National Aeronautics and Space Administration

GRADES 5-12

Why Do We Really Need Pressure Suits?

Physical Science Lessons
on Temperature, Pressure,
Density, and Human Survival
at High Altitudes

Aeronautics
Research
Mission
Directorate

Museum in a BOX Series

www.nasa.gov

About This Guide

This curriculum guide is broken down into several sections in order to make it easier to use and easier to find lessons and activities you need for your classroom. Each lesson can be completed as a stand-alone lesson made up of several activities or can be combined with any or all of the other lessons within this guide. The background information applies to all lessons and activities. Due to the interrelated nature of temperature, pressure, and density, some activities in one category explain several concepts simultaneously but were placed in the lesson that seemed to be most applicable to the concept being taught. Overall, in addition to the physical science nature of the lessons within this guide, there is an additional focus on human survival within temperature, pressure, and density parameters.

Introduction

Lessons are broken down as follows:

- Pressure Lesson One: Survival in a Vacuum
  - Four activities

- Pressure Lesson Two: Air Has Pressure
  - Three activities

- Temperature Lesson: Can Water Boil Without Heat?
  - Four activities

- Density Lesson: How To See Density
  - Two activities

Table of Contents

Background

What would happen if you were high above Earth's surface or in space without a protective pressure suit or spacesuit? Would you explode? Would your blood boil? Could you survive? The answers are a bit more complicated than you might think, and these lessons and activities will show you why humans need protective pressure suits in these conditions.

The quick answers to the above questions are as follows:
- Would you explode? No.
- Would your blood boil? That depends, but the water in your body would.
- Could you survive? Yes, but only for about 1 minute.

However, there is much more to those questions. Read on to find out.

The higher in altitude we travel, the more protection we need to keep ourselves safe. The higher you travel above Earth's surface, the less atmospheric pressure there is to exert on an object, including humans. Along with pressure, temperature also changes with altitude. So what exactly happens to a human during these travels? To answer that question, we will start with conditions on Earth and work our way into space. The focus will be on **pressure**, **temperature**, and **density**, relating each of these to what is needed for human survival.

Before we discuss the layers of Earth's atmosphere, we will also provide a definition of "space." When does "space" start? While there is no visible delineation between Earth's atmosphere and space, it is generally agreed that space begins 50 miles above Earth's surface. In order to earn an astronaut badge, the pilot must fly above 50 miles in altitude.

On Earth, we are subjected to a variance in pressure, temperature, and air density, and these variations are due in a large part to our altitude above sea level, surface weather, and the effects of the geology around us. For pressure, temperature, and density at Earth's surface, averages will be used for this discussion in order to simplify these concepts since our main focus is on what happens to humans when we are above Earth. The section below about the troposphere provides standard averages used for pressure calculations.

Earth's atmosphere is broken up into five basic layers, each of which fluctuates in height depending on seasons of the year and location (layers are thicker at the equator and thinner at the poles). Information about each of these layers can be found below.

This photograph of the colorful layers of Earth's upper atmosphere was taken from the Space Shuttle, looking sideways across Earth's atmosphere. (Image Credit: NASA, http://www.nasa.gov/audience/forstudents/k-4/dictionary/Atmosphere.html)

Layers of the Earth's Atmosphere

Troposphere

While studying the atmosphere itself can be a complicated process, the lowest layer of the atmosphere, the troposphere, is perhaps the most complex of the atmosphere's layers because it is a system that involves many different variables, all of which affect conditions within the troposphere. Among these variables are factors such as temperature fluctuations due to seasons, weather, and the uneven heating and cooling of Earth's surface (the other layers are not as susceptible to these kinds of fluctuations). Temperature, density, and altitude are all interrelated, so changes in any/all of these will affect the others as well. Finally, nearly all of the water vapor in our atmosphere is within the troposphere. The effects of water in the atmosphere further complicate the troposphere and atmospheric changes that occur.

The lowest layer of the atmosphere, the troposphere, begins at Earth's surface and reaches up to 7 kilometers (about 23,000 feet) at the poles and to about 17–18 kilometers (about 56,000 feet) at the equator. The height of the troposphere changes with the weather; it is higher in the summer months and lower in the winter (think of gas laws and changes in temperature—as gas temperature increases, density decreases. The decrease in density causes the atmosphere to expand, raising the height of the troposphere. Likewise, when the temperature of the air in the troposphere cools, the air condenses, lowering the height of the troposphere. Commercial aircraft travel in this region.

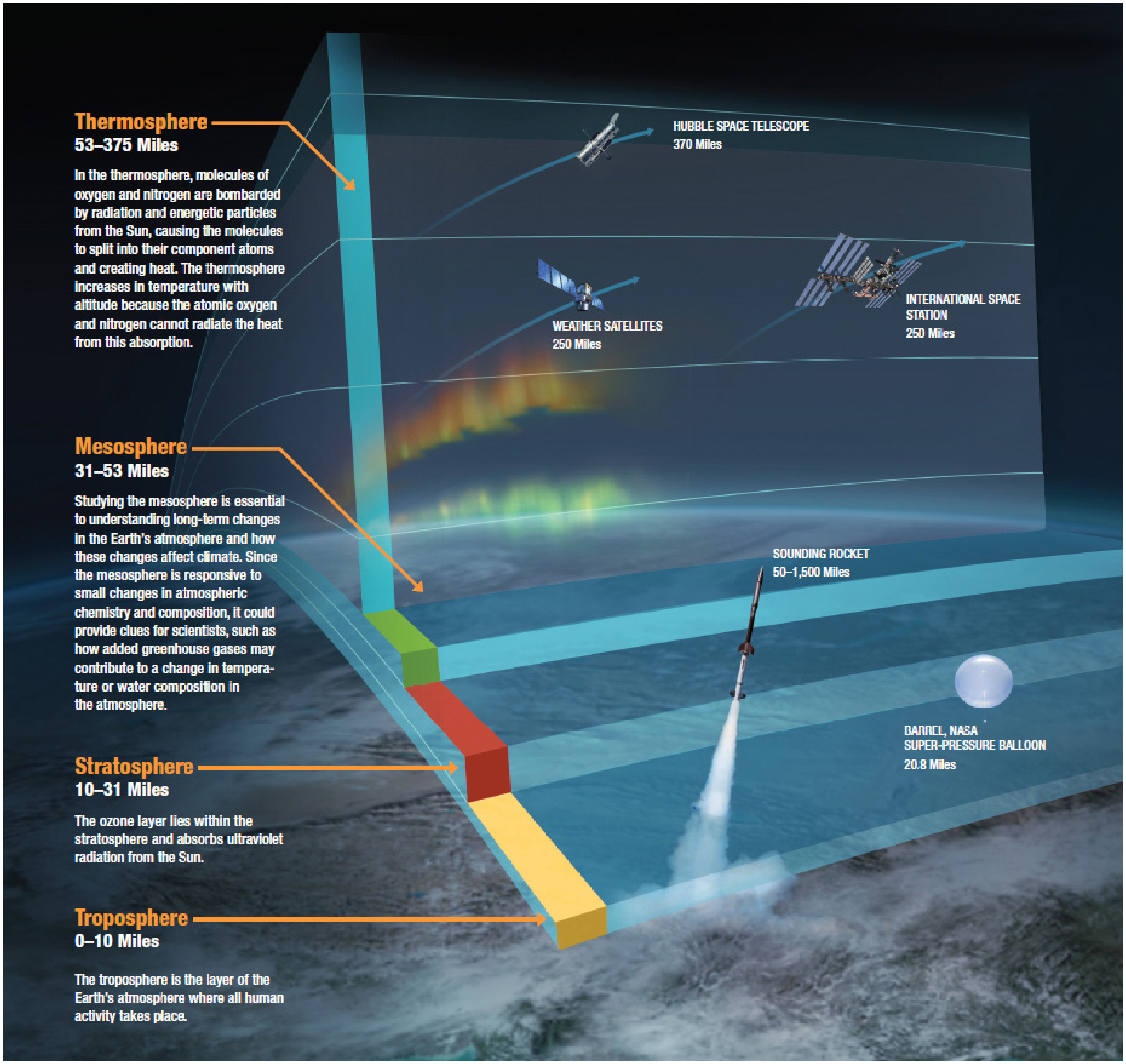
NASA's DC-8 Airborne Science research aircraft in flight .
(Image Credit: NASA, https://www.nasa.gov/centers/dryden/multimedia/imagegallery/DC-8/EC04-0047-006.html)

The troposphere is primarily composed of nitrogen (78 percent) and oxygen (21 percent), with only small concentrations of other trace gases.

Uneven temperature fluctuations occur in the troposphere, but overall, air temperature declines with an increase in altitude. On average, temperatures in this region decrease 6 degrees Celsius (C) for each kilometer rise in altitude, which is about 3.6 degrees Fahrenheit (F) for each 1,000 feet. When climbing in altitude, air pressure also decreases. Pressure decreases due to both a lessening of gravity's pull and a lessening of air pressure from above. At Earth's surface, more gravitational pull on air molecules increases density and, as a result, pressure. In addition, there is more air *above* the air closest to Earth's surface (which is also being pulled down due to gravity), which helps to increase air pressure at the surface. The higher in the atmosphere you travel, the less air there is. That means less gravitational pull on molecules and less mass pushing down on that region.

Since most of the air is located closest to Earth's surface, the troposphere is the densest layer of the atmosphere. Up to 75 percent of the mass of the atmosphere is in the troposphere. In fact, 50 percent of the *total* mass of the atmosphere is located in the lower 5.6 kilometers (about 18,000 feet) of the troposphere. At sea level, the atmospheric air pressure is 14.7 pounds per square inch absolute (psia), which is in reference to the absolutely zero pressure that exists in a perfect vacuum. So at sea level, the weight of Earth's atmosphere exerts a force of 14.7 pounds on every square inch of our bodies. The force exerted on about 1,000 square centimeters (about 1 square foot) at sea level is about 1 ton of pressure.

So why aren't we crushed under this pressure? Air *inside* our bodies is also exerting pressure, creating an equilibrium and preventing outside air pressure from crushing our bodies. However, if humans were to travel higher in the atmosphere without some kind of protection, where air pressure is much lower, we would have problems because of the difference in air pressure between what's inside our bodies and air pressure outside our bodies. At higher altitudes, air pressure inside our bodies would be much higher than pressure outside, unless we had some kind of protection to keep that from happening. Without that protection, our bodies would swell as the gases on the inside and the outside attempted to equaliz



The structure of the upper atmosphere. (Image credit: NASA, http://www.nasa.gov/mission_pages/sunearth/multimedia/upper-atmosphere-graphic.html)

At the upper limits of the troposphere, just before the stratosphere, is the tropopause, which is a thin boundary marked by stable temperatures.

Stratosphere

The stratosphere, the second lowest layer of Earth's atmosphere, lies above the troposphere and is separated from it by the tropopause. It extends from the top of the troposphere to about 50 kilometers (about 31 miles; about 164,000 feet).

The stratosphere contains the ozone layer, the part of Earth's atmosphere that contains relatively high concentrations of ozone. The stratosphere defines a layer in which temperatures rise with increasing altitude. This rise in temperature is caused by the absorption of ultraviolet (UV) radiation from the Sun by the ozone layer. Such a temperature profile creates very stable atmospheric conditions, and the stratosphere lacks the air turbulence that is so prevalent in the troposphere. Consequently, the stratosphere is almost completely free of clouds or other forms of weather.

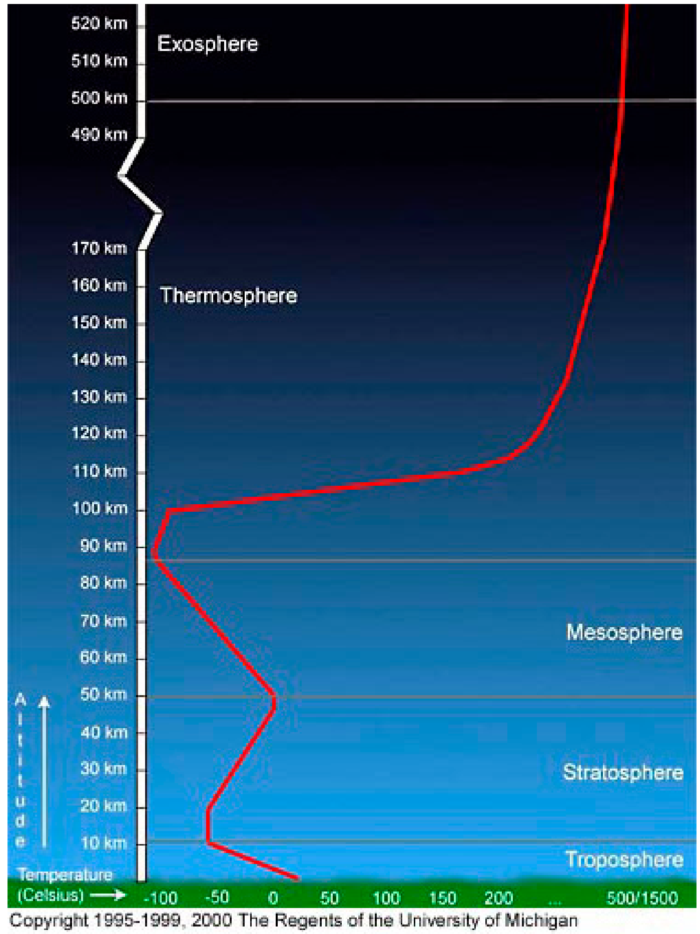
Mesosphere

The mesosphere is the third highest layer in our atmosphere, occupying the region above the stratosphere and below the thermosphere. It extends from the top of the stratosphere to the range of 80 to 85 kilometers (about 50 to 53 miles; about 260,000 to 280,000 feet).

Temperatures in the mesosphere drop with increasing altitude to about –100 degrees C (–148 degrees F). The mesosphere is the coldest of the atmospheric layers. In fact, it is colder than Antarctica's lowest recorded temperature. It is cold enough to freeze water vapor into ice clouds. You can see these clouds if sunlight hits them after sunset. They are called Noctilucent Clouds (NLCs). NLCs are most readily visible when the Sun is from 4 to 16 degrees below the horizon. The mesosphere is also the layer in which a lot of meteors burn up while entering Earth's atmosphere. From Earth, they are seen as shooting stars.

Thermosphere

The thermosphere (literally "heat sphere") is the outer layer of the atmosphere, separated from the mesosphere by the mesopause. It extends from the top of the mesosphere to over 640 kilometers (about 400 miles; about 2,100,000 feet).



This graphic illustrates the atmosphere's structure, starting with the troposphere at Earth's surface. (Image Credit: NASA, http://www.nasa.gov/centers/langley/news/factsheets/DIAL.html)

Within the thermosphere, temperatures rise continually to well beyond 1,000 degrees C. The few molecules that are present in the thermosphere receive extraordinary amounts of energy from the Sun, causing the layer to warm to those high temperatures. Although the measured temperature is very hot, the thermosphere would actually feel very cold to us because the total energy of the few air molecules residing there would not be enough to transfer any appreciable heat to our skin.

The lower part of the thermosphere, from 80 to 550 kilometers (49.7 to 341.8 miles) above Earth's surface, contains the ionosphere. Beyond the ionosphere, extending out to perhaps 10,000 kilometers (6,213.7 miles), is the exosphere or outer thermosphere, which gradually merges into space. Temperature increases with height. Although the temperature can rise to 1,500 degrees C (2,730 degrees F), a person would not feel warm because of the extremely low pressure. The International Space Station orbits in this layer, between 320 and 380 kilometers (about 200 and 240 miles).

Exosphere

The exosphere is the highest layer of the atmosphere. It extends from the top of the thermosphere up to 10,000 kilometers (about 6,200 miles; about 33,000,000 feet).

This is the upper limit of our atmosphere. The atmosphere here merges into space in the extremely thin air. Air atoms and molecules are constantly escaping to space from the exosphere. In this region of the atmosphere, hydrogen and helium are the prime components and are only present at extremely low densities. This is the area where many satellites orbit Earth. The exosphere contains free-moving particles that may migrate into and out of the magnetosphere or the solar wind.

Aircraft in Earth's Atmosphere

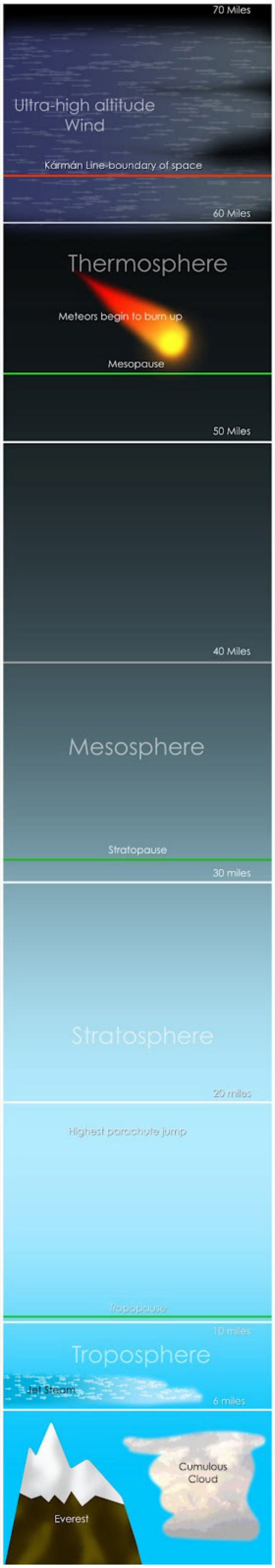
As elevation increases, air pressure decreases, and when we fly at high altitudes, the low pressure in these areas would be impossible for humans to survive in if it weren't for humanmade enclosures. In airplanes and spacecraft, internal cabins or cockpits are pressurized to help humans function. Since outside air pressure and density are higher near the ground, commercial aircraft have a higher internal air pressure during takeoff and landing to more closely match outside air pressure.

