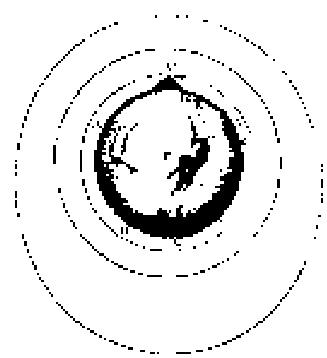

Figure 7. Illustration from Isaac Newton, *Principia, VII, Book III, p551.*

the presence of gravity would cause the path of the cannonball to bend into an arc ending at Earth's surface (Figure 7).

Newton demonstrated how additional cannonballs would travel farther from the mountain if the cannon were loaded with more black powder each time it was fired. With each shot, the path would lengthen and soon, the cannonballs would disappear over the horizon. Eventually, if a cannonball were fired with enough energy, it would fall entirely around Earth and come back to its starting point. The cannonball would begin to orbit Earth. Provided no force other than gravity interfered with the cannonball's

"Microgravity Room"

One of the common questions asked by visitors to the NASA Johnson Space Center in Houston, Texas is, “Where is the room where a button is pushed and gravity goes away so that astronauts float?” No such room exists because gravity can never be made to go away. The misconception comes from the television pictures that NASA takes of astronauts training in the KC-135 and from underwater training pictures. Astronauts scheduled to wear spacesuits for extravehicular activities train in the Weightless Environment Training Facility (WET F). The WET F is a swimming pool large enough to hold a Space Shuttle payload bay mock-up and mock-ups of satellites and experiments. Since the astronauts' spacesuits are filled with air, heavy weights are added to the suits to achieve neutral buoyancy in the water. The facility provides an excellent simulation of what it is like to work in space with two exceptions: in the pool it is possible to swim with hand and leg motions, and if a hand tool is dropped, it falls to the bottom.

motion, it would continue circling Earth in that orbit.

This is how the Space Shuttle stays in orbit. It is launched in a trajectory that arcs above Earth so that the orbiter is traveling at the right speed to keep it falling while maintaining a constant altitude above the surface. For example, if the Shuttle climbs to a 320-kilometer-high orbit, it must travel at a speed of about 27,740 kilometers per hour to achieve a stable orbit. At that speed and altitude, the Shuttle’s falling path will be parallel to the curvature of Earth. Because the Space Shuttle is free-falling around Earth and upper atmospheric friction is extremely low, a microgravity environment is established.

Orbiting spacecraft provide ideal laboratories for microgravity research. As on airplanes, scientists can fly with the experiments that are on the spacecraft. Because the experiments are tended, they do not have to be fully automatic in operation. A malfunction in an experiment conducted with a drop tower or small rocket means a loss of data or complete failure. In orbiting spacecraft, crewmembers can make repairs so that there is little or no loss of data. They can also make on-orbit modifications in experiments to gather more diverse data.

Perhaps the greatest advantage of orbiting spacecraft for microgravity research is the amount of time during which microgravity conditions can be achieved. Experiments lasting for more than two weeks are possible with the Space Shuttle. When the International Space Station becomes operational, the time available for experiments will stretch to months. The International Space Station will provide a manned microgravity laboratory facility unrivaled by any on Earth (Figure 8).

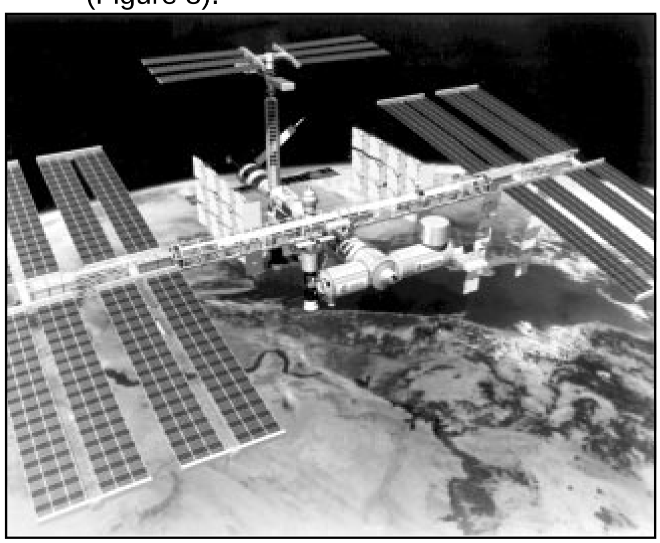

Figure 8. International Space Station.

Glossary

Acceleration - The rate at which an object's velocity changes with time.

Buoyancy-Driven Convection - Convection created by the difference in density between two or more fluids in a gravitational field.

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

Diffusion - Intermixing of atoms and/or molecules in solids, liquids, and gases due to a difference in composition.

