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Going to the Ends of the Earth

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They call it the Dark Sector. It's upwind from the base, away from any bright lights, bulldozers, and radio beacons that could interfere with observing. The telescope buildings sit on stilts, so that snow drifts won't bury them. Here, a 5-minute snowmobile ride from the South Pole, is the most remote observatory on Earth.

Astronomers have a reputation for going to far-off places to watch the stars, but even their endurance is tested at the South Pole. On a nice warm summer's day, it might get up to -7 degrees Fahrenheit (-20 degrees Celsius). Refrigerators have to be heated, rather than cooled, to preserve food. The nearest major city is 11 hours away by military transport planes, which make economy-class airliners look like flying palaces: Passengers sit in nets amid boxes of cargo, wearing earplugs the whole way.

No frequent flyer miles, no in-flight entertainment, no free drinks. A U.S. Navy LC–130 Hercules transport plane gives new meaning to the term "bare-bones." Passengers going to Antarctica sit in the cargo hold and think about Tahiti. Photo courtesy of Robert M. Morse.

Except for outer space, Antarctica is the most challenging place to do scientific research. Working there demands teamwork: scientists, technicians, mechanics, carpenters, pilots, cooks. This is true of science anywhere, but in most places the discoveries get front-page attention while the behind-the-scenes support gets forgotten. At the South Pole, the need for teamwork is impossible to forget. Your life depends on it.

On the Top of the World

In many ways, the South Pole is similar to other premier observatory sites. They all tend to be at high altitude -- in the case of the South Pole, atop a 9,500-foot (2,900-meter) thick ice sheet. The height gets astronomers above the bulk of Earth's atmosphere, especially above the water vapor, which blocks certain colors of starlight. For the same reason, the best observatories are also in deserts, where water vapor is minimal and the full spectrum of starlight reaches the ground for astronomers to study. Antarctica is one of the driest places on Earth. In fact, it's so dry that, for some kinds of observing, the air is as transparent as outer space.

Major observatories also tend to be remote, in order to avoid the bane of modern astronomy: light pollution. Indeed, many observatories used to be remote, but then cities grew up around them, and now street lamps drown out the stars. But the South Pole doesn't have to worry about urban sprawl.

The South Pole has another crucial advantage over other telescope sites: Day and night work differently there. In most places on Earth, there are 365 days per year. Each day, the Sun and stars rise and set. But at the South Pole, the Sun and stars rise and set only once each year.

Look at a globe and the reason becomes clear. Pick out Hawaii, the location of the world-renowned Mauna Kea observatories, and spin the globe. If you stand in one place, you can see Hawaii only part of the time. The rest of the time it's on the side away from you. But as you spin the globe, you can always see the South Pole.

Each time the globe spins around represents a day. Suppose you represent the Sun. If a team of tiny astronomers in Hawaii wanted to look at you, they could see you for only part of the day. But a team of tiny astronomers at the South Pole could see you all day.

Because the pole is right on the axis of rotation, it stays put as the world turns. The only motion that affects the pole is that of Earth's orbit around the Sun. To simulate this, stand still and ask a friend to carry the globe in a circle around you. Your friend should keep the axis of the globe pointing in the same direction, just as the axis of Earth always points in the same direction. Each trip around you represents one orbit of Earth around the Sun -- that is, one year. Notice that those tiny astronomers at the South Pole would see you for only half a year.

The same is true for real astronomers at the South Pole. The Sun is above the horizon for half the year. It rises in September and sets in March. During these months, no matter when you set your alarm clock, you always wake up and go to sleep in broad daylight. But for the other half of the year, the Sun never rises. Similarly, other objects in the heavens are visible for months at a time. During those months, they remain at about the same distance above the horizon.

The Middle of Nowhere

Solar astronomers were the first to take advantage of this weird day- night cycle. In the 1960s, solar astronomer Martin Pomerantz pioneered a branch of solar astronomy known as helioseismology, which relies on very long observations of the Sun. Antarctica provided the observing times Pomerantz needed.