As the plane ascends, internal air pressure is reduced to decrease the difference between internal and external air pressure. However, on transport aircraft such as commercial aircraft for passengers, the internal cabin pressure will not be lower than air pressure found at an altitude of 2.44 kilometers (8,000 feet), or about 75 percent of the air pressure at sea level, which helps pilots and passengers function without difficulty. The Federal Aviation Administration (FAA) requires that these aircraft be able to maintain a cabin pressure of at least 8.29 psia (equivalent to the atmospheric pressure experienced at 4.6 kilometers [15,000 feet] altitude) in the event of malfunctions in the pressurization system. The reason is that lower air pressure makes it more difficult for humans to breathe and get enough oxygen. Many newer, larger commercial planes have increased the internal pressure to be the same as air pressure at 1.5–1.8 kilometers (5,000–6,000 feet), even while cruising at around 12 kilometers (40,000 feet). This helps passengers, many of whom are not used to dealing with low-air-pressure situations, avoid some of the side effects from lower air pressure and reduced oxygen such as throbbing headaches, dizziness, loss of appetite, and sometimes vomiting. If oxygen levels are too low for living organisms to function properly, hypoxia can occur. Brain cells are particularly sensitive to a loss of oxygen, so aircraft are pressurized when flying above 8,000 feet to prevent these dangerous situations.

High-altitude pilots who are trained to better understand the effects of low oxygen levels and can respond quicker to potential problems when in lower-pressure environments still fly in cockpits that are pressurized, but the pressurization is lower. Throughout aeronautics history, there have been many planes that have flown at high altitudes, requiring pilots to wear specially designed suits. Some of these planes include the SR-71; the WB-57; the U-2;

A WB-57 high-altitude aircraft. (Image Credit: NASA, http://www.jpl.nasa.gov/images/earth/wb57_browse.jpg)

Research engineer Marta Bohn-Meyer stands in front of an SR-71. (Image Credit: NASA, http://www.dfrc.nasa.gov/Gallery/Photo/SR-71/Medium/EC92-2273-1.jpg)



This graphic provides another illustration of the atmosphere's structure. (Image Credit: NASA, http://www.nasa.gov/images/content/628270main_Atmosphere-map.jpg) and the U-2's sister aircraft, the ER-2. For example, the U-2 and ER-2 (NASA's ER-2 is the civilian version of the Air Force's U-2 high-altitude reconnaissance aircraft) both fly at an altitude of about 21 kilometers (about 70,000 feet) and have historically kept cockpit pressurization equal to 9,600 meters, or 30,000 feet. To prevent hypoxia from occurring, high-altitude pilots breathe oxygen the entire flight, even when at lower altitude. This helps prevent the buildup of nitrogen in their blood, which can lead to nitrogen narcosis, or "the bends." Early U-2 pilots had no formal training to fly at these altitudes—just bare-bones training at a dry lakebed in Nevada—and only wore partial pressure suits. Now, cockpit conditions are being improved to include more pressurization, which research has shown is better for the human body by helping to prevent decompression sickness, and it also helps the aircraft and sensors last longer. Decompression sickness, or "the bends," is a buildup of nitrogen bubbles in the bloodstream and other areas of the body (scuba divers must also learn how to avoid decompression sickness when they return to the surface after diving deep in the ocean). Pilots now wear full pressure suits and participate in an extensive 9-month training program that includes sessions in the high-altitude pressure chamber, which simulates atmospheric conditions at very high altitudes.

For spacecraft such as the Space Shuttle and the International Space Station, internal pressure has been set at 14.7 ± 0.2 psia. Only astronauts who are going outside the spacecraft in their spacesuits have specific pressure-related preparations, such as breathing pure oxygen before getting fitted to their extravehicular activity (EVA) spacesuits. High-altitude pilots also breathe nearly pure oxygen, called Aviator's Breathing Oxygen (ABO), before flying at high altitudes since they, too, will be breathing oxygen during their mission. ABO is the highest-quality oxygen available (higher than both hospital-grade oxygen and industrial-grade oxygen) due to its stringent safety requirements. For NASA's ER-2 pilots, preflight preparation includes breathing ABO for at least an hour prior to takeoff. NASA describes their prebreathing EVA preparations as follows:

> Spacewalkers must wear pressurized spacesuits in order to work in space. These suits have pressures significantly lower than [the] ambient cabin pressure of a spacecraft. This makes spacewalkers subject to decompression sickness, more commonly known as the "bends." Decompression sickness results from nitrogen bubbles forming in the tissues or blood stream and moving to other areas of the body. Therefore, spacewalking crewmembers must perform a pre-breathe protocol, which is designed to wash out any excess nitrogen from the body, before a spacewalk. This protocol takes advantage of the fact that exercise increases the speed at which nitrogen is removed from the body by increasing blood circulation through the extremities. The ISS pre-breathe protocol involves breathing pure oxygen for a total of 2 hours and 20 minutes and includes a short period of high-intensity exercise at the beginning of the pre-breathe procedure.
>
> Station astronauts begin the pre-breathe protocol by exercising vigorously on the space station's cycle ergometer for a total of 10 minutes while breathing pure oxygen via an oxygen mask. After 50 total minutes of breathing pure oxygen, including the 10 minutes initially spent exercising, the pressure in the station's airlock will be lowered to 10.2 pounds per square inch, or psi. During airlock depressurization, the spacewalkers will breathe pure oxygen for an additional 30 minutes. At the end of those 30 minutes, with the airlock now at 10.2 psi, the spacewalkers will put on their space suits. Once their spacesuits are on, the spacewalkers will breathe pure oxygen inside the suits for an additional 60 minutes before making final preparations to leave the station and begin their spacewalk. This protocol provides a total of 2 hours and 20 minutes of pre-breathe time, including the 10 minutes of vigorous exercise at the beginning of the procedure. ("Working Outside the International Space Station," *http://spaceflight.nasa.gov/station/eva/outside.html*)

STS-104 mission specialists Michael Gernhardt (dark shirt) and James Reilly (white shirt) are photographed wearing oxygen masks during their pre-breathe before an Extravehicular Activity (EVA) in the Quest airlock of the International Space Station (ISS). (Image Credit: NASA, http://archive.org/details/s104e5146)

Temperature

Oftentimes, when we think about temperature, we think about how warm or cool the air is, along with how hot or cold something is to the touch. Think about a pot of boiling water on your stove. As the water begins to heat up, you can see small bubbles beginning to form on the side of the pot. Those bubbles get bigger and bigger until they rise to the surface of the water and break, and steam also rises from the pot. You learned when you were young that you should never stick your fingers into this boiling water because you will get hurt. When that same pot of water is taken off the stove, you still wouldn't stick your fingers into the water because it would still be hot for some time. You may have also learned that water boils at 212 degrees Fahrenheit (100 degrees C) and that it freezes at 32 degrees Fahrenheit (F) (0 degrees C). However, that is not always the case. Those numbers are given for the boiling point and the freezing point of water at 1 atm (atmosphere) of pressure, or standard pressure and density at sea level. These numbers change depending on air pressure and density. If you live at a higher altitude, water boils at a lower temperature. In Denver, CO, for example, where the altitude is around 5,200 feet (just about 1 mile above sea level), reduced air pressure causes water to boil 4 to 5 degrees C (39–41 degrees F) below the standard 100 degrees C (212 degrees F). This makes a difference when cooking or baking at higher altitudes. If you look at a bag or box of cookie and cake mix, you will notice separate instructions for baking at these altitudes. These instructions adjust the amount of water and flour in your batter in order to still get cake and cookies that taste good.

A life-support technician assists a pressure-suited pilot into the cockpit of NASA's ER-2 earth resources aircraft. (Image Credit: NASA, http://www.dfrc.nasa.gov/Gallery/Photo/ER-2/Small/EC00-0037-27.jpg)

When we talk about temperature in terms of flying at high altitudes or when traveling in space, temperature can take on different meanings. In general, when we get higher in altitude, air temperature decreases. However, when we are in space, sunlight directly affects molecules with which it comes into contact, which makes those molecules heat up substantially. But that does not mean that space is "hot." In the near vacuum of space, there is no air or ambient temperature, since there is no air. Instead, the temperature of the object in space, such as the Space Station, an astronaut working out in space, or even larger objects like the Moon or Earth, changes when the Sun shines on them. During an EVA, the outer layer of an astronaut's spacesuit may be 248 degrees F (120 degrees C) for the side facing the Sun, and the part of that same suit facing away from the Sun could have an external temperature of –148 degrees F (–100 C).

When pilots fly at higher altitudes, they must also be protected from outside temperatures. The higher a plane flies, the fewer and fewer air molecules there are. Fewer molecules running into each other, along with less pressure to contain these molecules, makes temperatures decrease because a gas's temperature decreases when the pressure does. Pressurized, controlled cockpit environments protect the pilots from the reduction of air higher in the atmosphere, but if they were outside this protective environment, they wouldn't be able to survive without a suit to keep them warm. Extreme skydivers and high-altitude balloonists also need to wear pressure suits to maintain pressure on their bodies, but in addition, they must wear protection from the colder temperatures of the upper atmosphere.

Human Survival Above Earth

Different kinds of suits have been designed to help in different situations. A primary designation for types of suits is the partial pressure suit and the full pressure suit. Partial pressure suits are basically form-fitting garments that cover the body from the neck to the wrists and ankles. Inflatable tubes called capstan tubes are added to the suit; these will inflate to provide additional pressure when necessary (see the picture of the partial pressure suit sleeve with a capstan tube below). The added pressure from the partial pressure suit, and at times from the inflated capstan tubes, provides just enough counterpressure to allow pilots to breathe and prevent hypoxia at very high altitudes. While earlier partial pressure suits have been redesigned to cut down on heat buildup, weight, and bulk, the suits are not known to be comfortable. Imagine wearing a full-body blood pressure cuff while flying an airplane! Capstan tubes are inflated only in an emergency, such as a loss of cabin pressure. When capstan tubes are inflated, the extra pressure is much like the inflation of that blood pressure cuff. The pressure suit does not provide oxygen for the pilot to breathe, however; that is supplied through an attached helmet and mask.

Arm of a partial pressure suit with a capstan tube. (Image Credit: Maria Werries/NASA)

Full pressure suits are self-contained living environments for pilots and astronauts. Full pressure suits have the ability to enclose the pilot or astronaut in an envelope of pressurized gases. Everything needed for survival—breathing oxygen, pressure exerted on the body, and, for spacesuits, even a heating and cooling system—exists within the suit. Along with providing protection, these suits must also be functional. Cockpit controls and other equipment must still be used while wearing larger gloves and fully pressurized suits. For high-altitude pilots, the suits are pressurized with air instead of pure oxygen in order to reduce the dangers associated with the flammability of oxygen. There is a seal surrounding the pilot's face that prevents that air from escaping the suit. The resulting face cavity, which is the face area of the pilot's helmet, is the only area to have nearly pure oxygen for pilots to breathe.

Different options are added to partial and full pressure suits to account for different situations. For example, fighter pilots aren't subjected to the same low-pressure extremes as pilots who fly the U-2, which flies in the upper limits of Earth's atmosphere, at about 21 kilometers (about 70,000 feet), so they don't need some of the additional components U-2 pilots do. Instead, fighter pilots wear g-suits, which help their bodies handle g-forces, or the additional forces exerted on their bodies when flying at very high speeds and making quick maneuvers. High-altitude pilots who fly extended missions that sometimes last more than 12 hours have helmets specially made to allow them to eat and drink while keeping their helmets on. Pilots must be able to consume high-altitude rations without using utensils or removing their helmets, so the food comes in a tube. Pilots attach a special straw to the tube, which is then inserted through a valve in the helmet. Spacesuits worn by astronauts as they work outside the International Space Station are full pressure suits, but they must contain additional components that will keep the astronauts alive outside their spacecraft; unlike aircraft pilots, they need protection from micrometeors and extreme temperature fluctuations. Depending on where the astronaut is facing, the temperature on the side of the suit facing the Sun can be nearly 135 degrees C (275 degrees F) warmer than the side in the shade. Since astronauts also have to be able to move and work in space, their suits are pressurized at 4.3 psia of oxygen for both breathing and pressurization, which is enough pressure to allow astronauts to work, but not so much as to prevent the suits from being moveable (if a spacesuit were pressurized at 14.7 psia, the suit would be too stiff to move properly). Since the suits are pressurized with pure oxygen instead of air, the pressure can be lower and astronauts can still have enough oxygen to breathe and function well.

A NASA Airborne Science ER-2 aircraft. (Image credit: NASA, http://www.nasa.gov/centers/dryden/news/FactSheets/F5-046-DFRC.html)

Likewise, U-2 and ER-2 pilots also breathe ABO and wear pressurized suits. At 30,000 feet, atmospheric pressure is 4.3 psia. In an emergency, the pilots' suits will pressurize to nearly an additional 3 pounds per square inch (that is, 3 pounds per square inch gauge, or psig—pressure that is measured in addition to the atmospheric pressure at that location) while maintaining a slight positive pressure of 0.04 psi within the face cavity of the helmet. This positive breathing pressure environment will remain the same whether the suit is inflated

Astronaut Rick Mastracchio, STS-118 mission specialist, on the mission's first planned session of extravehicular activity (EVA). (Image Credit: NASA, http://archive.org/details/HSF-photo-s118e06305)

or not. These suits are also equipped with standard survival gear for short-term water and land survival. When comparing air pressure psi, at sea level Earth's surface air pressure is about 14.7 psia. At about 9.1 kilometers (30,000 feet), air pressure is 4.3 psia. Astronauts on spacewalks use suits pressurized at 4.3 psia, and the pressure in high-altitude pilot suits varies with the altitude but rarely goes above 3 psi.

Other explorers, including high-altitude balloonists as well as deep ocean explorers, also need protective suits or environments. While their basic needs are the same—the regulation of pressure and temperature, the ability to breathe, and the ability to perform specific tasks—they are accomplished differently depending on the outside environment. In high-altitude, low-pressure environments, pressure suits or pressurized capsules of some kind are needed to exert pressure on the body. In contrast, for deep sea, high-pressure environments, humans must be protected from the excessive pressure outside their bodies. For deep sea exploration, pressure suits cannot protect us. Instead, we need to rely on an enclosure that will prevent too much pressure from pushing in on us. Historically, early designers such as Auguste Piccard worked on creating gondolas, in this case metal spheres, that would protect both high-altitude balloonists and deep sea explorers. In 1930, Piccard designed a pressurized aluminum gondola that would allow balloonists to reach heights of up to 75,000 feet (about 22,860 meters) without a pressure suit. Then, in 1937, he worked on a steel gondola for deep ocean exploration, which the French Navy redesigned and ultimately used to take men safely to 13,701 feet (4,176 meters) below the ocean surface. While the pressures were different for each situation (low pressure for high altitude and high pressure for ocean exploration), the human need for pressure regulation was the same. Today, high-altitude balloonists must either stay inside a pressurized gondola or wear full pressure suits. Deep sea explorers must remain inside pressurized gondolas or vehicles while in the depths of the ocean.

The deep sea submarine Ben Franklin made space exploration history in 1969 by studying the behavior of aquanauts in a sealed, self-contained, self-sufficient capsule. (Image Credit: NASA, http://www.nasa.gov/vision/space/preparingtravel/px15.html)

So what exactly happens to the human body in low-pressure environments?

Information about what happens to humans in low-pressure or vacuum environments is limited because there haven't been many situations in which humans have had to survive in these conditions. However, we have gained information about human survival in extremely low pressures in several incidents including pilot and suit testing in vacuum chambers, in a situation in which an astronaut punctured his glove, in a high-altitude balloon experience when the pilot lost a glove, and in an incident during a Russian spacecraft reentry problem.

The first part of the explanation will cover the human body in space, since that is the most extreme of the high-altitude environments for humans. If a human being were to be subjected to space without a spacesuit of any kind, there would be a lack of air, which means both a lack of oxygen to breathe and a lack of air pressure to help our bodies function as they were meant to. Hypoxia would occur, which is an inadequate oxygen supply to the cells and tissues of the body. The central nervous system, which includes the brain and the eyes, is particularly sensitive to oxygen deficiency. Very low oxygen levels result in impaired judgment and ability to concentrate, lack of night vision acuity, shortness of breath, nausea, and fatigue. For about the first 9 to 11 seconds, there would probably be some degree of consciousness, although you would only have between 5 and 10 seconds to help yourself. (High-altitude pilots and astronauts are trained to react quickly to try to help themselves in these situations. Although they can't extend the amount of time to think and function in an emergency, they are prepared to take steps to help themselves and/or others within that time.) After 13 seconds, the human brain is acutely impaired. Because of this danger, the FAA requires an oxygen supply to be provided if the vehicle's cabin pressure is equal to or less than that found at 15,000 feet (about 4.6 kilometers).

While in space, your body would swell without a pressure suit because liquid in your soft tissues and, to a lesser extent, water in your circulatory system would begin to vaporize. Contrary to some existing myths, you would not explode—your skin is too strong for that to happen.

Your blood would not immediately boil in your veins because as long as blood was circulating through your system, circulating blood pressure would keep the water in your blood below its boiling point for that pressure. But within 1 minute, blood would no longer circulate. Gas and vapor would flow out of airways, cooling the mouth and nose to near-freezing temperatures. The water in your nose and on your tongue would begin to boil. Soon after that, the water that lines your lungs would also boil. In 1965, a test subject at NASA's Manned Spacecraft Center (which is now Johnson Space Center) was in a vacuum chamber while wearing a leaking space suit. When the vacuum chamber's pressure was at a near vacuum (less than 1 psia), the test subject remained conscious for about 14 seconds, then lost consciousness until the people running the experiment could repressurize the chamber. Once the chamber was repressurized to the equivalent of that found at 15,000 feet in altitude, or about 8.3 psia, the test subject regained consciousness. Later, he reported that as he was losing consciousness, he could hear air leaking from his body and could feel the water on his tongue begin to boil.