Drop Tower - Research facility that creates a microgravity environment by permitting experiments to free fall through an enclosed vertical tube.

Exothermic - Releasing heat.

Fluid - Anything that flows (liquid or gas).

Free Fall - Falling in a gravitational field where the acceleration is the same as that due to gravity alone.

G - Universal Gravitational Constant (6.67×10^{-11} Nm^2/kg^2)

g - The acceleration Earth's gravitational field exerts on objects at Earth's surface. (approximately 9.8 meters per second squared)

Gravitation - The attraction of objects due to their masses.

Inertia - A property of matter that causes it to resist changes in velocity.

Law of Universal Gravitation - A law stating that every mass in the universe attracts every other mass with a force proportional to the product of their masses and inversely proportional to the square of the distances between their centers.

Microgravity (μg) - An environment that imparts to an object a net acceleration that is small compared with that produced by Earth at its surface.

Parabolic Flight Path - The flight path followed by airplanes in creating a microgravity environment (the shape of a parabola).

Skylab - NASA's first orbital laboratory that was operated in 1973 and 1974.

Spacelab - A scientific laboratory developed by the European Space Agency that is carried into Earth orbit in the Space Shuttle's payload bay.

NASA Educational Materials

NASA publishes a variety of educational resources suitable for classroom use. The following resources specifically relate to microgravity and living, working, and science research in the microgravity environment. Resources are available from different sources as noted.

Educational Videotapes
Educational videotapes and slide sets are obtainable through CORE.
Microgravity, from the NASA Educational Satellite Videoconference Series.
Length: 60:00
Grades: 4-12
Application: Chemistry, Life Science, Physical Science
NASA astronauts, scientists, and aerospace education specialists present microgravity concepts, discuss scientific research, and engage in interactive hands-on activities with students/teachers that call in. 1992

Gravity and Life, Episode 2 of NASA Biology: On Earth and In Space Series.
Length: 30:00
Grades 8-12
Application: Life Science
Dr. Richard Keefe, Professor of Anatomy, Case Western Reserve University, explains the role of gravity in the development of life. 1987

Gravity - A Force of Nature, Episode 3 of What's In the News-Space
Length: 15:00
Grades: 4-12
Application: Physical Science
Explains the concept of universal gravity, microgravity, and weightlessness using examples from Earth such as a roller coaster and from space such as Skylab and Space Shuttle acrobatics. 1993

Slides
Microgravity Science
Grades: 8-12
This set of 24 slides comes illustrates the basic concepts of microgravity and describes four areas of microgravity research, including: biotechnology, combustion science, fluid physics, and materials science. 1994

Educational Software
Microgravity
Grades: 4-8
This tutorial is one of a series that NASA Jet Propulsion Laboratory developed to motivate teachers and students to study science, mathematics, and technology. Students use inverses, squares, and ratios to calculate gravity in space and orbits. *Apple II Software.*

NASA Publications
To obtain NASA publications, contact the NASA Field Center that the desired publication specifies. A listing of addresses for NASA Field Centers appears on pages 71-72.

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Suggested Reading

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NASA Educational Resources

NASA Spacelink: An Electronic Information System

NASA Spacelink is an electronic information system designed to provide current educational information to teachers, faculty, and students. Spacelink offers a wide range of materials (computer text files, software, and graphics) related to the space program. Documents on the system include: science, mathematics, engineering, and technology education lesson plans, historical information related to the space program, current status reports on NASA projects, news releases, information on NASA edcuational programs, NASA educational publications, and other materials, such as computer software and images, chosen for their educational value and relevance to space education. The system may be accessed by computer through direct-dial modem or the Internet.

Spacelink's modem line is (205) 895-0028.
Data format 8-N-1, VT-100 terminal emulation required.
The Internet TCP/IP address is 192.149.89.61
Spacelink fully supports the following Internet services:

World Wide Web:	http://spacelink.msfc.nasa.gov
Gopher:	spacelink.msfc.nasa.gov
Anonymous FTP:	spacelink.msfc.nasa.gov
Telnet:	spacelink.msfc.nasa.gov (VT-100 terminal emulation required)

For more information contact:
Spacelink Administrator
Education Programs Office
Mail Code CL 01
NASA Marshall Space Flight Center
Huntsville, AL 35812-0001
Phone: (205) 544-6360

NASA Education Satellite Videoconference Series

The Education Satellite Videoconference Series for Teachers is offered as an inservice education program for educators through the school year. The content of each program varies, but includes aeronautics or space science topics of interest to elementary and secondary teachers. NASA program managers, scientists, astronauts, and education specialists are featured presenters. The videoconference series is free to registered educational institutions. To participate, the institution must have a C-band satellite receiving system, teacher release time, and an optional long distance telephone line for interaction. Arrangements may also be made to receive the satellite signal through the local cable television system. The programs may be videotaped and copied for later use. For more information, contact:

Videoconference Producer
NASA Teaching From Space Program
308 A CITD
Oklahoma State University
Stillwater, OK 74078-0422
E-Mail: nasaedutv@smtpgate.osu.hq.nasa.gov

NASA Television

NASA Television (TV) is the Agency's distribution system for live and taped programs. It offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science.