Only in this decade, however, have researchers made a concerted effort to build observatories at the South Pole. Two groups have led the way: the Center for Astrophysical Research in Antarctica (CARA), which includes scientists from various institutions in the United States and Australia, and the Antarctic Muon and Neutrino Detector Array (AMANDA), built by a team of American, German, and Swedish scientists. Both groups operate from the Dark Sector, about a half-mile from the Amundsen-Scott South Pole station, the base maintained by the United States since 1957 (see photo).

Welcome to the Dark Sector. The South Pole observatories are located about 800 meters (half a mile) from the main station, on the other side of the airplane runway. The mirror is for the AST/RO submillimeter telescope, which, appropriately, probes the cold gas in interstellar space. Photo © 1994 Maohai Huang. Used by permission of Maohai Huang.

CARA's telescopes look at wavelengths of light which the eye doesn't see: the infrared and radio [see "There's More to Light Than Meets the Eye," The Universe in the Classroom, summer 1996]. Although each of CARA's telescopes looks at a different set of wavelengths, they all have the same basic structure. The first crucial element is the primary mirror, which collects the light from the sky and redirects it into the telescope. The other, secondary mirrors focus the light until it forms a greatly magnified image. In a backyard telescope, this image is seen through an eyepiece. In a research telescope, the image is instead focused on an electronic detector.

One of CARA's telescopes, known as AST/RO, is sensitive to submillimeter wavelengths of light, which are sandwiched between infrared light and radio waves. These wavelengths are given off by the cold gas in interstellar space which forms stars. Because submillimeter wavelengths are especially sensitive to water vapor, the South Pole is one of the few places on Earth where they can be observed. Other scientists use AST/RO to study our own atmosphere, particularly the ozone hole directly above the South Pole.

Another of CARA's telescopes, SPIREX, looks at infrared light. Although only 24 inches (70 centimeters) wide, it matches the performance of much larger infrared telescopes in other locations, where observing conditions are worse. SPIREX began working in early 1994 and viewed the collisions of comet Shoemaker-Levy with Jupiter in July of that year [see "The Comet About to Smash Into Jupiter," The Universe in the Classroom, spring 1994].

A third telescope, PYTHON, collects the microwave radiation produced by the Big Bang [see "The Biggest Bang of Them All," The Universe in the Classroom, first quarter 1997]. It produces high-resolution maps of the ancient universe, including the slight lumps that were the seeds for today's galaxies.

CARA has also developed a robotic telescope, which can be deployed in even more remote Antarctic sites to see whether they are better for astronomy than the South Pole.

Look Down

While CARA exploits the dry air and the high latitude of the South Pole, AMANDA takes advantage of all that ice. It is an example of how modern astronomers are redefining what we mean by the word telescope. AMANDA doesn't look for light, but for neutrinos, subatomic particles that are created by supernova explosions and other cataclysms in space. It doesn't look up, but down, searching for neutrinos coming through the earth rather than from the skies. And it doesn't use mirrors, but special detectors embedded as far as 2 kilometers (over 1 mile) underground. These detectors watch for flashes of "Cherenkov radiation," an eerie blue glow produced when high-speed neutrinos interact with the ice.

It's easier to picture what AMANDA does by thinking of speedboats and buoys on a lake. As a speedboat races across a lake, it leaves a wake behind it -- just as neutrinos produce Cherenkov radiation as they race through the ice. As the wake passes the buoys on the lake, they bounce up and down, rolling with the waves created by the boat. If you could measure the height and timing of the waves at each buoy, you could deduce the direction and the speed of the boat. Similarly, from the brightness and timing of the Cherenkov radiation seen by each detector, AMANDA can determine the energy and direction of the neutrinos.

Neutrino astronomers are forced to use such a roundabout technique because neutrinos are impossible to capture by run-of-the-mill telescopes. To build AMANDA, they are lowering its strings of detectors into holes drilled using hot water. When finished, the holes are about 2 kilometers deep and 1 meter (over 3 feet) wide. They refreeze within a couple of days, so the AMANDA scientists have only that amount of time to install their detectors.

Despite the hazards of the South Pole, the research program continues to grow -- in large part because of the successes of the astronomy. Three years ago, the Amundsen-Scott station could support 120 people. Now it can maintain a population of 173, and in each of the past three years new laboratories, observatories, and sleeping quarters have been constructed.