You would not instantly freeze solid, as some movies have shown. Space doesn't have an actual temperature since there are no molecules to measure. It is actually a good insulator because it is difficult to transfer heat to nothing. In fact, it is harder for humans to cool off when out in space. On Earth, this concept is used in vacuum bottles (such as a Thermos), which use a vacuum for insulation between the outside and inside of the bottle to help keep liquids warm.

Lungs are perhaps the most vulnerable part of the body if decompression occurs. Since the lungs contain a large volume of air and the lungs are made up of intricate airways, air's expansion within low pressures and/or the vacuum of space would most definitely affect the lungs. If a human were to hold his or her breath before going into space, the effect would be especially disastrous, since there would be little room for expansion. This effect is very similar to air embolisms that can occur in scuba divers if they ascend from lower depths while holding their breath.

If recompression occurred within about 60 to 90 seconds, as long as the person didn't hold his or her breath, it would be possible for him or her to survive, and recovery would be quick.

Because of the human body's vulnerability in low-pressure environments, there has been years of research and development of methods to help humans both survive and function in low-pressure situations. A properly fitted pressure suit can restrain the body and prevent both swelling and water vaporization in soft tissues under pressures as low as 15 millimeters of mercury (mmHg) absolute, which is 0.29 psia. While the description above discusses the most extreme of low-pressure environments—the vacuum of space—other low-pressure situations in which high-altitude pilots fly have similar reactions. The higher the altitude, the more serious the effects on the human body.

Below are some NASA video resources that can be used to help explain concepts discussed above:

Where does space begin? BrainBites:
http://brainbites.nasa.gov/#/where-does-space-begin

Earth's atmosphere video clip:
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Earths_Atmosphere.html

Spacesuit video:
http://www.nasa.gov/mov/196817main_052_A_Look_At_Spacesuit.mov

EVAs and problems we encounter in space video clip:
http://www.nasa.gov/mov/217387main_079_Space_Environment.mov

How do you scratch your nose in space?
http://brainbites.nasa.gov/#/scratch-nose-in-spacesuit

What Is Atmospheric Pressure? video:
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/What_is_Atmospheric_Pressure.html

Pressure Lesson One: Survival in a Vacuum

GRADES 5-12

Objective

Students will learn about the properties of matter and the changes of these properties in matter, as well as the structures and functions in living systems, as they conduct experiments on pressure.

Lesson Overview

Students will conduct basic experiments on pressure using a vacuum pump, marshmallows (or Peeps), and balloons in order to help them understand what happens to the human body in a reduced-pressure and/or near vacuum environment. In addition, students will develop a method for retaining the marshmallow at normal pressure while in a vacuum chamber, simulating the effects of a pressure suit.

Materials

- Vacuum pump and jar[1] (please see options below for other ways to conduct this lesson)
- Small balloons
- Large marshmallows or Peeps (Peeps make a much more dramatic demonstration)
- Small marshmallows
- Various materials for students to develop a pressure suit for their marshmallows (items could include tape, latex or nitrile gloves, and small containers such as film canisters)
- Large plastic syringes (60 cubic centimeters) with caps or clay to block the tip
- Design packet (can be downloaded at *http://www.nasa.gov/pdf/324206main_Design_Packet_II.pdf*)
- Student worksheets

Safety note: As a component of good safety practices, advise students that they should never eat their experiments, even if the materials are candy.

Introduction

When high-altitude pilots and astronauts travel above the lower layers of Earth's atmosphere, the air pressure exerted on them would be significantly reduced if they were not protected from the outside environment by a pressurized cockpit or capsule or a specially designed suit. This reduction in air pressure would be harmful or even fatal to a pilot or astronaut. To protect pilots from this situation, engineers have developed various types of pressure suits that allow pilots and astronauts to function in these environments. Pressure suits exert pressure on the human body when external environments lack the pressure usually provided by the air at lower altitudes. In the event of aircraft cabin pressure loss at high altitudes, such as about 70,000 feet, where high-altitude aircraft such as the U-2 fly, engineers have developed partial pressure and full pressure suits. Development of high-altitude pilot suits led to the evolution of the spacesuit (background informa-

1 There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

tion at the beginning of this curriculum discusses these types of suits in further detail). Loss of cabin pressure on aircraft flying at lower altitudes does result in hazards to flyers such as loss of consciousness or hypoxia but does not lead to other medical problems experienced by flyers at higher altitudes. So how does a reduction in air pressure, whether high in Earth's atmosphere or in space, affect living organisms? The following activities allow students to simulate the effects of reduced pressure on objects and to develop their own "pressure suits" to tackle the challenge of preventing those effects.

The NASA Aeronautics Research Mission Directorate's 2012 publication, *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Space Shuttle*, is a book about the development and operation of pressure suits in aviation and access to space via the Space Shuttle. This book contains more detailed information about pressure suits and can be accessed as a free download in multiple formats for most platforms from the following location: *http://www.nasa.gov/connect/ebooks/dress_for_altitude_detail.html*.

Procedure

The first two activities can be completed as an introductory demonstration. After background information has been given to students, allowing them to connect the demonstration and last two activities to human survival in a high-altitude, low-pressure or near vacuum environment, students will be able to see why humans need assistance to survive in these situations. Several links to short video clips are also included, which may be shown to help explain low-pressure environments.

Caution: If you have never used a vacuum pump and bell jar before, use caution when placing objects in the vacuum chamber. Objects can break when exposed to vacuum conditions, sometimes damaging the bell jar in the process. Always check to make sure the bell jar is in good condition (no cracks or signs of excessive wear), that seals and gaskets are clean, and that you know how to operate a vacuum chamber. When you repressurize the chamber following an activity, items in the chamber will not stay where they are when air floods back in (for example, the marshmallows or Peeps will bounce all over the inside of the chamber), so use care. Also take into consideration that many of your students' pressure suit designs for activity four may not hold up in a vacuum chamber, so be aware of what materials they are using for their suits.

Activity One: Peeps in Peril

The human body, when exposed to the vacuum of space, would swell if it were not contained in a pressure suit. Large marshmallows or marshmallow Peeps will also expand in a vacuum, so this demonstration is a good replication of what the human body would do without a suit.

Materials

- Vacuum pump and jar[2]
- Large marshmallows or Peeps
- Student worksheets

1. Ask students what they think will happen when the marshmallow or Peep is placed in a vacuum and why. Have them record their answers on their worksheet.

2. Place your marshmallow and/or Peep in the bell jar (you can put more than one in the bell jar at once).

3. Turn on the vacuum pump and have students observe the difference in size of the marshmallows. Ask students why they think this is happening.

4. When finished, turn off the pump and repressurize the chamber. Have students observe what happens to the marsh-mallow or Peep. If necessary, explain that the air has been forced out of the marshmallow or Peep during the vacuum process. Based on that piece of information, ask them to explain why the marshmallows are now shriveled once air pressure has been reintroduced.

Marshmallow Peeps before the vacuum pump was turned on.

Marshmallow Peeps during air evacuation from pump.

Marshmallow Peeps at full vacuum.

Marshmallow Peeps after repressurization.

2 There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

Activity Two: Balloons in a Vacuum

Like the marshmallows and Peeps, balloons will expand in a vacuum environment. Your skin and your lungs, which are somewhat similar to a balloon, can expand and stretch, but only to a certain point. Placing a small balloon inside the vacuum chamber will show students what would happen to your lungs if you were in a vacuum environment such as space.

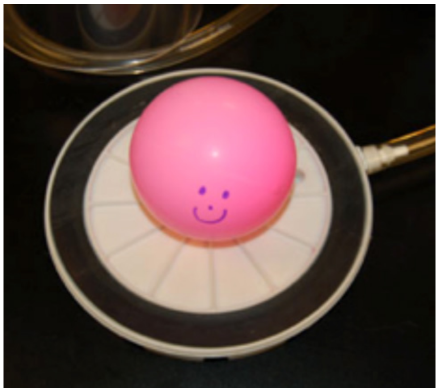
Materials

- Vacuum pump and jar[3]
- Small balloon
- Water (optional)
- Student worksheets

1. Inflate a small balloon and place it inside the bell jar. Be careful not to overinflate the balloon or place too large of a balloon in the jar. The balloon will expand to many times its normal size, so leave plenty of room for expansion in the jar.

2. Turn on the vacuum pump and ask students to observe what is happening to the balloon in the vacuum.

3. **Optional:** For an extension to this activity, place a small balloon filled with water in the chamber. The balloon will expand when the pump is turned on, but not as much as with an air-filled balloon since water does not expand as a gas does. However, there is still air in the balloon, which allows the balloon to expand somewhat. The water in the balloon will begin to boil, even though the water's temperature is not increasing. (Information about water's boiling point can be found in the background information of this curriculum, and more activities about the relationship between temperature and pressure can be found in the temperature section of this guide. In addition, the short NASA video clip at *http://www.nasa.gov/mov/196817main_052_A_Look_At_Spacesuit.mov shows water boiling in a balloon*.) Use a transparent balloon so students can see the water.



Small balloon under normal sea-level pressure.

Small balloon under normal sea-level pressure.

Balloon in vacuum.

3 There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

Activity Three: Hands-On Vacuum Environment

Although watching demonstrations about pressure is helpful, allowing students to create a vacuum and manipulate their own mini vacuum chamber strengthens their understanding about the effects of air pressure. In this activity, students will take small marshmallows and place them in a large plastic syringe. They will create a miniature pressure chamber that will allow them to change the amount of pressure acting on their marshmallows; then they will note the effects of various amounts of air pressure on the marshmallows.

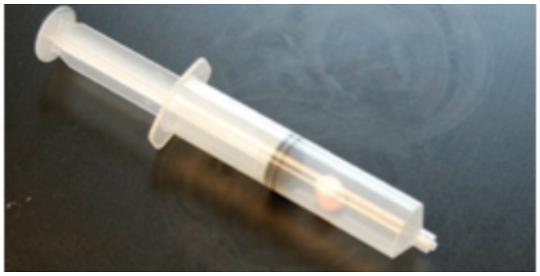
Materials

- Large plastic syringes with caps or pieces of clay to plug the ends of the syringes (one per student or small group of students)
- Small marshmallows (several per student or group)
- Student worksheets

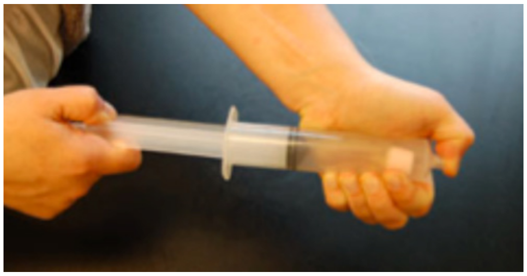
Safety note: Always use a cap or piece of clay to cover the syringe tip opening (don't use your finger as a cap) to avoid injury.

---

1. Have students place a small marshmallow inside their syringe.
2. Have students replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.
3. Once the plunger is in place, have students put the cap or the piece of clay on the tip of the syringe.
4. Once students have capped the tip of the syringe, ask students to pull back on the plunger, creating a lower-pressure environment. Students should note what happens to the marshmallow (it should expand).
5. Also have students push the plunger in as far as they can to create a higher-pressure environment, again noting what happens to the marshmallow (it should contract).
6. Let students experiment on their own with the marshmallow, noting the effects of changes in air pressure inside the syringe as they do so. Remind students that the effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them), but also as they travel underwater (the deeper they dive or swim, the more pressure is exerted on them).



Large syringe and marshmallow.

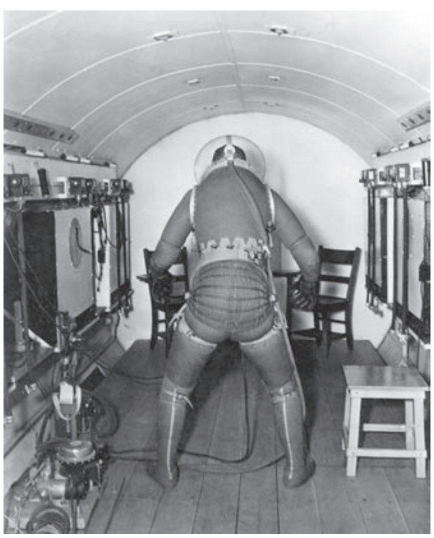


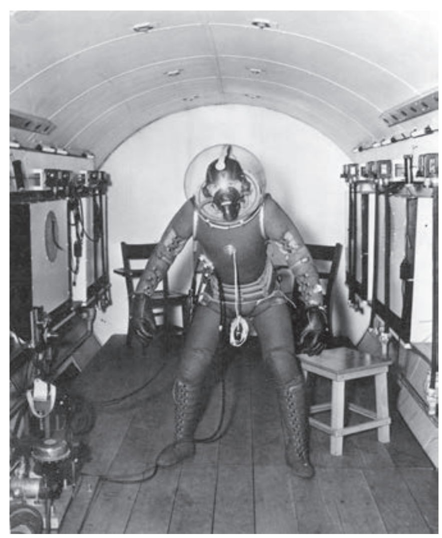
Creating a low-pressure environment for the marshmallow.

Activity Four: Designing a Pressure Suit

At this point, the activities have focused on the effects of pressure on objects and the human body. The final activity asks students to design a pressure suit for marshmallows or Peeps that would keep the Peep from expanding in a vacuum environment like it would without a pressure suit. An alternative activity follows the same procedure but uses a water balloon instead of a marshmallow. Students must design a pressure suit that will keep the water balloon from expanding and allowing the water in the balloon to boil. Activity One in this section shows students what happens to a marshmallow in a vacuum, and Activity Two shows students what happens to a balloons filled with air and with water. (More can be found about water boiling in a vacuum in the background section of this curriculum and in Activity One in the section about temperature.)

The two basic types of pressure suits are partial pressure suits and full pressure suits. In general terms, a partial pressure suit uses a tight-fitting suit to cover the body; then, when needed, the suit is squeezed using capstan tubes to stop the body from expanding (capstan tubes are inflatable rubber tubes covered by nylon restraint sleeves). Gloves with bladders that inflate to restrict the hands from expanding are also used. In general, a hard helmet with a partial face shield is used to protect the face and provide air to the crewmember, such as the one used with the classic MC-3 suits.





A full pressure suit encases the body in its own environment. Think of a balloon filled with air, protecting the body. However, as the pressure decreases around a balloon, the balloon expands. A person could not function in that situation, so a restraint layer is also needed to keep the bladder layer, or balloon, from expanding past a certain size. Full pressure suits also usually have an exterior layer to protect the wearer and the inner workings of the suit. It is normally made out of a brightly colored (for visibility), fire-retardant material such as Nomex. Suits may also include anti-g garments as a layer, sometimes inserted along with an exposure layer to protect the occupant in case of a water landing. Anti-g layers are restraint layers of a suit that help counteract changes in pressure exerted on the body resulting from changes of gravitational pull (due to abrupt turns and maneuvers often encountered in fighter aircraft, as well as strong g-forces during rocket launches and landings). Most modern-day high-altitude aircraft use full pressure suits such as the S1034 used in the U-2 aircraft, while the Shuttle used both full and partial pressure suits, completing the program with the Advanced Crew Escape Suit (ACES) full pressure suit.

Crew members for Space Shuttle Endeavour's STS-126 mission depart for Launch Pad 39A. The sleeves of their tube-lined thermal suits are visible beneath their orange launch-and-entry suits. (Image Credit: NASA, http://www.nasa.gov/images/content/298053main_126_walkout_lg.jpg)

Additional information on partial and full pressure suits can be found in *Dressing for Altitude*. You can ask students to create either a partial pressure suit or a full pressure suit or let them choose which kind of suit they would like to design.

Materials

- Larger marshmallows or Peeps (as before, Peeps make a more dramatic activity; in this case, they also simulate fitting a pressure suit around a person or animal)
- Vacuum pump and bell jar[4] (see below for additional equipment ideas)
- Various materials for students to develop a pressure suit for their marshmallows (items could include tape, latex or nitrile gloves, and small containers such as film canisters and small plastic water bottles)
- Design packet and student worksheets

Food sealer vacuum chamber.

1. Review the background information about pressure suits and the need for humans to have the restraint layer of the suit as they function in high altitudes and/or in space.

2. Tell students that they will need to design a pressure suit for their marshmallow or Peep that will keep it from expanding like it did in the earlier demonstration.

3. Have students complete steps 1 through 4 of their design packet (which can be downloaded at *http://www.nasa.gov/pdf/324206main_Design_Packet_II.pdf*).

4. Once the students have designed their pressure suits, have them construct their suits from available materials. Students will also complete step 5 in their packets.

4 There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

5. Test student designs in the vacuum chamber. Use an unprotected marshmallow or Peep as a control inside the chamber as well. Have students complete step 6 of their design packets.

6. Allow students to refine their designs and retest, using a new marshmallow or Peep. This is step 7 in their packets.

7. Finally, if time allows, have the students present their pressure suit prototypes to the class. Encourage the students to explain and share their designs, along with any challenges, hurdles, or failures along the way.

Activity hints: There are many variations to a pressure suit that can work for this activity. Several ideas include using tape to restrict expansion, cutting off fingers from rubber gloves (not thin, latex gloves, but rubber gloves used for household cleaning) and placing the Peep inside the finger, and placing the Peep inside a small water bottle.

NATIONAL SCIENCE STANDARDS

5–8

Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Properties and changes of properties in matter
Motions and forces
Structure and function in living systems
Abilities of technological design
Understandings about science and technology
Science and technology in society
Science as a human endeavor
Structure of the Earth system

9–12

Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Structure and properties of matter
Motions and forces
Natural and human-induced hazards
Science and technology in local, national, and global challenges
Science as a human endeavor

Survival in a Vacuum Student Worksheets

GRADES **5-12**

Pre-Lab Questions

Before beginning your activities for this lesson, answer the following questions.

1. What concerns do you think humans have when flying or working in a high-altitude situation?

2. What do humans need to worry about when living or working in space?

3. Describe what you think happens in the following situations:
   a. Pressure as you travel from sea level on Earth up to space:

   b. Pressure as you travel from sea level on Earth down to the bottom of the ocean:

   c. Air density as you travel from sea level on Earth up to space and why:

Activity One: Peeps in Peril

Observations

1. Make a drawing of the marshmallow or Peep prior to its being placed in the vacuum jar. Include the approximate initial measurements of the item.