The educational programming is designed for classrooom use and is aimed at inspiring students to achieve– especially in science, mathematics, and technology. If your school's cable TV system carries NASA TV or if your school has access to a satellite dish, the programs may be downlinked and videotaped. Daily and monthly programming schedules for NASA TV are also available via NASA Spacelink. NASA Television is transmitted on Spacenet 2 (a C-band satellite) on transponder 5, channel 8, 69 degrees West with horizontal polarization, frequency 3880.0 Megahertz, audio on 6.8 megahertz. For more information contact:

NASA Headquarters
Technology and Evaluation Branch
Code FET
Washington, DC 20546-0001

NASA Teacher Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center (TRC) network. TRCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Because each NASA field center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. A list of the centers and the geographic regions they serve starts at the bottom of this page.

Regional Teacher Resource Centers (RTRCs) offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as RTRCs in many states. Teachers may preview, copy, or receive NASA materials at these sites. A complete list of RTRCs is available through CORE.

NASA Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

IF YOU LIVE IN:		Center Education Program Officer	Teacher Resource Center
Alaska Arizona California Hawaii Idaho Montana	Nevada Oregon Utah Washington Wyoming	Mr. Garth A. Hull Chief, Education Programs Branch Mail Stop 204-12 **NASA Ames Research Center** Moffett Field, CA 94035-1000 PHONE: (415) 604-5543	NASA Teacher Resource Center Mail Stop T12-A **NASA Ames Research Center** Moffett Field, CA 94035-1000 PHONE: (415) 604-3574
Connecticut Delaware District of Columbia Maine Maryland Massachusetts	New Hampshire New Jersey New York Pennsylvania Rhode Island Vermont	Mr. Richard Crone Educational Programs Code 130 **NASA Goddard Space Flight Center** Greenbelt, MD 20771-0001 PHONE: (301) 286-7206	NASA Teacher Resource Laboratory Mail Code 130.3 **NASA Goddard Space Flight Center** Greenbelt, MD 20771-0001 PHONE: (301) 286-8570
Colorado Kansas Nebraska New Mexico	North Dakota Oklahoma South Dakota Texas	Dr. Robert W. Fitzmaurice Center Education Program Officer Education and Public Services Branch - AP-4 **NASA Johnson Space Center** Houston, TX 77058-3696 PHONE: (713) 483-1257	NASA Teacher Resource Room Mail Code AP-4 **NASA Johnson Space Center** Houston, TX 77058-3696 PHONE: (713) 483-8696
Florida Georgia Puerto Rico Virgin Islands		Dr. Steve Dutczak Chief, Education Services Branch Mail Code PA-ESB **NASA Kennedy Space Center** Kennedy Space Center, FL 32899-0001 PHONE: (407) 867-4444	NASA Educators Resource Laboratory Mail Code ERL **NASA Kennedy Space Center** Kennedy Space Center, FL 32899-0001 PHONE: (407) 867-4090

IF YOU LIVE IN:	Center Education Program Officer	Teacher Resource Center
Kentucky North Carolina South Carolina Virginia West Virginia	Ms. Marchell Canright Center Education Program Officer Mail Stop 400 **NASA Langley Research Center** Hampton, VA 23681-0001 PHONE: (804) 864-3307	NASA Teacher Resource Center for **NASA Langley Research Center** Virginia Air and Space Center 600 Settler's Landing Road Hampton, VA 23699-4033 PHONE: (804)727-0900 x 757
Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	Ms. Jo Ann Charleston Acting Chief, Office of Educational Programs Mail Stop 7-4 **NASA Lewis Research Center** 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216) 433-2957	NASA Teacher Resource Center Mail Stop 8-1 **NASA Lewis Research Center** 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216) 433-2017
Alabama, Arkansas, Iowa, Louisiana, Missouri, Tennessee	Mr. JD Horne Director, Education Programs Office Mail Stop CL 01 **NASA Marshall Space Flight Center** Huntsville, AL 35812-0001 PHONE: (205) 544-8843	NASA Teacher Resource Center for **NASA Marshall Space Flight Center** U.S. Space and Rocket Center P.O. Box 070015 Huntsville, AL 35807-7015 PHONE: (205) 544-5812
Mississippi	Dr. David Powe Manager, Educational Programs Mail Stop MA00 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601) 688-1107	NASA Teacher Resource Center Building 1200 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601) 688-3338
The Jet Propulsion Laboratory (JPL) serves inquiries related to space and planetary exploration and other JPL activities.	Dr. Fred Shair Manager, Educational Affairs Office Mail Code 183-900 **NASA Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-8251	NASA Teacher Resource Center JPL Educational Outreach Mail Stop CS-530 **NASA Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-6916
California (mainly cities near Dryden Flight Research Facility)		NASA Teacher Resource Center Public Affairs Office (Trl. 42) **NASA Dryden Flight Research Facility** Edwards, CA 93523-0273 PHONE: (805) 258-3456
Virginia and Maryland's Eastern Shores		NASA Teacher Resource Lab NASA Goddard Space Flight Center **Wallops Flight Facility** Education Complex - Visitor Center Building J-17 Wallops Island, VA 23337-5099 Phone: (804) 824-2297/2298