Just a few years ago, most of the researchers worked in tents, affectionately known as Jamesways, left over from the Korean War. Each summer, the crews had to pitch the Jamesways and then take them down again. The tents didn't even have bathrooms; you either used a bedpan or walked outside, in -20 degree Fahrenheit weather, to the bathroom. Now, the observatories have permanent buildings. Scientists can observe year-round, and they don't need to spend weeks each year setting up camp.

Down Under

Simply getting to the South Pole is an adventure. You take the first step of your journey months in advance by passing a thorough medical exam. When the time comes to begin the trip, you fly to Los Angeles and then on to Christchurch, New Zealand. That's a 12-hour flight over the Pacific, and because you cross the International Date Line, you lose another day -- if you leave the United States on Monday night, you arrive in Christchurch at noon on Wednesday.

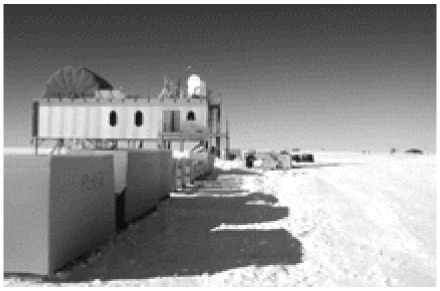
In Christchurch, your next stop is the National Science Foundation's clothing distribution center. There you can leave any bags you don't want to take with you to Antarctica, and you receive special cold-weather gear: long underwear, pants, jackets, gloves, hats, parkas, and insulated shoes called "bunny boots." Then you're given a time to report for your flight, usually a day or two later.

The plane is a Hercules LC-130, a cargo plane equipped with skis. Before you board the plane, you need to put on all that cold-weather clothing as a safety precaution in case the plane crashes (see photo, top of page). It takes eight hours to fly to McMurdo station, the main U.S. base in Antarctica, with a population of about 1,000. There you await your trip to the South Pole.

That trip usually comes within a day or two. You board another LC-130 for the three-hour flight. During the first hour of that trip, you'll pass over the Transantarctic Mountains, one of the most beautiful sights in the world. At the same time you're climbing from sea level to an elevation of about 9,500 feet (2,900 meters).

When you finally arrive, you notice two things: the cold, of course, and the elevation. Because the pole is at a high altitude where there's less oxygen, most people feel dizzy and short of breath. Newcomers don't sleep well for the first few nights and have a dull headache. Fortunately, your body gets used to the altitude after a few days.

At the South Pole you live with about 50 scientists and 120 support staff. Most people have a tiny room in a Jamesway tent. To save fuel, you're only allowed two 2-minute showers per week. Fortunately, it's so dry and cold that people don't get too smelly. The dining room, TV lounge, pool room, laundry, libraries, and bar are in three major buildings, which are protected under an aluminum dome. The dome connects to arches that hold the station's fuel, power plant, garage, gym, carpentry shop, and hospital.



Taking out the trash. The line of cardboard boxes on the left are for sorting trash. All garbage has to be shipped back to Washington state in order to protect the delicate Antarctic environment. The boxy building at the rear houses the AST/RO submillimeter telescope. It is up on stilts so that drifting snow can slide underneath rather than piling up and burying the building. Photo © 1994 Maohai Huang. Used by permission of Maohai Huang.

Because the Sun is up all the time in summer, people adopt their own strange sleep cycles. Some people are sleeping while others are working. On the only day off, Sunday, friends get together to jog the 15,000-foot-long runway or, on New Year's, the "Race Around the World," a three-lap race around the metal stick that marks the exact location of the South Pole.

The dome also has facilities for the staff members who spend the winter at the South Pole in order to operate the telescopes and maintain the equipment. Most people come only for the summer, which runs from early November to mid-February. Outside that period, it's too cold for aircraft to land. Summer temperatures are usually -20 to -50 degrees Fahrenheit (-30 to -45 degrees Celsius), but during the winter, temperatures can drop to -100 degrees Fahrenheit (-70 degrees Celsius). Eight scientists and 20 support staff stay the winter -- over half a year in total isolation.