2. Draw and describe what happened to the item while in the vacuum jar. Again, include the approximate measurements of the item while the vacuum pump was turned on.

3. Why do you think it reacted this way?

Activity Two: Balloons in a Vacuum

Observations

1. Make a drawing of the balloon prior to its being placed in the vacuum jar. Include the approximate initial measurements of the inflated balloon.

2. Draw and describe what happened to the balloon while in the vacuum jar. Again, include the approximate measurements of the balloon while the vacuum pump was turned on.

3. Why do you think it reacted this way?

Questions for Optional Water Balloon Activity

1. Draw and describe what happened to the water-filled balloon in the vacuum jar.

2. Compare and contrast the water-filled balloon's reaction with that of the air-filled balloon in a vacuum.

3. Why do you think the water-filled balloon and the air-filled balloon reacted differently?

4. Explain how the reaction of the water-filled balloon is similar to how the human body would react in a vacuum.

Activity Three: Hands-On Vacuum Environment

For this activity, you will be creating a miniature pressure chamber with a large plastic syringe and a cap or piece of clay to seal the tip of the syringe. Follow the instructions below and complete the questions.

Be sure to follow the steps in the correct order so you create the proper pressure within your chamber.

1. Place a small marshmallow inside your syringe.

2. Replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.

3. Once the plunger is in place, put the cap or the piece of clay on the tip of the syringe. **Do not place the cap on the tip of the syringe until the plunger is halfway down the inside of the syringe or you will not be able to properly change the pressure inside your chamber.**

4. Once you have capped the tip of the syringe, pull back on the plunger.
   a. What is happening to the pressure as you pull back on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

   b. What happened to the marshmallow? Explain in a complete sentence and draw a picture.

5. Now push the plunger in as far as you can.
   a. What is happening to the pressure as you push in the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

b. What happened to the marshmallow? Explain in a complete sentence and draw a picture.

6. Experiment on your own with the marshmallow, noting the effects of changes in air pressure inside the syringe as you do so. The effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them). In addition, increasing the pressure inside the chamber mimics the effects of traveling underwater (the deeper you dive or swim, the more pressure is exerted on you).
   a. Describe some of the effects of your own experimentation with the marshmallow inside the pressure chamber.

Activity Four: Designing a Pressure Suit

For this activity, use the design packet.

Post-Lab Questions

Once you have completed the above activities, answer the following questions:

1. Based on the above activities, explain how a pressure suit would help you if you were working in a high-altitude environment or up in space.

2. What is the difference between a partial pressure suit and a full pressure suit?

3. Take the design you made for your pressure suit, choose two of the following suit requirements, and explain what would have to happen to the design of your suit in order to meet them:
   a. Full pressure high-altitude pilot suit

   b. Spacesuit designed for working outside the International Space Station

   c. Emergency suit for use inside the International Space Station

d. Pressure suit for high-altitude skydiving (high-altitude skydiving occurs at least 23,000 feet above Earth's surface)

Type of Suit	Abilities of Suit	Limitations of Suit	Changes from Original Design
Original design: partial or full (circle one)			n/a
1.			
2.			

Survival in a Vacuum Student Worksheets

GRADES **5-12**

Pre-Lab Questions

Before beginning your activities for this lesson, answer the following questions.

1. What concerns do you think humans have when flying or working in a high-altitude situation?
   Answers will vary but may include the need to protect against temperature extremes or UV radiation, the need for oxygen to breathe, and the need to wear a pressurized suit.

2. What do humans need to worry about when living or working in space?
   Answers will vary but will probably be similar to the answers for question one. Some students may also add the need to protect against micrometeors. For the longer term, humans also need to worry about muscle loss, osteoporosis, and many other health factors.

3. Describe what you think happens in the following situations:
   a. Pressure as you travel from sea level on Earth up to space:
   Students should answer that pressure will decrease

   b. Pressure as you travel from sea level on Earth down to the bottom of the ocean:
   Students should answer that pressure will increase. As a side note, students may wonder if a pressure suit can be used underwater. The suits do not protect divers underwater because pressure suits **exert** pressure and do not help a diver **withstand** existing pressure, which is what a diver encounters underwater.

   c. Air density as you travel from sea level on Earth up to space and why:
   Students should answer that air density will decrease because there is less and less air the higher you travel in the atmosphere.

Activity One: Peeps in Peril

Observations

1. Make a drawing of the marshmallow or Peep prior to its being placed in the vacuum jar. Include the approximate initial measurements of the item.
   Answers will vary.

2. Draw and describe what happened to the item while in the vacuum jar. Again, include the approximate measurements of the item while the vacuum pump was turned on.
   Answers will vary, but students should notice that the marshmallows expanded while the pump was turned on (then shriveled once the pump was turned off and the chamber was repressurized).

3. Why do you think it reacted this way?
   Answers will vary, but students should be able to answer that before the marshmallows or Peeps were placed in the vacuum chamber, the air pressure pushing in on the marshmallow was equal to the pressure exerted by the trapped air inside the marshmallow—approximately 14.7 psia or pounds per square inch absolute. As the pressure decreased inside the chamber, the greater pressure within the marshmallow caused the marshmallow to expand. In addition, some of the air molecules that were contained within the marshmallow were now being pulled out of the marshmallow. As the pressure was equalized after the pump was turned off and the chamber was repressurized, the marshmallow shriveled, allowing students to see that some of the air molecules were pulled out of the marshmallow.

Activity Two: Balloons in a Vacuum

Observations

1. Make a drawing of the balloon prior to its being placed in the vacuum jar, include the approximate initial measurements of the inflated balloon.
   Answers will vary.

2. Draw and describe what happened to the item while in the vacuum jar. Again, include the approximate measurements of the item while the vacuum pump was turned on.
   Answers will vary, but students should notice that the balloon expands and oftentimes fills the vacuum chamber.

3. Why do you think it reacted this way?
   The size and shape of the inflated balloon is a relationship between the air pressure inside the balloon and the pressure exerted on the balloon from the outside. When the pressure is reduced around the outside of the balloon, the air molecules inside the balloon can exert more pressure against the inside of the balloon, causing the balloon to expand.

Questions for Optional Water Balloon Activity

1. Draw and describe what happened to the water-filled balloon in the vacuum jar.
   Students should notice that the water-filled balloon expands a small amount, but not as much as the air-filled balloon. The water in the balloon should begin to boil soon after the balloon is in a vacuum situation.

2. Compare and contrast the water-filled balloon's reaction with that of the air-filled balloon in a vacuum.
   Answers will vary, but students should observe that the air-filled balloon expands more than the water-filled balloon, although both expand. The water inside the balloon boils. Be sure to clarify to students that the balloon is not getting hot, a misconception students may have since the water begins to boil. Pressure reduction inside the vacuum chamber lowers the boiling point of water, which is why the water begins to boil.

3. Why do you think the water-filled balloon and the air-filled balloon reacted differently?
   Students should recognize that the air in the balloon is a gas and the water in the other balloon is a liquid. Gases and liquids have different properties, and a liquid does not expand in a vacuum like a gas does.

4. Explain how the reaction of the water-filled balloon is similar to how the human body would react in a vaccum.
   Like the water-filled balloon, our bodies contain large amounts of water. In addition, our bodies have air, much like the water-filled balloon does. If a human were exposed to the vacuum of space of the low pressure high in our atmosphere, the water could boil inside our bodies and the air ould expand.

Activity Three: Hands-On Vacuum Environment

For this activity, you will be creating a miniature pressure chamber with a large plastic syringe and a cap or piece of clay to seal the tip of the syringe. Follow the instructions below and complete the questions.

Be sure to follow the steps in the correct order so you create the proper pressure within your chamber.

1. Place a small marshmallow inside your syringe.

2. Replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.

3. Once the plunger is in place, put the cap or the piece of clay on the tip of the syringe. Do not place the cap on the tip of the syringe until the plunger is halfway down the inside of the syringe or you will not be able to properly change the pressure inside your chamber.

4. Once you have capped the tip of the syringe, pull back on the plunger.

   a. What is happening to the pressure as you pull back on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.
   Pressure is decreasing.

   b. What happened to the marshmallow? Explain in a complete sentence and draw a picture.
   The marshmallow expands.

5. Now push the plunger in as far as you can.

   a. What is happening to the pressure as you push on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.
   Pressure inside the syringe is increasing.

   b. What happened to the marshmallow? Explain in a complete sentence and draw a picture.
   The marshmallow should shrivel up.

6. Experiment on your own with the marshmallow, noting the effects of changes in air pressure inside the syringe as you do so. The effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them). In addition, increasing the pressure inside the chamber mimics the effects of traveling underwater (the deeper you dive or swim, the more pressure is exerted on you).

   a. Describe some of the effects of your own experimentation with the marshmallow inside the pressure chamber-
   Answers will vary.

Activity Four: Designing a Pressure Suit

For this activity, use the design packet.

Post-Lab Questions

Once you have completed the above activities, answer the following questions:

1. Based on the above activities, explain how a pressure suit would help you if you were working in a high-altitude environment or up in space.
   A pressure suit exerts pressure on the person wearing the suit. As the outside pressure decreases, either at high altitudes or in space, a person without a suit would swell to about twice his or her normal size. Wearing a pressure suit would keep the body contained and prevent the person from swelling.

2. What is the difference between a partial pressure suit and a full pressure suit?
   A partial pressure suit exerts pressure on the body but does not full contain or seal the person off from the outside environment. The full pressure suit is a fully contained unit that enables the person to exist in a controlled environment.

3. Take the design you made for your pressure suit, choose two of the following suit requirements, and explain what would have to happen to the design of your suit in order to meet them:

   a. Full pressure high-altitude pilot suit
   A full pressure, high-altitude pilot suit would have to contain air to breathe and exert pressure on the body. Arms and hands would have to be able to move in order for the pilot to land the aircraft. The pilot would also have to be able to see.

   b. Spacesuit designed for working outside the International Space Station
   The spacesuit would have to protect the astronaut from the near vacuum of space, from UV radiation, from extreme hot and cold temperatures, and from micrometeors. Like the high-altitude pilot, the astronaut would have to be able to move his or her arms and hands. However, unlike with earlier spacesuits that needed to be functional for walking on the Moon, lower limbs are not really used on spacewalks today.

c. Emergency suit for use inside the International Space Station
Someone using an emergency suit for use inside the Space Station would need air to breathe and the ability to use his or her hands and arms.

d. Pressure suit for extreme high-altitude skydiving (as of 2012, three people have made high-altitude jumps over 70,000 feet).
The pressure suit for high-altitude skydiving would be a full pressure suit because the skydiver would need air tobreathe, pressurization, and protection from the elements. The suit would be inflated during the full flight up and then the jump. The skydiver would need some mobility to control the flight of the parachute and operate any equipment on ascent and descent

Type of Suit	Abilities of Suit	Limitations of Suit	Changes from Original Design
Original design: partial or full (circle one)			n/a
1.	Answers will vary		
2.			

Pressure Lesson Two: Air Has Pressure

GRADES 5-12

K–4: Demonstration

This lesson can be taught as a demonstration at the K–4 level to introduce students to the concept of air pressure. Worksheets and math skills that accompany this lesson are designed for higher grades.

Objective

Students will learn about the properties of matter and how those properties change as air pressure does. Students will also learn about motions and forces as they participate in activities that show that air exerts pressure.

Lesson Overview

Four hands-on activities about air pressure highlight that air has pressure and that air takes up space. Students will try to put a straw through a potato with and without air pressure inside the straw. They will attempt to pull apart Magdeburg vacuum plates, which are held together with air pressure, and will lift a soda can from a flat surface while it is held down with suction and air pressure.

Materials

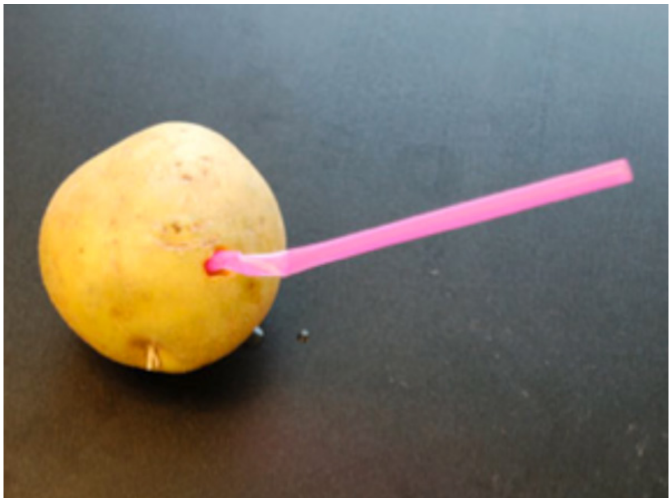
- Potatoes and drinking straws (one per student or group)
- Magdeburg vacuum plates
- Handheld vacuum pump
- Lil' Suctioner rubber suction cup
- Unopened soft drink can
- Student worksheets

Safety note: When stabbing the potato with the straw, place the potato on a flat surface while holding the sides (not the bottom!) to avoid injury.

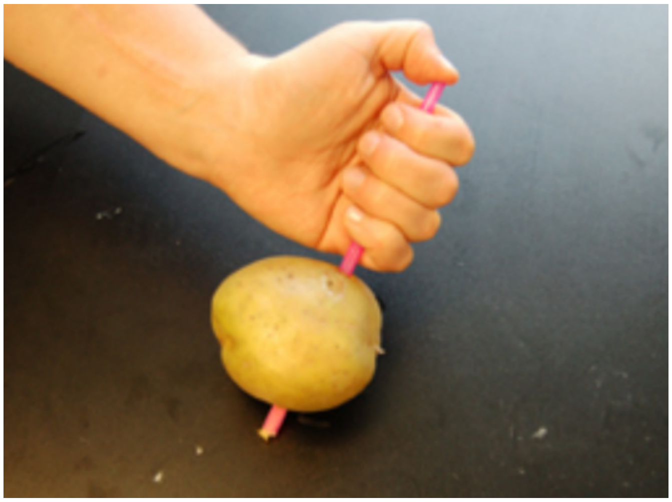
Activity One: Potato and Straw Experiment

In this activity, students are challenged to stab a straw through a potato without bending or breaking the straw. The key to getting the straw to go through the potato is to create a pocket of air in the straw by placing your thumb over one end. The pressure exerted on the insides of the straw by the air will make the straw strong enough for the task.

Caution: This activity asks students to stab potatoes with a straw. Be sure to caution students about the safety of this activity. Remind students to hold the potato on the sides and not to hold the potato underneath so that they don't stab themselves.



An open straw has equal pressure inside and out. It is not very rigid and will not go very far into the potato without buckling.



When the end of the straw is blocked, pressure increases inside the straw as it is pushed into the potato, thus increasing the rigidity of the straw and preventing buckling.

Materials

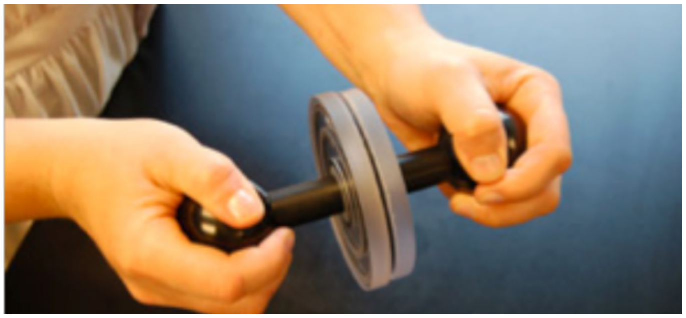
- Per student or group:
- Drinking straw (straight, inflexible straw; cut flexible end off if necessary)
- Potato

1. Challenge students to stab the straw through their potato without bending or breaking the straw. Tell students they may not add anything to reinforce the straw (such as tape) and ask them how they might be able to accomplish the task. Warn students to be careful to hold the potato on the sides and not the bottom so that they don't stab themselves with the straw.

2. You can either show students that it can be done ahead of time, being careful not to give away the secret to the success of the experiment, or you can wait until students figure it out before you show that you, too, can stab your potato.

3. Once students have figured out how to correctly stab their potatoes, discuss how air pressure inside the straw was responsible for reinforcing the straw.

Activity Two: Magdeburg Vacuum Plates



Magdeburg vacuum plates.

Pressure is defined as the amount of force acting on a unit of area (e.g., pounds per square inch). It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. Air is a fluid. At sea level, the weight of the atmosphere is pushing down on with a force of 14.7 pounds over every square inch of surface.

In 1684, Otto von Guericke (the inventor of the air pump) placed two empty copper hemispheres called Magdeburg hemispheres (after the name of the town in which the demonstration took place) together and removed the air from between them. Two teams of horses could not separate them.

Students will replicate this classic physics demonstration on the effect of air pressure. A simple hand-operated vacuum pump is used to produce a partial vacuum between two small plastic plates separated by an O-ring. Using the value for standard air pressure at sea level, students will predict the force necessary to separate the two plates.

Materials

- Magdeburg vacuum plates
- Handheld vacuum pump assembly (vacuum pump setup and assembly are easier with two people)

1. Attach the hand pump assembly to the vacuum plate that contains the hose port. The assembly consists of several small hoses, two one-way valves, and a branch assembly. The flat side of the one-way valve should face the vacuum plates.

2. Attach the large syringe to the branch assembly. This is your vacuum pump.

3. Place either the small O-ring or the large O-ring between the vacuum plates and hold the plates together (do not use both O-rings at the same time). Steps 3 and 4 work best with two people.

4. Pull back on the syringe plunger to evacuate the air from between the two plates.

5. Pump the plunger back and forth a few times to remove as much air as possible (since there is a one-way valve attached to the assembly, you don't have to worry about repressurizing the plates).