Liftoff To Learning Educational Videotape Series

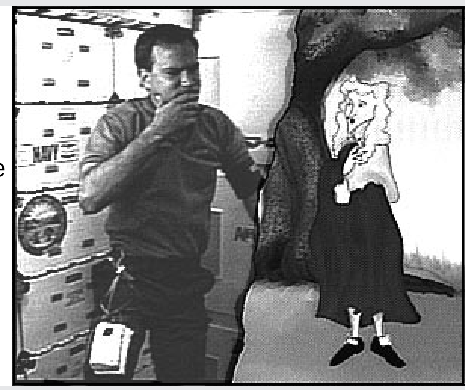
To obtain a copy of any of these videotapes and the accompanying Video Resource Guide, or for more information on the Liftoff to Learning Educational Videotape Series, contact NASA Central Operation of Resources for Educators (CORE). *See page 71.*

Living In Space demonstrates what it is like to live and work in space. Viewers are invited by the Space Shuttle Crew to join the astronauts as they go through their daily routine living onboard the Space Shuttle. Students see the similarities and differences in eating, exercising, relaxing, maintaining personal hygience, sleeping, and working in space versus on Earth.

Grade Levels: K-4
Application: Life Sciences, Physical Science
Length: 10:00

Newton In Space offers an introduction to Isaac Newton's Laws of Motion and how these laws apply to space flight. The program explains the difference between weight and mass, the basic prin-ciples of balanced and unbalanced forces, action and opposite reac-tions, and how the three laws of motions affect the way a rocket operates. Using the microgravity environment of Earth orbit, Space Shuttle astronauts conduct simple force and motion demonstrations in ways not possible on Earth.

Grade Levels: 5-8
Application: Physical Science
Length: 12:37

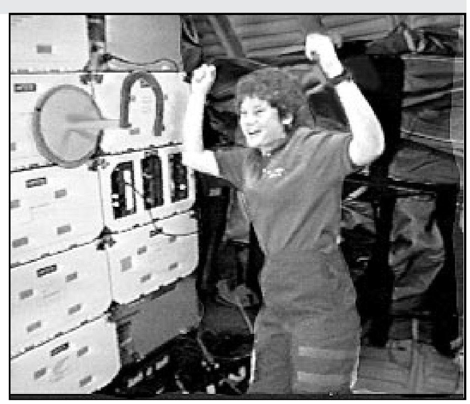


Space Basics answers basic questions about space flight including: how spacecraft travel into space; how spacecraft remain in orbit; why astronauts float in space; and how spacecraft return to Earth. Viewers learn how English scientist Isaac Newton formulated the basic science behind Earth orbit more than 300 years ago.

Grade Levels: 5-8
Application: History, Physical Science, Technology
Length: 20:55

Toys In Space II provides a hands-on way for students to investigate principles of mathematics and science that make many common toys function. The Space Shuttle crew invite students to experiment with similar toys in their classroom and hypothesize how these same toys will operate in microgravity. Scenes of the astronauts operating the toys in space serve as data for students to confirm or reject their hypotheses.

Grade Levels: K-12
Application: Mathematics, Physical Science, Technology
Length: 20:55



Educators and scientists at the National Aeronautics and Space Administration would appreciate your taking a few minutes to respond to the statements and questions below. Please affix proper postage and return by mail.

SA	**-**	**Strongly Agree**
A	**-**	**Agree**
D	**-**	**Disagree**
SD	**-**	**Strongly Disagree**

Microgravity - Teacher's Guide With Activities For Physical Science

1. The teaching guide is easily integrated into the curriculum.	**SA A D SD**
2. The procedures for the activities have sufficient information and are easily understood.	**SA A D SD**
3. The illustrations are adequate to explain the procedures and concepts.	**SA A D SD**
4. Activities effectively demonstrate concepts and are appropriate for the grade level I teach.	**SA A D SD**

5. a. What features of the guide are particularly helpful in your teaching?

____

b. What changes would make the guide more effective for you?

____

6. I teach _____ grade. Subjects ______________________________

7. I used the guide with _____ (number of) students.

Additional comments: ______________________________

Today's Date: ______________________________

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