But probably the most remarkable thing about living at the South Pole is the camaraderie. Because there are so few people and they all realize how remote and far from help they are, there is a special teamwork there that you don't see in many other places. You'll be surprised when, on your final day as you board the LC-130 for your trip back, you'll feel like you're leaving a place that has become home.

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THE UNIVERSE IN THE CLASSROOM

Classroom Activity: Playground Physics

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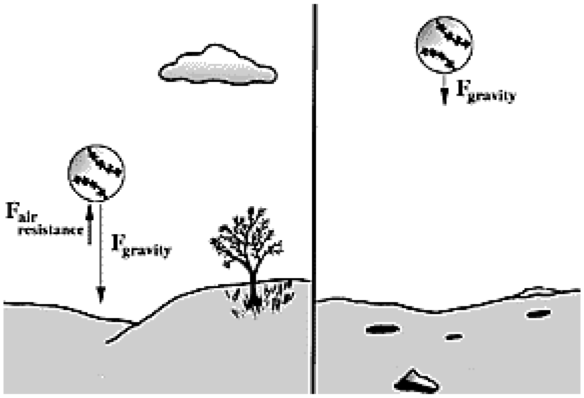
Little do most children know that their playground is an ideal laboratory for physics. Simply by swinging, climbing, and jumping, they have already developed an intuitive grasp of many basic concepts in physics. The Playground Physics program relates this experience to scientific experiment and theory. Designed at the University of Colorado and tested in local schools, the program is geared toward fourth- through seventh- graders. For the younger children (grades four and five), the experience is mostly conceptual, but for the older children, there is a slightly more formal and mathematical approach.

The portion of Playground Physics presented here is a shortened version of "Jungle-Gym Drop," one of three modules in the complete program. The full program, available on the World Wide Web at http://lyra.colorado.edu/sbo/mary/play, includes introductory materials, student handouts, experiment reports, and teacher guides.



Fly ball. On Earth (left), the force of gravity and the force of air resistance both act on falling objects, such as a baseball. But the Moon (right) has no atmosphere and therefore no air resistance; only the force of gravity acts on falling objects there. The importance of air resistance depends not only on the density of the atmosphere, but also on the shape and weight of the object and the distance it is dropped. Eventually all objects dropped on Earth will reach a terminal speed--air resistance prevents them from falling any faster. Diagram by Mary Urquhart.

In "Jungle-Gym Drop," students drop objects from the top of a jungle gym to learn about gravity. The students choose objects of different shapes, sizes, and masses to drop. You may need to help your students to select appropriate objects, such as:

- balls
- paper
- pens and pencils
- rocks
- feathers
- balloon
- water balloon (messy, but fun)
- coins
- anything else not too heavy, awkward, or breakable.

The Theory

to be explained only after students do the experiments

In a vacuum, such as that on the surface of the Moon, all objects fall with the same acceleration. This is a natural consequence of how the force of gravity acts. If you drop a feather and a bowling ball, they'll hit the ground at the same time. On Earth, too, this is usually true for objects dropped from small distances. But for some objects, another force besides gravity makes itself felt: air resistance. Feathers and paper, for example, have little mass and a high surface area, making air resistance important -- so they fall slower.

When you discuss this in class, your students may mention that some objects, such as hot air balloons, won't fall at all. Because they contain hot air, the air inside them is less dense than the surrounding air, and their buoyancy keeps them up. You can explain this to your students by saying that the balloon is supported by the air around it. The same principles apply in water, except that water resistance is even stronger than air resistance.