6. Loosen the hose from the plate; you now have a vacuum between the plates.

7. Have two students hold the vacuum plates (one holding on to each plate) and ask them to pull the plates apart.

8. Repeat the steps above using the other O-ring. Ask students which one made the plates harder to separate. Why?

9. Have students calculate the amount of force needed to separate both sets of plates using the equation **Pressure = Force ÷ Area** or **Force = Pressure × Area**. You can use the standard for atmospheric pressure at sea level of 14.7 psi (pounds per square inch) or if you know the specific atmospheric pressure in your location, replace that value.

Activity Three: Lil' Suctioner

This next activity about air pressure uses a device called a Lil' Suctioner, which is a circular foam section that uses air pressure to hold a soda can on a table. Again, using standard air pressure, students calculate the force of air pressure exerted on the device.

Lil' Suctioner and soda can.

Materials

- Lil' Suctioner rubber suction cup
- One unopened soft drink can
- Scale
- Calculator

Safety note: When pulling up on the soft drink can, do not lean directly over the can or allow students to lean directly over the can.

1. Have students weigh the soft drink can. Ask them how much force they think is needed to lift that can (force = mass × acceleration, or $F = m \times a$). In this case, a = the acceleration due to gravity, or 9.8 meters per second squared.
2. Ask students to predict what will happen when you stick the can to a flat surface with the Lil' Suctioner.
3. Turn the unopened can upside down and stretch the Lil' Suctioner over the bottom of the can (the fabric side should be facing down).
4. Turn the can right-side up and slide the suctioner down to about ½ inch from the bottom of the can edge.
5. Press the suctioner to a flat, nonporous surface.
6. Have one student, or several students, try to pick up the can (you can easily reattach the suctioner to the flat surface by pressing down on it), noting how much force it takes to do that. Students will be able to remove the can, but it will be difficult.
7. Ask students why this is happening.
8. Finally, have students calculate the weight of the air pushing down on the Lil' Suctioner. (Note: You can easily lift the can from the flat surface by lifting up one edge of the suctioner, repressurizing the area under the suctioner.)

NATIONAL SCIENCE STANDARDS

K–4

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Properties of objects and materials

5–8

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Properties and changes of properties in matter

Motions and forces

Structure of the Earth system

9–12

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Structure and properties of matter

Motions and forces

Pressure Lesson Two: Air Has Pressure Worksheet

Activity One: Potato and Straw Experiment

For this activity, your task is to get the straw through the potato. You cannot use anything else besides the straw, and you cannot alter the straw in any way. Can you do it without bending or breaking the straw?

Caution: When stabbing the potato with the straw, be careful to hold the potato from the sides and not underneath so that you don't stab your hand or fingers instead.

---

1. Describe what techniques you tried. Which techniques worked? Which ones didn't work?

2. Explain why some of the techniques you tried didn't work and why some did work.

Activity Two: Magdeburg Vacuum Plates

1. Measure the inside diameter of the O-ring that is used to separate the two plastic plates. Use inches if you are figuring out force in pounds and meters if you are measuring force in Newtons. To convert from pounds to Newtons, multiply the number of pounds by 4.45. If you are using kilograms, multiply kilograms by 9.8 to get Newtons.

2. Determine the area inside the O-ring ($\pi \times r^2$).

3. Using standard atmospheric pressure (14.7 pounds per square inch or 1.013×10^5 Newtons per square meter), determine the force necessary to separate the plates once the air has been evacuated from between the plates. Show your work.

4. Repeat steps 1 through 3 to figure out the force necessary to separate the plates using the other O-ring. Again, show your work.

5. Explain what is happening to keep these plates together. Add an illustration if needed.

Activity Three: Lil' Suctioner

The Lil' Suctioner is an example of an invention that failed in its original purpose but became useful in another way. A graduate student was trying to develop a flashlight hood that would block glare and improve visibility. The invention did not work as designed, but the designer found that it was very useful for holding items to flat surfaces. In this activity, the Lil' Suctioner will be used to hold a soda can to a flat surface.

Pre-Activity Questions

1. Look at the can of soda. How much do you think a full can of soda weighs in ounces? Using the conversion of 1 oz = 28.4 g, convert your estimate to grams.

2. Explain how you think the Lil' Suctioner works to hold a can of soda to a flat surface. Draw a picture if that helps.

Post-Activity Questions

After the demonstration, answer the following questions:

1. Weigh the can of soda with a scale. How much does it weigh? (You need to write your answer in grams.)

2. Based on your answer to question #1, figure out how much force is needed to lift a can of soda. $F = m \times a$ (force = mass × acceleration). Use kilograms for mass and 9.8 meters per second squared for the force. Show your work. When using the Lil' Suctioner, air pressure is pushing down on the can and suctioner. Since the air has been removed from under the suctioner, there is no air to help equalize the force of the air from above.

   Using the radius of the Lil' Suctioner and standard air pressure, calculate the total force of the air pushing down on the suctioner and can of soda. **r = 2.19 inches** and **standard air pressure = 4.7 pounds per square inch**. Use the equation **$\pi \times r^2 \times$ standard air pressure = total pressure (pound-force, or lb-F)**. Then convert pound-force to Newtons using the conversion 1 pound-force = approximately 4.5 Newtons. Show your work.

3. Finally, calculate the amount of force needed to lift the can of soda when attached to the Lil' Suctioner. Use your answer to question #3 to help answer this question. Explain your answer.

Pressure Lesson Two: Air Has Pressure Worksheet

Activity One: Potato and Straw Experiment

For this activity, your task is to stab the straw through the potato. You cannot use anything else besides the straw, and you cannot alter the straw in any way. Can you do it without bending or breaking the straw?

Caution: When stabbing the potato with the straw, be careful to hold the potato from the sides and not underneath so that you don't stab your hand or fingers instead.

---

1. Describe what techniques you tried. Which techniques worked? Which ones didn't work?
   Answers will vary. Students should note that the straw bent or broke when the top of the straw was not sealed off, which would hold the air inside the straw and strengthen the straw. Covering the top of the straw with their thumb would allow a buildup of air pressure inside the straw to increase the rigidity of the straw and allow them to stab the straw through the potato.

2. Explain why some of the techniques you tried didn't work and why some did work.
   Answers will vary, but students should be able to explain that additional air pressure inside the straw is needed to increase the straw's rigidity. In addition, stabbing the potato quickly works better than trying to poke the straw through the potato more slowly.

Activity Two: Magdeburg Vacuum Plates

1. Measure the inside diameter of the O-ring that is used to separate the two plastic plates. Use inches if you are figuring out force in pounds and meters if you are measuring force in Newtons. To convert from pounds to Newtons, multiply the number of pounds by 4.45. If you are using kilograms, multiply kilograms by 9.8 to get Newtons.
   Larger O-ring (approx.):
      In inches: 3.35 in (outside diameter is approx. 3.77 in); radius = 1.68 in
      In centimeters: 8.5 cm (outside diameter is approx. 9.5 cm); radius = 4.25 cm
   Smaller O-ring (approx.):
      In inches: 1.97 in (outside diameter is approx. 2.39 in); radius = 0.99 in
      In centimeters: 5.0 cm (outside diameter is approx. 6.0 cm); radius = 2.5 cm

2. Determine the area inside the O-ring ($\pi \times r2$).
   Larger O-ring:
      In inches: $\pi \times 1.68^2 = 8.86$ in^2
      In centimeters: $\pi \times 4.25^2 = 56.7$ cm^2
   Smaller O-ring:
      In inches: $\pi \times 0.99^2 = 3.08$ in^2
      In centimeters: $\pi \times 2.5^2 = 19.63$ cm^2

3. Using standard atmospheric pressure (14.7 pounds per square inch or 1.013×10^5 Newtons per square meter), determine the force necessary to separate the plates once the air has been evacuated from between the plates. Show your work.
   The calculations below will use force (F) = pressure (P) × area (A). An assumed standard air pressure of 14.7 pounds per square inch will be used. Actual air pressure for your location can be substituted here if you know that number.

   Larger O-ring: A = 8.86 in^2 or 56.7 cm^2
      English units: F = 14.7 lb/in^2 × 8.86 in^2
         F = 130.2 lb
      Metric units (convert cm to m): F = 101,300 N/m^2 × 0.57 m^2
         F = 577 N

   Smaller O-ring: A = 3.08 in^2 or 19.63 cm^2
      English units: F = 14.7 lb/in^2 × 3.08 in^2
         F = 45.3 lb
      Metric units (convert cm to m): F = 101,300 N/m^2 × 0.20 m^2
         F = 203 N

4. Repeat steps 1 through 3 to figure out the force necessary to separate the plates using the other O-ring. Again, show your work.
   See above for both O-rings.

5. Explain what is happening to keep these plates together. Add an illustration if needed.
   Answers will vary, but students should explain that air pressure is pushing on the plates from the outside, and when the air has been evacuated from between the plates, there is no equalizing pressure on the inside of the plates. If there were no difference in air pressure, then the plates would not stay together. However, without air pressure on the inside, between the plates, the normal atmospheric pressure of the air on the outside of the plates is pushing on the plates, keeping them together.

Activity Three: Lil' Suctioner

The Lil' Suctioner is an example of an invention that failed in its original purpose but became useful in another way. A graduate student was trying to develop a flashlight hood that would block glare and improve visibility. The invention did not work as designed, but the designer found that it was very useful for holding items to flat surfaces. In this activity, the Lil' Suctioner will be used to hold a soda can to a flat surface.

Pre-Activity Questions

1. Look at the can of soda. How much do you think a full can of soda weighs in ounces? Using the conversion of 1 oz = 28.4 g, convert your estimate to grams.
   Cans of soda will vary slightly, but on average, a full can of soda should weigh just under 14 ounces (about 390 g).

2. Explain how you think the Lil' Suctioner works to hold a can of soda to a flat surface. Draw a picture if that helps.
   With the air removed from underneath the Lil' Suctioner and can of soda, a vacuum is formed. Air pressure from above the suctioner and soda is pushing down on the soda, making it very difficult to pull the can from the flat surface.

Post-Activity Questions

After the demonstration, answer the following questions:

1. Weigh the can of soda with a scale. How much does it weigh? (You need to write your answer in grams.)
   Cans of soda will vary slightly, but on average, a full can of soda should weigh just under 14 ounces (about 390 grams).

2. Based on your answer to question #1, figure out how much force is needed to lift a can of soda. $F = m \times a$ (force = mass × acceleration). Use kg for mass and 9.8 m/s^2. Show your work.
   $m = 390\ g = 3.9\ kg$

   $a = 9.8\ m/s^2$

   $F = 3.9\ kg \times 9.8\ m/s^2$

   $F = 38.2\ N$ ($N = kg \times m/s^2$)

   When using the Lil' Suctioner, air pressure is pushing down on the can and suctioner. Since the air has been removed from under the suctioner, there is no air to help equalize the force of the air from above.

Using the radius of the Lil' Suctioner and standard air pressure, calculate the total force of the air pushing down on the suctioner and can of soda. **r = 2.19 inches** and **standard air pressure = 14.7 pounds per square inch**. Use the equation **$\pi \times r^2 \times$ standard air pressure = total pressure (pound-force)**. Then convert pound-force to Newtons using the conversion 1 pound-force = approximately 4.5 Newtons. Show your work.

$\pi \times (2.19 \text{ in})^2 \times 14.7 \text{ lb}$

$3.14 \times 4.80 \text{ in} \times 14.7 \text{ lb} = 221.6 \text{ lb}$

$221.6 \text{ lb-f} \times 4.5 = 997.2 \text{ N}$

3. Finally, calculate the amount of force needed to lift the can of soda when attached to the Lil' Suctioner. Use your answer to question #3 to help answer this question. Explain your answer.
   Any force more than 221.6 pounds or 997.2 Newtons would lift the can of soda from the flat surface when attached with the Lil' Suctioner since that is the amount of force holding the can to the surface.

Lesson: Can Water Boil Without Heat?

Intro video: BrainBites—What Temperature Is Space? *http://brainbites.nasa.gov/#/temperature-in-space*

Introduction

Students are used to associating boiling with heat. Water boils when it's hot. However, students often don't think about the effect of air pressure on the boiling point of a liquid—in this case, water. The boiling point is the temperature at which the vapor pressure is equal to the atmospheric pressure around the water. Therefore, if you lower atmospheric pressure, you also lower the vapor pressure, or the boiling point. The background information included in this activity guide provides an introduction to temperature and how a liquid can boil without feeling "hot." Refer to the background information about temperature and its effects on human survival at high altitudes as you complete the activities below.

The following activities about air temperature and pressure will show students that room-temperature water will boil in a vacuum; how increasing gas temperatures in a soda can, then quickly cooling that air, will crush the can; how the students can melt an ice cube with pressure and refreeze that same cube when pressure is reduced; and finally, that a small piece of cotton can be ignited using air pressure.

Activity One: Boiling in a Vacuum

Objective

Students will learn about the properties of matter and how those properties can change; they will also learn about the transfer of energy as they observe room-temperature water boiling in a vacuum.

Lesson Overview

The instructor will demonstrate that room-temperature water will boil in a vacuum by placing a cup of water in a vacuum pump and making it boil. Students will then take warm water in large plastic syringes, create low-pressure environments, and make the water in their syringes boil.

Materials

- Vacuum pump
- Clear plastic cup
- Water (room-temperature for the vacuum pump and warm for the syringe activity)
- Large plastic syringes with cap or piece of clay to seal syringe tip (one per student or group)
- **Optional:** Infrared laser thermometer
- Student activity worksheets

Safety note: If you have never used a vacuum pump and bell jar before, use caution when placing objects in the vacuum chamber. Objects can break when exposed to vacuum conditions, sometimes damaging the bell jar in the process. Always check to make sure the bell jar is in good condition (no cracks or signs of excessive wear), that seals and gaskets are clean, and that you know how to operate a vacuum chamber. When you repressurize the chamber following an activity, items in the chamber may not stay where they are when air floods back in, so use care.

Vacuum Pump and Water

1. Ask students what they think it means to boil a liquid. Also ask them to write down at what temperature they think water boils. Have them write their criteria for boiling water on their worksheets.

2. Fill a clear plastic cup about half full with room-temperature water.

3. Place the cup in the vacuum pump chamber.

4. Turn on the vacuum pump. As air is evacuated from the chamber, the water will begin to boil. Have students record what happens as the water begins to boil, then reaches a full boil.

5. **Optional:** Use an infrared laser thermometer to show students that the water in the chamber is not hot as it boils. You will not be able to read the temperature of the water while the chamber is operating because the thermometer will be reading the temperature of the outside of the chamber. However, you can read the temperature of the water before it is placed in the chamber and again once the bell jar is removed; the difference will show a drop in temperature as the water loses energy (i.e., heat).

6. Turn off the vacuum pump. Carefully repressurize the chamber, trying not to move the chamber so the water does not spill.

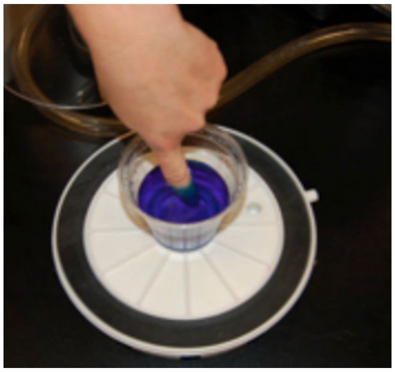
7. As quickly as possible, remove the bell jar of the chamber and stick your finger into the water (it will still be at the same temperature).

8. Discuss why the water temperature did not increase as the water boiled.

9. Have students complete their worksheets.


Water before pump is activated.


Water boiling in a vacuum.


Testing water temperature immediately after the water leaves the vacuum environment.

Hand-Held Low-Pressure Environment

1. Give students the opportunity to create a low-pressure environment of their own, which will allow them to boil warm water in a large syringe.

2. Heat a container of water until it is very warm to the touch, but not boiling (hot tap water works for this as well).

3. Fill each syringe about 1/3 full of the warm water; then put the plunger into the syringes (at about the level of the water) and cap the syringes.

4. Have students pull back on the syringe plungers, reducing the air pressure inside the syringes. The water should boil.

5. When students release the plunger, the air pressure will increase, stopping the water from boiling.

6. Students can do this several times until the water cools down so much that the pressure inside the syringe cannot be lowered enough to boil the water anymore.

Activity Two: Collapsing Soda Can

Objective

Students will learn about the properties of matter and how those properties can change; they will also learn about motions, forces, and the transfer of energy as they watch a change in air pressure collapse a soda can.

Lesson Overview

Students will watch a demonstration in which a small amount of water is heated inside an otherwise empty soda can; the can is then quickly placed upside down in a container of ice water. The hot, expanded steam inside the heated can is quickly condensed and cooled when placed in the ice water. This rapid change of phase of the steam inside the can creates a pressure differential between the inside and the outside of the can that is enough to collapse the soda can.

Materials

- Empty soda can
- About ¼ cup of water to pour inside the can
- Tongs to handle the heated soda can
- Container of ice water (must be larger than the soda can)
- Heat source (a Bunsen burner or hot plate works well)

Safety note: Use care when conducting an experiment with a heat source such as a Bunsen burner or hot plate. The water inside the soda can will be boiling, and the outside of the can will get extremely hot, so use tongs when handling the heated soda can. You may want to practice the activity before demonstrating it to students so that you can see how it occurs and you don't spill boiling water from the can as you flip it over into the container of ice water during the actual demonstration.

In addition, due to safety concerns, this activity should be performed as a demonstration by an adult (not students). Students should stand away from the demonstration in case the water splatters. **THE DEMONSTRATOR SHOULD WEAR EYE PROTECTION**.

---

1. Ask students for ways you can collapse an empty soda can. Have them write as many ideas down on their student worksheet as they can.

2. Tell students that you are going to use air to collapse the can. Ask them if they know how that could happen.

3. Heat the small amount of water in the otherwise empty soda can (about ¼ cup works well, but it doesn't have to be exact) until the water boils. You may see steam rising from the opening of the can.

4. Ask students what is happening to the air and the water inside the can as you are heating the can. If necessary, explain that the water is changing phase from liquid to gas and that the air temperature is increasing as well. Although air pressure increases with an increase in temperature, most of the pressure inside the can, once heated,

comes from the water, which has turned into steam. This increase is not enough to damage the can, but students will be able to notice steam coming from the can opening.

5. Set a container of ice water nearby. Ask students what happens to air pressure as air temperature decreases, along with what happens to water when there is a change in temperature (in this case, when the water is heated, it changes to a gas—steam—and later, when that gas is cooled, it will change phase once more and condense into a liquid). Students should also answer that air pressure decreases with a decrease in temperature.

6. Using tongs, take the heated soda can and quickly invert it and submerge the lid into the ice water, which will prevent outside air from entering the can as the steam and remaining air inside the can cool.

7. As the air pressure decreases inside the can, and the steam, which took up more space than the liquid water, condenses, the higher air pressure outside the can will cause the can to collapse.

Image of collapsed soda can.

Activity Three: Melting Under Pressure

Objective

Students will learn about the transfer of energy as they observe that pressure can cause ice to melt, then observe that when pressure is reduced, water refreezes. Examples of this process, called regelation, can be observed in nature as the pressure from a glacier causes the underlying water to melt, allowing the glacier to slide along the ground. The water that is left behind then refreezes once the pressure has been reduced.

Lesson Overview

In this activity, two demonstrations will show students that pressure can be used to lower the melting point of ice. First, the pressure of a thin wire attached to weights and stretched over a piece of ice will melt through the ice. The students will observe that when the pressure is removed, as the wire travels through the ice, the water above the pressurized wire will refreeze due to the reduction of pressure. In the second demonstration, a heavy object on top of a second piece of ice will cause the ice to melt faster than a piece of ice without pressure exerted on it.

Materials

Three larger chunks of ice (these activities will work with any piece of ice, but a larger piece of ice allows students to better see what is happening)

Activity 3A setup.

For Activity 3A:

- One of the above chunks of ice
- Thin wire
- Two weights wrapped around the wire (water bottles work well)
- Shallow tray to hold the chunk of ice
- Small shelf to allow the weights to pull down on the wire

For Activity 3B:

- Two equal-sized chunks of ice
- Larger tray, such as a cookie sheet, to hold chunks of ice
- Weight to place on top of one chunk of ice
- Student worksheet

Safety note: Do not touch large chunks of ice since your finger may freeze to the ice.

Activity 3A:

1. Place the chunk of ice on the shallow tray; then put the tray on a small shelf, which provides room for the weights to hang down over the sides of the tray.
2. Take a piece of thin wire, stretch it across the ice, and then wrap it around your two weights.
3. Hang the weights over the sides of the shelf, which will create tension on the wire and put pressure on the chunk of ice.
4. Have students observe what happens as pressure is placed on the chunk of ice from the weighted wire.
5. After about 15 to 20 minutes, students should see that the wire has melted through some of the ice.
6. Ask a student to pull up on the wire after that time; the water above the wire will have refrozen.
7. Have students draw what has happened on their worksheet, along with an explanation of why this occurred.

Activity 3B:

1. Ask students to list what is needed to make ice melt faster.
2. On your larger tray, place two chunks of ice.
3. Put a weight on top of one piece of ice while leaving the second piece open on the tray.
4. After about 15 minutes, remove the weight from the first piece of ice and have students compare the sizes of the ice pieces. Explain to students that the pressure from the weight increased the temperature above the piece of ice, which made it melt faster.

Activity Four: The Fire Syringe

Objective

Students will learn about the transfer of energy and motions and forces as they observe a demonstration about air pressure in which an increase in air pressure within a chamber ignites a small piece of cotton or paper.

Lesson Overview

Using a fire syringe, you will ignite a small piece of cotton or paper by quickly increasing the air pressure and temperature within the chamber. This dramatic demonstration shows students the direct increase of temperature when pressure is increased.

Materials

- Fire syringe
- Small piece of cotton or paper
- Unbent paper clip to feed cotton into fire syringe
- Student worksheet

1. Ask students how they would ignite a piece of cotton or piece of paper. Have them record their answers on their worksheets. Tell students that you will ignite cotton or paper using air pressure.

2. Take the fire syringe and put it on a flat surface. Place a small piece of paper or cotton inside the chamber of the syringe. (**Hint:** Use a **very small** piece of cotton! If using a cotton ball, pull apart a tiny section, leaving lots of surface area. Use the paper clip to place the cotton into the syringe—do not pack it into the bottom. Again, you want lots of air around the cotton.)

3. Press down quickly and forcefully on the syringe plunger. The paper or cotton will ignite. If you see only smoke, the precursor to fire, you may not get the cotton to ignite after that. Replace with a new piece of cotton.

4. This demonstration can be repeated with different materials. Pieces of paper and cotton should be small so they can easily ignite. **Never place a hazardous material in the chamber to ignite!**

NATIONAL SCIENCE STANDARDS

K–4

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Properties of objects and materials

Light, heat, electricity, and magnetism

5–8

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Properties and changes of properties in matter

Motions and forces

Transfer of energy

Structure of the Earth system

9–12

Abilities necessary to do scientific inquiry

Understandings about scientific inquiry

Structure and properties of matter

Motions and forces

Conservation of energy and increase in disorder

Lesson: Can Water Boil Without Heat? Worksheets

Activity One: Boiling in a Vacuum

Pre-Lab Questions

1. Explain what it means for something to boil. Describe what occurs.

2. At what temperature does water boil?

Activity Questions

1. As you watch the following demonstration, describe what you see. Draw a picture along with your explanation if that helps.

2. After the vacuum chamber was repressurized, describe the water. Explain what just happened.

3. Does this support or contradict your original definition of "boil"? How so?

4. Using your own syringe and very warm water, create a low-pressure environment by pulling back on the plunger once the water has been added. Describe what happens to the water. Why is this happening?

5. Once you released the plunger, what happened to the pressure inside the syringe? What happened to the water? Why? Did the water change temperature during this time?

6. Based on the demonstration and your activity with the syringe, come up with your own definition of the relationship between pressure and water's boiling point.

Activity Two: Collapsing Soda Can

Pre-Lab Question

1. List as many ways as you can think of to crush an empty soda can.

Activity Questions

1. Draw a picture of what is happening to the water and air inside the soda can as it is being heated. Label your drawing.

2. Describe what happened as the soda can was quickly inverted into the ice water bath. Why?

3. What would have happened if the opening had not been sealed off by the water? Again, explain why.

Activity Three: Melting Under Pressure

Pre-Lab Questions

The first two activities showed you how temperature and pressure are related. In the following activity, you will be able to see the effects of pressure on temperature. You will then be able to watch as the reaction is reversed.

1. Make a list of as many ways you as can think of to melt ice. Why is this sometimes necessary?

2. Restate the definition you came up with during the earlier activity for the relationship between temperature and pressure.

3. Based on your definition, describe what should happen to ice in the following situations:
   a. A chunk of ice that has a thin wire pulling down on it.

   b. A chunk of ice that has a heavy weight on top of it.

   c. A chunk of ice that is sitting on a metal cookie sheet.

Activity Questions

Describe what happens to the three chunks of ice in this activity. Draw what you see in addition to your description. For the first activity, explain why this has happened.

1. A chunk of ice that has a thin wire pulling down on it.

2. A chunk of ice that has a heavy weight on top of it.

3. A chunk of ice that is sitting on a metal cookie sheet.

4. For 2 and 3, which chunk of ice melted faster? Why?

5. The first chunk of ice with the wire pulling down on it is an example of a process known as regelation. Regelation is seen in nature when glaciers melt on the bottom, causing the glaciers to slide along the ground. This process also helps you make great snowballs. Explain how regelation makes it possible to create a good snowball.

Activity Four: The Fire Syringe

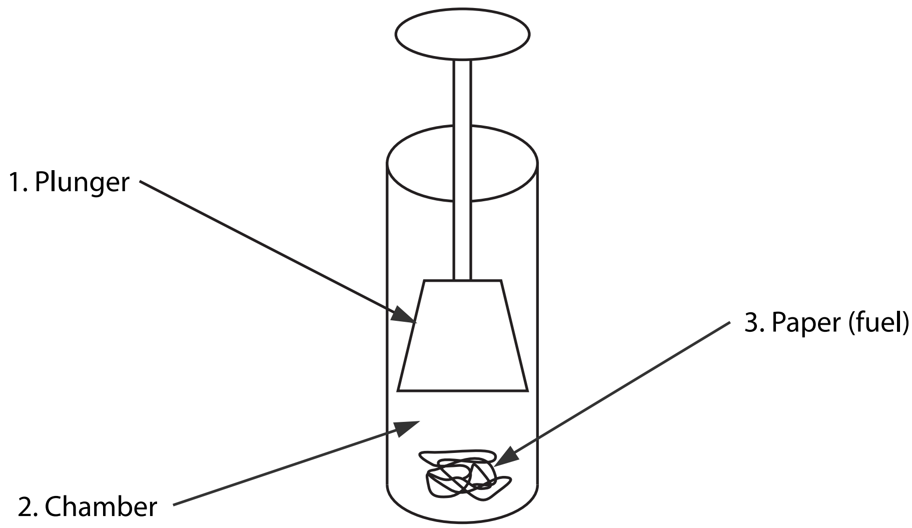
Pre-Lab Questions

1. What is needed to make fire? List as many ingredients as you can think of.

2. How would you try to make a fire if you were stranded in the wilderness? Describe the process you would use. What do you think would be difficult about making a fire?

Activity Questions

1. As your instructor demonstrates the fire syringe, explain what is happening at each of the numbered areas:



2. The Fire Syringe is much like the piston of a diesel engine. What is the fuel for a diesel engine's piston?

3. What would be an advantage of having more pistons (or cylinders) in a vehicle engine? What would be a drawback?

Lesson: Can Water Boil Without Heat? Worksheets

Activity One: Boiling in a Vacuum

Pre-Lab Questions

1. Explain what it means for something to boil. Describe what occurs.
   Answers will vary, but most students will answer that water boils when it's hot. They may describe bubbles forming on the side of a pot, or churning water as it reaches the boiling point.

2. At what temperature does water boil?
   Students will probably answer that water boils at 100 degrees Celsius or 212 degrees Fahrenheit.

Activity Questions

1. As you watch the following demonstration, describe what you see. Draw a picture along with your explanation if that helps.
   Students should describe that after the vacuum pump was turned on, the cup of water began to form tiny bubbles along the side, and then the bubbles increased in size until the water began to boil.

2. After the vacuum chamber was repressurized, describe the water. Explain what just happened.
   Once the chamber was repressurized, the water immediately stopped boiling. Since a reduction in pressure allowed water to reach its boiling point at a lower temperature, that's when the water boiled (not because of a change in temperature). Once air pressure returned, the boiling point increased. Since the water was not hot enough to boil under normal air pressure, the boiling stopped.

3. Does this support or contradict your original definition of "boil"? How so?
   Answers will vary, but for most students, it will contradict their original definitions.

4. Using your own syringe and very warm water, create a low-pressure environment by pulling back on the plunger once the water has been added. Describe what happens to the water. Why is this happening?
   As students pull back on their plungers, they are reducing the air pressure inside the syringe, which is allowing the warm water to boil.

5. Once you released the plunger, what happened to the pressure inside the syringe? What happened to the water? Why? Did the water change temperature during this time?
   As soon as students release the plunger, air pressure increases, which stops the water from boiling. There was no change in temperature, just in pressure—and, because of that, in the boiling point.

6. Based on the demonstration and your activity with the syringe, come up with your own definition of the relationship between pressure and water's boiling point.
   Answers will vary, but students should figure out that a reduction in pressure lowers water's boiling point. Likewise, an increase in temperature will raise water's boiling point.

Activity Two: Collapsing Soda Can

Pre-Lab Question

1. List as many ways as you can think of to crush an empty soda can.
   Answers will vary.

Activity Questions

1. Draw a picture of what is happening to the water and air inside the soda can as it is being heated. Label your drawing.
   Students should explain that as the water and air inside the can increase in temperature, the pressures of both the water and air increase. However, the pressure only increases to a certain point inside the can, since water vapor and heated air escape the can as vapor.

2. Describe what happened as the soda can was quickly inverted into the ice water bath. Why?
   Students should observe that the can crushes as soon as it is inverted into the bath. As the air and water in the can cool, the pressure inside the can is reduced. The reduction in pressure, along with the inability of air from outside the can to enter (since the can's opening is under the water in the bowl), allows the higher pressure outside the can to crush the can.

3. What would have happened if the opening had not been sealed off by the water? Again, explain why.
   If the can opening had not been sealed off by the water, air from outside the can would instead fill the can, equalizing the outside and inside pressure. The can would not crush.

Activity Three: Melting Under Pressure

Pre-Lab Question

The first two activities showed you how temperature and pressure are related. In the following activity, you will be able to see the effects of pressure on temperature. You will then be able to watch as the reaction is reversed.

1. Make a list of as many ways as you can think of to melt ice. Why is this sometimes necessary?
   Student answers will vary. They may suggest that sometimes we need to melt ice to make driving on the roads or walking on sidewalks safer during the winter and that we use salt or other chemicals to do that. The point to this question is to show that most people don't think of melting ice with pressure; instead, we think of other ways, such as using salt or heating the ice with a more traditional heat source.

2. Restate the definition you came up with during the earlier activity for the relationship between temperature and pressure.
   Answers will vary.

3. Based on your definition, describe what should happen to ice in the following situations:
   Answers will vary.

   a. A chunk of ice that has a thin wire pulling down on it.

   b. A chunk of ice that has a heavy weight on top of it.

   c. A chunk of ice that is sitting on a metal cookie sheet.

Activity Questions

Describe what happens to the three chunks of ice in this activity. Draw what you see in addition to your description. For the first activity, explain why this has happened.

1. A chunk of ice that has a thin wire pulling down on it.
   Students should observe that the ice will melt where the wire is pulling down on it. As the wire melts its way through the chunk of ice, the water above the wire will refreeze as pressure is reduced. Eventually, the wire will be frozen in the middle of the chunk of ice.

2. A chunk of ice that has a heavy weight on top of it.
   If a heavy object such as a book or weight is on top of the chunk of ice, that ice will melt faster than the chunk without the weight on it. Students should also observe that it melts from the bottom of the chunk.

3. A chunk of ice that is sitting on a metal cookie sheet.
   This chunk of ice will melt from all sides.

4. For 2 and 3, which chunk of ice melted faster? Why?
   Students should observe that the chunk of ice with the weight on top melts faster than the others. The wire will melt through the ice quickly as well, but only the section in contact with the wire will melt quickly. The rest of that chunk should melt at approximately the same rate as the ice chunk without any weight on it. Since an increase in pressure increases temperature, the weight on the ice causes the ice to melt quicker.

5. The first chunk of ice with the wire pulling down on it is an example of a process known as regelation. Regelation is seen in nature when glaciers melt on the bottom, causing the glaciers to slide along the ground. This process also helps you make great snowballs. Explain how regelation makes it possible to create a good snowball.
   Answers will vary, but when we compress the snowball in our hands or gloves, we are increasing pressure. The increase in pressure increases temperature, which causes some of the ice to melt. This newly melted water allows us to pack the snowballs tighter. Once we release the pressure on the snowball, the water refreezes, creating a tougher snowball.

Activity Four: The Fire Syringe

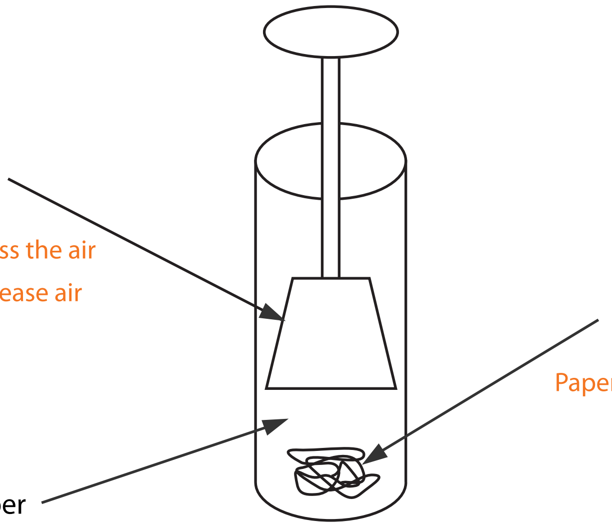
Pre-Lab Questions

1. What is needed to make fire? List as many ingredients as you can think of.
   Students should suggest that fuel, heat, and an oxidizer (often oxygen) are needed for fire.

2. How would you try to make a fire if you were stranded in the wilderness? Describe the process you would use. What do you think would be difficult about making a fire?
   Answers will vary but may include using matches, rubbing sticks together, etc. Factors that could make building a fire difficult include having a fuel and/or heat source but not knowing how to use it to build a fire.

Activity Questions

1. As your instructor demonstrates the fire syringe, explain what is happening at each of the numbered areas. Remember that fire needs three ingredients: heat, fuel, and an oxidizer.



1. Plunger

The plunger is used to compress the air in the chamber, which will increase air pressure and air temperature.

3. Paper (fuel)

Paper is the fuel in the chamber.

2. Chamber

The chamber contains air. Oxygen in the air acts as the oxidizer, which is needed for fire.

2. The fire syringe is much like the piston of a diesel engine. What is the fuel for a diesel engine's piston?
   Diesel fuel is the fuel used in a diesel engine.

3. What would be an advantage of having more pistons (or cylinders) in a vehicle engine? What would be a drawback?
   Answers will vary, but more pistons or cylinders would provide more energy for the vehicle. However, more pistons require more fuel, are heavier, and have more parts that need to work together.

Activity One: Sinking and Floating Bowling Balls

Objective
Students will learn about the properties of matter and how they can change as the students learn about the density of solids and liquids.