Before the playground

First, have the students make their own hypotheses about how objects move when dropped. The students may work in small groups or individually. Some questions they can think about:

- What makes things fall when you drop them?
- Do heavy objects fall faster, slower, or at the same speed as lighter objects?
- Does it matter how high up you are when you drop an object? If you will also be examining the concept of momentum on the playground, introduce it first in class. Some questions you might ask:
- Which of your chosen objects will hit the ground with the most momentum? Which with the least?
- Does the height you drop an object from affect the momentum of the object when it hits the ground? You may also ask about students' personal experience:
- How does a kite stay in the air when you fly one? And there are more involved questions:
- What would be different about our experiment on the Moon? Why might our results change if we dropped things on the Moon? Because the Moon has no atmosphere, gravity is the only force that acts on objects there. Everything falls with the same acceleration. But on Earth, objects eventually stop accelerating when they reach their "terminal speed," at which air resistance is as strong as gravity. Different objects have different terminal speeds--slower for feathers than for bowling balls. Another difference between Earth and Moon is that, because the Moon has a smaller mass, its gravity is weaker. It takes longer for objects on the Moon to hit the ground.

On the playground

Materials:

- objects to drop
- a kitchen scale (preferably with metric units)
- clipboards with paper (or notebooks)
- stopwatches
- a tape measure (preferably with metric units)

First, ask whether the students have ideas for the experiment. They may suggest just what I have in mind. If not, they can try their own experiments in addition to the ones I suggest here.

First, measure the mass of your objects with the scale and determine which are heaviest (the most massive) and which are lightest (the least massive). Have your students climb the jungle gym two at a time to drop their objects. By dropping two objects at a time, the students will get a subjective view of how fast objects fall.

To provide a more objective measurement, have the students measure the distance between each object and the ground before they drop it. Try to drop all of the objects from the same height the first time through. Then students can vary the height. While some students are dropping their objects, others should time the fall with the stopwatches.

Timing is tricky

Single measurements can be very misleading. Each student may see a slightly different number on the stopwatch. Use at least three stopwatches or repeat each drop at least three times. This shows that results in science need not be (and often aren't) identical.

This might be a good time to talk about uncertainty and error in science. Errors in measurements are normal and happen because people and equipment are never perfect. Uncertainty is another way of saying how trustworthy the measurements are. If, after several drops of a ball from the same height, the students all record times within a second of one another, then their measurements are believable to a second or two.

The problem in this experiment is that, because of the short distances involved, most objects only take a second or two to fall. So, these measurements aren't going to be very precise. The stopwatches are mainly a device to illustrate the idea of scientific measurement and error. You might try asking your students how the experiment could be changed to make the measurements more precise.

Momentum

Additional materials

- pie pans
- a can of shaving cream

Measuring how long it takes a ball to fall is hard enough; measuring the momentum of an object as it hits the ground is nearly impossible. I have come up with a fun and messy solution.

Students should select only a few objects for this experiment. For each object, fill a pie pan with shaving cream (try to keep the amounts fairly consistent). After a practice drop to determine the best location of the target pie pans, let the students drop their objects two at a time into different pie pans. They might miss a time or two, but they'll probably hit it after that. To prevent an utter mess on the playground, try putting an old blanket under the pans. The bigger the splash, the more momentum the object has when it hits. No throwing allowed--students must simply drop their objects.

Follow-up

Before you leave the playground, ask the students about how their hypotheses held up. Would they change any of their answers to the questions? Did they learn anything new? If the experiments didn't work well, discuss what should have happened and have the students come up with reasons why it didn't. Discuss the responses and add your own suggestions if necessary.

Assessment

The students should record data for their experiments, always with measurement units. I also recommend each student write a short essay in which they discuss how well their own hypotheses held up against experimentation, what new things they learned from the experiments, and what other experiments they might like to do on their own. The full World Wide Web version of Playground Physics includes a worksheet for students to record data and answer questions about their experiments.

For the older students, you can assign more formal reports and calculations using the time and distance measurements. For instance, you can give students the acceleration due to gravity and have them determine the time the objects would take to hit the ground if air resistance were neglected. This requires a calculator with a square-root key. The formulas are:

$$\text{distance} = 1/2 \times \text{acceleration} \times \text{time} \times \text{time}$$
$$\text{time} = (2 \times \text{distance} \div \text{acceleration})^{1/2}$$

On Earth, the acceleration due to gravity is 10 meters, or 32 feet, per second per second. On the Moon, it is 1.6 meters, or 5.3 feet, per second per second. For example, if you drop an object from 8 feet high on Earth, it should take 0.7 seconds to hit the ground; on the Moon, 1.7 seconds.

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