Lesson Overview
Students will predict whether bowling balls will float or sink in a container of water, then watch as one bowling ball floats and a second one sinks. Students will then calculate the densities of each ball to help determine the density of water.

Materials
- Large, transparent container of water (a 10-gallon aquarium works well)
- Two bowling balls (one weighing less than 12 pounds and one weighing more than 12 pounds)
- Scale
- String
- Rulers or meter stick (one per student or group)
- Calculator (one per student or group)
- Student worksheet

1. Fill the aquarium about two-thirds full of water. Note: Before conducting the demonstration, check to make sure that you did not fill the tank too full of water. If you are going to have both bowling balls in the tank at the same time, ensure that they will both fit in the tank with the water.

2. Ask students whether the bowling ball will sink or float in water. Have them write their response on their student worksheet.

3. Carefully place one of the bowling balls in the water (decide whether you first want to confirm most students' initial thoughts—that it will sink—or first show them the floating bowling ball). **Do not drop the bowling ball into the tank—you will break the glass!**

4. Now ask students what they think should happen to the next bowling ball. Again, carefully place the second ball in the tank of water. One will sink and the other will float.

5. Have students hypothesize about the reason one ball sank and the other ball floated.

6. Place each bowling ball on a scale. Students should be able to see that the bowling ball that weighed less than 12 pounds floated and the one that weighed more than 12 pounds sank. They should also be able to assume that the density of water is somewhere between the densities of the two balls.

7. Have students calculate the densities of the bowling balls.

Activity Two: Burning Candle Activity

Objective

Students will learn about the properties of matter and how those properties can change as they watch the changes in air density as a candle burns itself out in a jar.

Lesson Overview

By placing a burning candle in an inverted jar over a trough of water, students can observe, through the change in water level, the increase in air density as the air in the jar heats up, then watch as air contracts once the air cools down. This extension on a classic candle-in-a-jar demonstration adds temperature and density components to this activity.

Materials

- Candle
- Matches
- Clear jar
- Trough of water
- Spacers such as coins to place jar on in the trough
- Food coloring (optional)

Safety note: Adults should light the candle and handle the glass jar during the activity.

Introduction

Many students and adults have seen the demonstration of burning a candle in a sealed jar. In a relatively short time, the flame inside the jar is extinguished. This activity shows that fire needs three basic ingredients: oxygen, fuel, and heat. As the oxygen inside the jar is lowered enough, the flame is extinguished. However, there is also more going on inside the jar. The density of the air is changing as the air is first heated with the flame, then cools once the flame is extinguished. This can be observed by inverting the jar into a trough of water. As the air inside the jar heats up and expands, several air bubbles can be seen in the water as the air inside the jar moves from a high-pressure area to an area with lower pressure. Once the candle is extinguished, the air begins to cool and condense. As a result, the water level begins to rise inside the jar.

Some students may argue that the water level is rising inside the jar because the oxygen is being used up. However, if that were the case, then the water level would have risen steadily while the candle was burning and the oxygen was being depleted. Instead, the water level rises after the candle flame is extinguished and the air inside the jar begins to cool.

Candle, jar, and trough setup.

Burning candle.

Water level after candle has been extinguished.

Procedure

1. Fill a trough larger than the clear jar with water that is deep enough to allow the jar to sit in the trough, with several small spacers (coins work well) that will allow water to flow in and out of the inverted jar. Adding a couple drops of food coloring will allow students to see the water level change more easily.

2. Place the candle in the water, securing the candle so that it doesn't tip over.

3. Light the candle and place the jar on the spacers, making sure the jar is sealed with the water.

4. Ask students to observe both the candle burning and the water level as the candle burns, then extinguishes. Have students note the water bubbles that appear as the water in the jar heats up.

5. This demonstration can be repeated several times, if necessary, in order for students to have a chance to develop hypotheses about the rising water level, bubbles, etc.

Lesson: How To See Density Worksheets

Activity One Worksheet: Sinking and Floating Bowling Balls

Pre-Lab Question

What do you think will happen when you place a bowling ball in a tank of water? Why?

Activity

1. Describe what happened when the first bowling ball was placed in the tank of water.

2. Describe what happened when the second bowling ball was placed in the tank of water.

3. Why did this happen?

4. Using the results of the two bowling balls in water and the density calculations you will complete for the bowling balls, you are going to determine the approximate density of water. Show your work for each step.

    a. Use a scale to weigh the first bowling ball. If your scale measures in pounds, convert from pounds to kilograms.

b. Repeat for the second bowling ball.

c. For each bowling ball, calculate the circumference. An easy way to calculate the circumference of a ball is to take a piece of string and wrap it around the ball. Lay the string on a meter stick to determine the string's length. Calculate the circumference in centimeters.

d. In order to determine the volume of each bowling ball, use the following formulas:
Volume = $4/3 \times \pi \times r^3$
Circumference = $2 \times \pi \times r$

e. To calculate the density of the bowling ball, divide the mass of the ball by the volume. Be sure to use kilograms for the ball's mass and cubic centimeters for the volume. Complete these calculations for each bowling ball.

f. Using the densities of each bowling ball, what can you infer about the density of water? Explain your answer.

Activity Two Worksheet: Burning Candle Activity

In the following demonstration, you will watch as a burning candle is placed inside a jar, which is sealed with a pan of water.

Pre-Lab Question

What do you think is going to happen? Why?

Observation

Write and/or draw a picture to show what is happening during this demonstration. Add as many details as possible about the candle, the flame, and the water.

Followup Questions

1. Explain what happened during the demonstration.

2. Based on your instructor's explanation, why did that occur?

3. Did that support or contradict your pre-lab explanation? How so?

4. Think of another demonstration or experiment you would like to try that would test the results of this experiment. What would you do? How would that test and/or challenge the results of the experiment you just took part in?

Activity One Worksheet: Sinking and Floating Bowling Balls

Pre-Lab Question

What do you think will happen when you place a bowling ball in a tank of water? Why?

Answers will vary, but most students will probably assume that the bowling ball will sink in the water because it's heavy.

Activity

1. Describe what happened when the first bowling ball was placed in the tank of water.
   Depending on which ball is placed in the water first, one will sink and the other will float.

2. Describe what happened when the second bowling ball was placed in the tank of water.

3. Why did this happen?
   The density of water is 1.0 gram per cubic centimeter, so a bowling ball that weighs less than or equal to 10 pounds will float and a bowling ball that weighs greater than or equal to 12 pounds will sink because of the difference in densities.

4. Using the results of the two bowling balls in water and the density calculations you will complete for the bowling balls, you are going to determine the approximate density of water. Show your work for each step.
   a. Use a scale to weigh the first bowling ball. If your scale measures in pounds, convert from pounds to kilograms.
      Answers will vary. For purposes of this example problem, we will use an 8-pound ball for calculations.

   b. Repeat for the second bowling ball.
      Answers will vary. For purposes of this example problem, we will use a 13-pound bowling ball for calculations.

   c. For each bowling ball, calculate the circumference. An easy way to calculate the circumference of a ball is to take a piece of string and wrap it around the ball. Lay the string on a meter stick to determine the string's length. Calculate the circumference in centimeters.
      Regulation bowling balls are the same size, so students should figure the circumference for each ball to be 68.6 centimeters.

   d. In order to determine the volume of each bowling ball, use the following formulas:

      Volume = $4/3 \times \pi \times r^3$
      Circumference = $2 \times \pi \times r$
      Circumference/$(2 \times \pi) = r$
      68.6 cm/(2 x 3.14) = r
      r = 10.9 cm

      Volume = $4/3 \times \pi \times r^3$
      Volume = $4/3 \times 3.14 \times (10.9\ \text{cm})^3$
      Volume = 5,422 cm^3

Note: Each bowling ball has three holes that affect the ball's volume and density slightly. However, for the purposes of this activity, these will not be calculated. They have a minimal effect on this activity.

e. To calculate the density of the bowling ball, divide the mass of the ball by the volume. Be sure to use kilograms for the ball's mass and cubic centimeters for the volume. Complete these calculations for each bowling ball.

8 lb = 3,629 g

3,632 g/5,422 cm^3 = 0.67 g/cm^3

13 lb = 5,897 g

5,902 g/5,422 cm^3 = 1.09 g/cm^3

f. Using the densities of each bowling ball, what can you infer about the density of water? Explain your answer.

Based on the densities of the two bowling balls, students should be able to infer that water has a density that is between that of the less dense bowling ball and that of the denser bowling ball. Water's density is 1.0 g/cm^3, and although student calculations will not be able to make that precise of an answer, they should be able to see that water's density is close to that. In the example above, which used an 8-pound ball and a 13-pound ball, they would be able to calculate that water has a density that is more than 0.67 g/cm^3 and less than 1.09 g/cm^3.

Activity Two Worksheet: Burning Candle Activity

In the following demonstration, you will watch as a burning candle is placed inside a jar, which is sealed with a pan of water.

Pre-Lab Question

What do you think is going to happen? Why?

Answers will vary. Most students will probably say that the candle will burn out. Some students may suggest that the oxygen is being used up in the jar, which is causing the water level to rise (see introduction for an explanation about why that is not the reason).

Observation

Write and/or draw a picture to show what is happening during this demonstration. Add as many details as possible about the candle, the flame, and the water.

Answers will vary, but students should be able to show that outside pressure pushes down on the water in the trough with more pressure once the candle has been extinguished than while the candle is burning and heating the air inside the jar.

Followup Questions

1. Explain what happened during the demonstration.
   Students should focus on what is physically happening during the demonstration, not the reasons behind it.

2. Based on your instructor's explanation, why did that occur?
   Students should be able to recount the explanation given in the introduction, that the density of the air in the jar is decreasing as the air expands when the flame is burning in the jar. As the candle is extinguished, the air will cool and condense, allowing the water level in the jar to rise.

3. Did that support or contradict your pre-lab explanation? How so?
   Answers will vary.

4. Think of another demonstration or experiment you would like to try that would test the results of this experiment. What would you do? How would that test and/or challenge the results of the experiment you just took part in?
   Answers will vary, but students may want to test jars of different sizes or shapes or candles of different sizes. Existing experiments have also been conducted about the cause of the candle's extinguishing. Some have tested whether it was the elimination of oxygen in the jar vs. creating carbon dioxide that extinguishes the flame. Others may want to test the idea of air density by trying to heat the air in the jar without depleting oxygen levels. (This can be done by heating the glass jar in a hot water bath and adding very warm water into the jar, then pouring out the water and removing the jar from the water bath. The jar can then be inverted over the water trough as was done with the candle and jar, and the same result, although slower, will occur.)

NEXT GENERATION SCIENCE STANDARDS: PHENOMENA AND ALIGNMENTS

Section One: Pressure

Pressure Lesson One: Survival in a Vacuum

Activity One: Peeps in Peril.
Phenomena: How will a marshmallow Peep change when subjected in reduced air pressure, and then normal air pressure is restored?

Activity Two: Balloons in a Vacuum.
Phenomenon: How will a partially inflated balloon change when subjected to reduced air pressure, and then normal air pressure is restored?

Activity Three: Hands-On Vacuum Environment.
Phenomenon: How can a plastic syringe be used to simulate a vacuum, reducing air pressure on a marshmallow?

Activity Four: Designing a Pressure Suit.
Phenomenon: How can materials be used to reduce the effects of changing air pressure on an object?

Pressure Lesson Two: Air Has Pressure

Activity One: Potato and Straw Experiment.
Phenomena: How can changing air pressure allow a plastic straw to pass through a raw potato?

Activity Two: Magdeburg Vacuum Plates.
Phenomenon: How can changing air pressure cause two metal plates to become virtually inseparable?

Activity Three: Lil' Suctioner.
Phenomenon: How can a suction device decrease air pressure, and increase the force needed to separate a soft drink can from a surface?

Section Two: Temperature

Lesson One: Can Water Boil Without Heat?

Activity One: Boiling in a Vacuum.
Phenomena: How can water boil without adding heat?

Activity Two: Collapsing Soda Can.
Phenomenon: What causes a soft drink can to collapse when placed in ice water?

Activity Three: Melting Pressure.
Phenomenon: Why does applying greater pressure to ice cause it to melt more rapidly?

Activity Four: The Fire Syringe.
Phenomenon: How does a material in a chamber burn without the use of an ignition device like a flame or heat?

Section Three: Density

Lesson: How to See Density

Activity Three: Sinking and Floating Bowling Balls.
Phenomenon: Why does one bowling ball float and one bowling ball sink in the same tank of water?

Activity Four: Burning Candle Activity.
Phenomenon: In a jar placed in a pan of water with a burning candle inside, why does the water level inside the jar rise after the candle goes out?

NGSS Elementary Level Standards:

5-PS1 Matter and Its Interactions
5-PS1-1: Develop a model to describe that matter is made of particles too small to be seen.

5-PS2: Matter and Stability: Forces and Interactions
5-PS2-1: Support an argument that the gravitational force exerted by an object is directed down.

3-5-ETS1 Engineering Design
3-5-ETS1-1: Define a simple design problem reflecting a need or a want that included criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

NGSS Middle School Standards:

MS-PS1 Matter and Its Interactions

MS-PS1-4: Develop a model that predicts and describes changes in particle motion, temperature, and a state of a pure substance when thermal energy is added or removed.

MS-PS2 Motion and Stability: Forces and Interactions

MS-PS2-1: Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects

MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS2-4: Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of the interacting objects.

MS-PS3 Energy

MS-PS3-4: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

MS-PS3-5: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

MS-ETS1 Engineering Design

MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or a process such that optimal design can be achieved.

NGSS High School Standards:

HS-PS2 Motion and Stability: Forces and Interactions

HS-PS2-3: Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during collision.

HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.**HS-PS3 Energy**

HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the relative position of particles (objects).

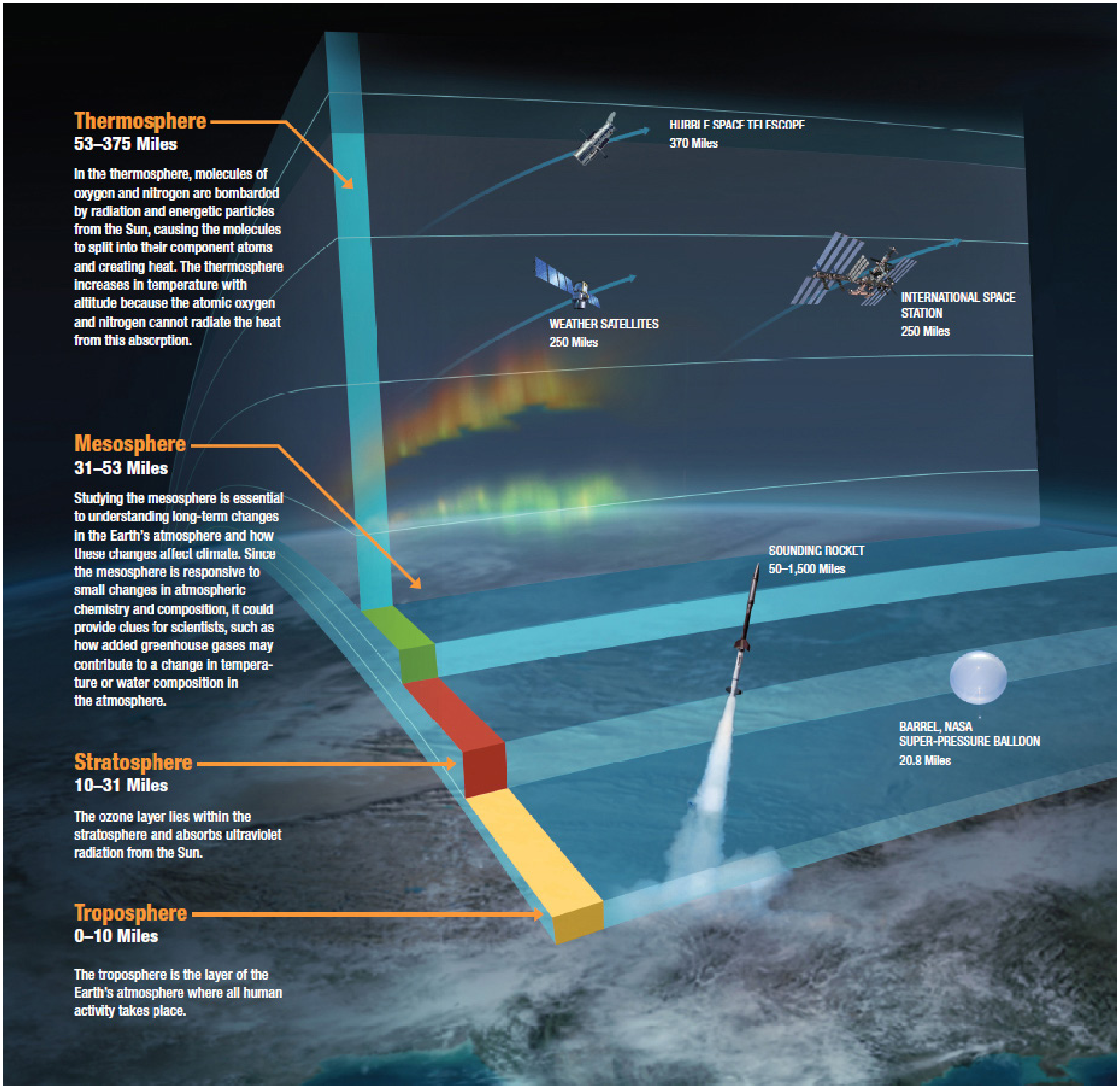
HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-PS3-4: Plan and conduct an experiment to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

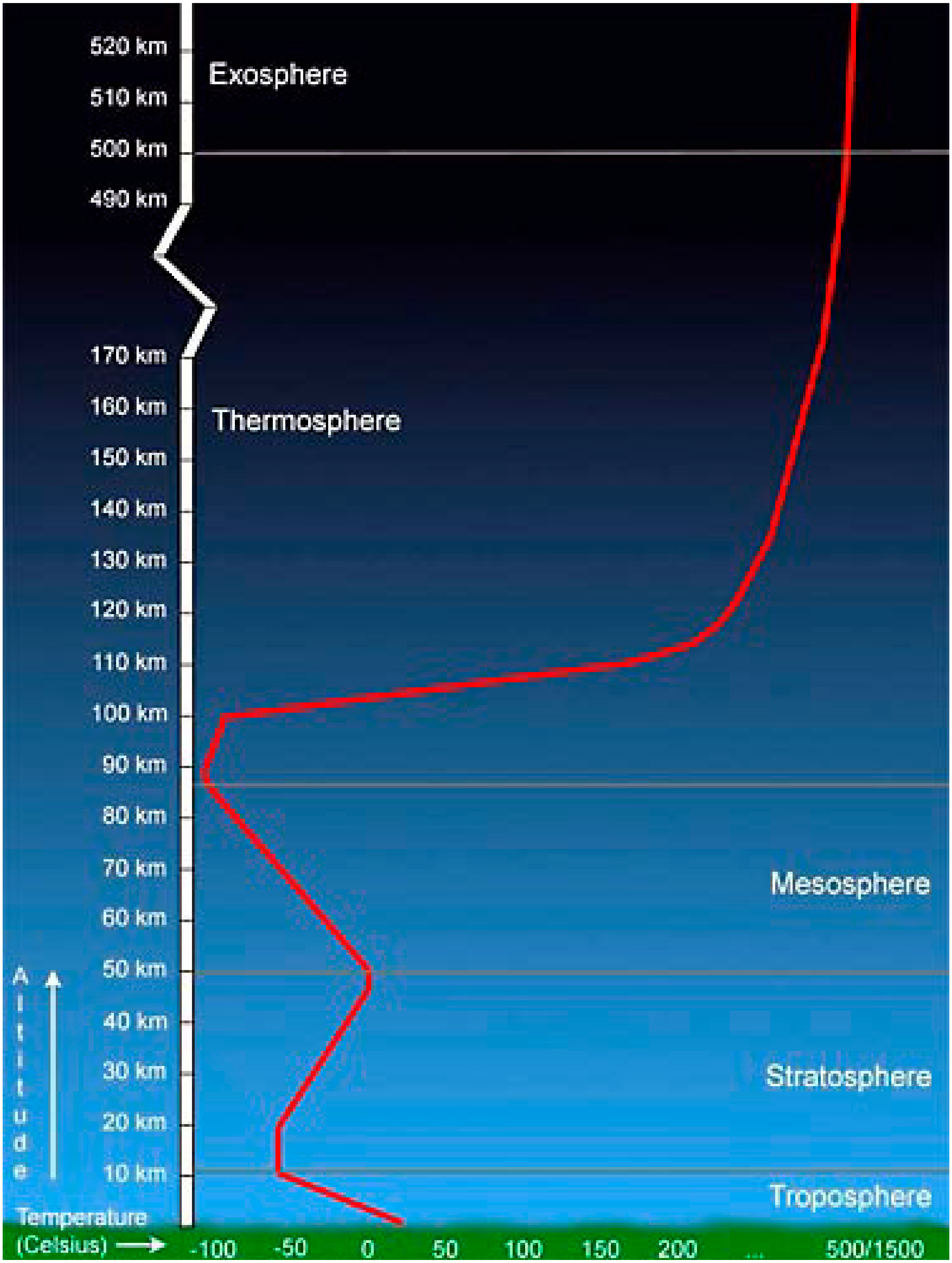
HS-ETS1 Engineering Design

HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Images



The structure of the upper atmosphere.



This graphic illustrates the atmosphere's structure, starting with the troposphere at Earth's surface. (Image Credit: NASA, http://www.nasa.gov/centers/langley/news/factsheets/DIAL.html)

Research engineer Marta Bohn-Meyer stands in front of an SR-71.
(Image Credit: NASA, http://www.dfrc.nasa.gov/Gallery/Photo/SR-71/Medium/EC92-2273-1.jpg)

A WB-57 high-altitude aircraft.
(Image Credit: NASA, http://www.jpl.nasa.gov/images/earth/wb57_browse.jpg)

STS-104 mission specialists Michael Gernhardt (dark shirt) and James Reilly (white shirt) are photographed wearing oxygen masks during their pre-breathe before an Extravehicular Activity (EVA) in the Quest airlock of the International Space Station (ISS). (Image Credit: NASA, http://archive.org/details/s104e5146)

A life-support technician assists a pressure-suited pilot into the cockpit of NASA's ER-2 earth resources aircraft.
(Image Credit: NASA, http://www.dfrc.nasa.gov/Gallery/Photo/ER-2/Small/EC00-0037-27.jpg)

Astronaut Rick Mastracchio, STS-118 mission specialist, on the mission's first planned session of extravehicular activity (EVA).
(Image Credit: NASA, http://archive.org/details/HSF-photo-s118e06305)

The deep sea submarine Ben Franklin made space exploration history in 1969 by studying the behavior of aquanauts in a sealed, self-contained, self-sufficient capsule. (Image Credit: NASA, http://www.nasa.gov/vision/space/preparingtravel/px15.html)

Marshmallow Peeps before the vacuum pump was turned on.

Marshmallow Peeps during air evacuation from pump.

Marshmallow Peeps at full vacuum.

Marshmallow Peeps after repressurization.

GENUINE OFFICIAL U.S. GOVERNMENT SURPLUS
ASTRONAUT SPACE SUIT

BRAND-NEW, HIGH ALTITUDE FLYING SUITS MADE FOR THE AMERICAN ASTRONAUTS!

NOW FOR THE FIRST TIME IN HISTORY you can own a genuine, absolutely brand-new high-altitude space suit originally made for the U.S. Government at a cost of $180.00 each. THIS IS THE REAL THING—purchased by us at a special surplus sale. Each suit weighs seven pounds and is constructed of specially reinforced lightweight Air Force green nylon with padded ribbing at cuffs and neck. ELASTIC AIR COMPRESSION CHAMBERS run the entire length of both arms and legs, and along the sides of the body. These chambers are easily inflated with any hand pump or gas station air pump through the three AIR HOSES and AIR-LOCK VALVES. Suits come complete with a total of 8 ZIPPERS (on cuffs, ankles, neck & shoulders, front & back) and 2 concealed INSIDE POCKETS. Only a LIMITED QUANTITY of these valuable suits available at only $7.95.

★ ORIGINALLY COSTS $180

★ 8 ZIPPERS

★ INSIDE POCKETS

★ ALL NYLON CONSTRUCTED

★ WEIGHS 7 LBS.

MONEY-BACK GUARANTEE—MAIL COUPON TODAY

CAPTAIN COMPANY, Dept. STI-1
BOX 6573 PHILADELPHIA 38, PENNA.

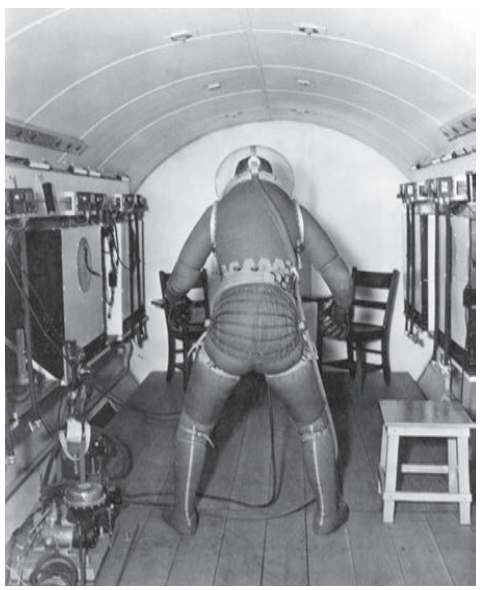
YES! I WANT ONE! Rush my ASTRONAUT SPACE SUIT to me by return mail. I enclose $7.95 plus 75c postage & handling charges. If not satisfied I can return for full refund. Hurry!

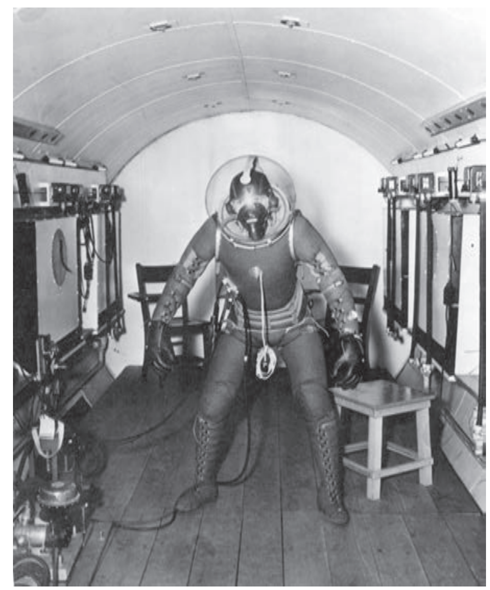
NAME..................

ADDRESS..................

CITY.................. ZONE..........

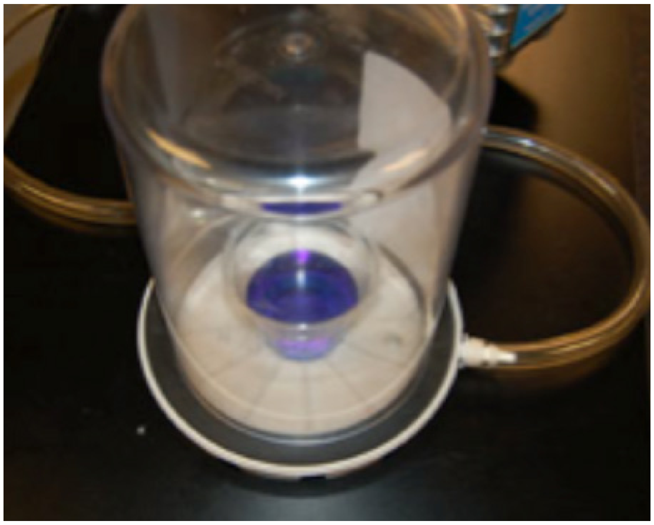
STATE..................



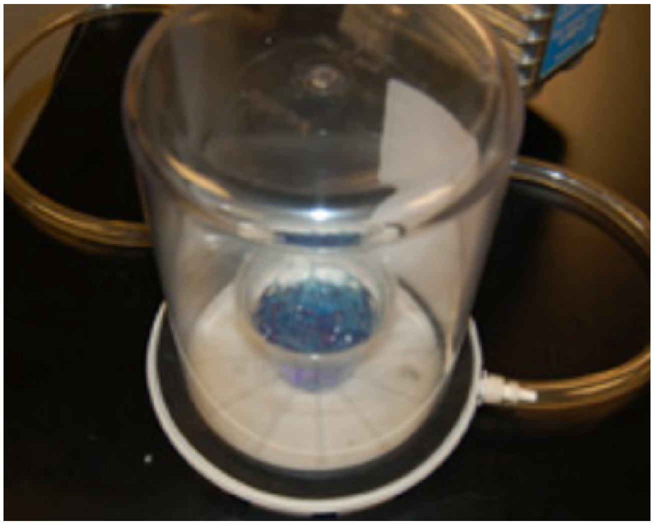


Older pressure suits.

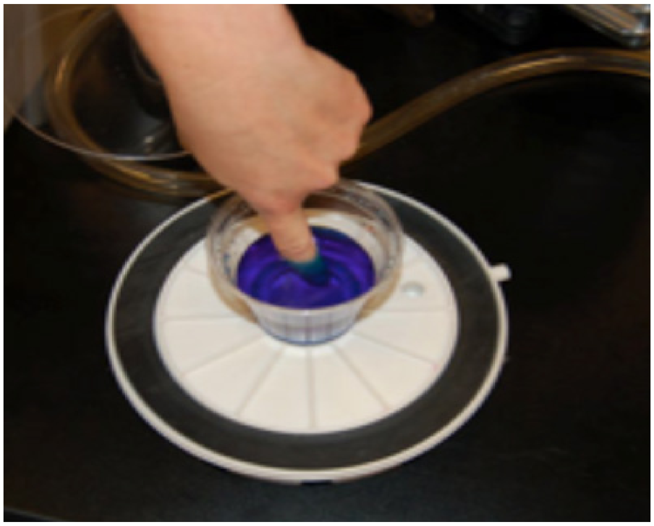
Crew members for Space Shuttle Endeavour's STS-126 mission depart for Launch Pad 39A. The sleeves of their tube-lined thermal suits are visible beneath their orange launch-and-entry suits. (Image Credit: NASA, http://www.nasa.gov/images/content/298053main_126_walkout_lg.jpg)



Water before pump is activated.



Water boiling in a vacuum.



Testing water temperature immediately after the water leaves the vacuum environment.

Candle, jar, and trough setup.

Burning candle.

Water level after candle has been extinguished.

Resources

NASA Resources

Special thanks to James Sokolik, Operations Manager, Dryden Flight Research Center.

"A Brief History of the Pressure Suit":
http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/pshis.html

Jenkins, D.R. *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Space Shuttle*. NASA SP-2011-595. 2012.

Parker, James F., and Vita R. West, eds. *Bioastronautics Data Book*, 2nd ed. NASA SP-3006. 1973.

Roth, Emanuel M. "Rapid (Explosive) Decompression Emergencies in Pressure-Suited Subjects," prepared by the Lovelace Foundation for Medical Education and Research for NASA. NASA CR-1223. Albuquerque, NM. 1968. *http://www.ncbi.nlm.nih.gov/pubmed/5305515*.

NASA Education Links

"Spacesuits and Spacewalks." NASA Web site (provides many links and activities to learn about both spacesuits and spacewalks):
http://www.nasa.gov/audience/foreducators/spacesuits/home/index.html

"Suited for Spacewalking." Educators' guide:
http://www.nasa.gov/pdf/143159main_Suited_for_Spacewalking.pdf

"AtmosModeler Simulator." Temperature and pressure simulator:
http://www.grc.nasa.gov/WWW/k-12/airplane/atmosi.html

"The Atmosphere":
http://www.grc.nasa.gov/WWW/k-12/airplane/atmosphere.html

"Astro-Venture Geology Educator Guide, Lesson 2: Temperature, Pressure, and the Earth":
http://astroventure.arc.nasa.gov/teachers/pdf/AV-Geolesson-2.pdf

"What Is the Temperature of Space?" Activity Guide:
http://www.nasa.gov/pdf/379068main_Temperature_of_Space.pdf

"The Layers of Earth's Atmosphere":
http://airs.jpl.nasa.gov/maps/satellite_feed/atmosphere_layers/

"Spacesuits: Pressurized Protection from Thermal Effects." Activity Guide:
http://www.nasa.gov/pdf/379066main_Spacesuits_Pressurized_Protection.pdf

"Ask an Astrophysicist: Human Body in a Vacuum"
http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970603.html

"Gas Temperature." Fact sheet:
http://www.grc.nasa.gov/WWW/K-12/airplane/temptr.html

"Atmospheric Structure." Information:
http://disc.sci.gsfc.nasa.gov/ozone/additional/science-focus/about-ozone/atmospheric_structure.shtml

Outside Resources

Abramov, I., and I. Skoog. *Russian Spacesuits*. Springer Praxis Books. Germany. 2003.

Broadway, Chuck. "55 Years of the U-2 Dragon Lady: The Evolution of Training." 2010. *http://www.af.mil/news/story_print.asp?id=123220436*.

FAA. "Oxygen Equipment: Use in General Aviation Operations." Information about Aviator's Breathing Oxygen. *http://www.faa.gov/pilots/safety/pilotsafetybrochures/media/Oxygen_Equipment.pdf.*

FAA. "Environmental Control and Life Support Systems for Flight Crew and Space Flight Participants in Suborbital Space Flight." Version 1. Washington, DC. April 2010.

Gagarin, Yuri, and Vladimir Lebedev. *Survival in Space*. Frederick A. Praeger Publishers. New York. 1969.

Grossman, David. "Flying Can Be a Pain in the Ear." *http://www.usatoday.com/travel/columnist/grossman/2004-06-07-grossman_x.htm.*

Hoversten, Paul. "Diary of a Spy." *Air and Space Magazine*. April/May 2012.

Kozloski, L. *US Space Gear*. Smithsonian Institution Press. Washington, DC. 1994.

Landis, Geoffrey A. "Human Exposure to Vacuum." *http://www.geoffreylandis.com/vacuum.html*.

Mallan, L. *Suiting Up for Space: The Evolution of the Space Suit*. John Day Co. New York. 1971.

Pickard, J.S., D.P. Gradwell. "Respiratory Physiology and Protection Against Hypoxia," *Fundamentals of Aerospace Medicine*. Ed. J.R. Davis, R. Johnson, J. Stepanek, and J.A. Fogarty. Lippincott Williams & Wilkins. New York. 2008. Pp. 20–45.

Scott, Jeff. "Airline Cabin Pressure." December 12, 2004. *http://www.aerospaceweb.org/question/atmosphere/q0206a.shtml*.

Svetcos, Kevin. "The SR-71 Pilot Full Pressure Suit: David Clark S1030 Suit." *http://www.wvi.com/~sr71webmaster/press_suit001.html*.

"Taking the Pressure off U-2s." 2011. *http://www.strategypage.com/htmw/htairfo/articles/20120306.aspx*.

"Temperature/Pressure Fact Sheet" and "Temperature/Pressure Experiment." *http://lasp.colorado.edu/rocket/eop/EOP_Temp_Exp.html*.

Thomas, K. *US Spacesuits*, 2nd ed. Springer Praxis Books. New York. 2011.

Wilson, Charles. "Flying the U-2." *http://www.blackbirds.net/u2/u-2mission.html*.

Wyle Labs Life Sciences and Services, Inc. "Impact of Recent Altitude Physiology Research on Design of Cockpit Pressurization Systems." 1997. *http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA426909*.

Young, A. *Spacesuits: The Smithsonian National Air and Space Museum Collection*. Powerhouse Books. New York. 2009.

Aeronautics
Research
Mission
Directorate

www.nasa.gov