The Young Scientist

September 1981 $2.00

The Shuttle's next stop—

Colonizing Space

From the editor's desk

NASA's next step should be a space station

You were probably as excited as I when the Space Shuttle Columbia took off last April. But I had a question—where was it going? Why did we need a "space truck" if there is nowhere to park once we get out into space? What is the Shuttle really doing?

I did some research and found out that the Shuttle was supposed to be traveling to a space station! The original plans that the National Aeronautics and Space Administration (NASA) made right after the Apollo Project successfully landed Neil Armstrong and Edwin Aldrin on the Moon were to build a space station. The Shuttle was planned as the transportation to and from the space station, after carrying the materials into orbit to construct the station itself. Scientists at NASA called this space station the Space Operations Center (SOC, for short), and have detailed blueprints for several possible types. They estimate that it will take 10 years to build the SOC; if we start this year, it could be finished by 1992.

As exciting and important as the other space projects are (the Voyager exploration of Jupiter and Saturn, the Solar Polar Mission, and the rest), they will lead nowhere if we do not build the SOC.

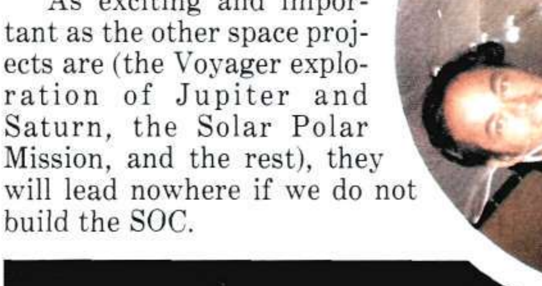
As Carol White describes in her article on page 10, the whole idea of the space program is the colonization of space. The next step is a space station where astronauts can rest, refuel, and repair their ships. In fact, it will be much easier and cheaper to build the spacecraft themselves right at the space station. Without a space station, it is impossible to colonize the Moon or travel on to Mars. The Soviet Union is now building its own space station, which it hopes to have completed by 1985. The station will be manned by 12 astronauts and scientists.

NASA scientists predict that 30 years after the first space station is built, millions of people will be visiting space. Tourists, explorers, scientists, and engineers—these people will be the new Pilgrims, starting man's colonization of the solar system.

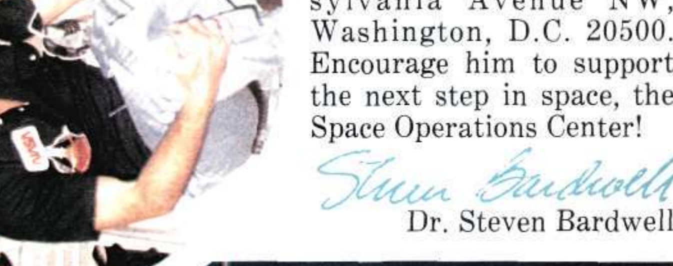
If our nation starts right now to build the SOC, you and I can be among those space travelers. You can help by writing to President Ronald Reagan, The White House, 1600 Pennsylvania Avenue NW, Washington, D.C. 20500. Encourage him to support the next step in space, the Space Operations Center!

Steven Bardwell

Dr. Steven Bardwell



Apollo Astronaut James Irwin saluting the flag next to the lunar module and lunar rover.



Space Shuttle Columbia at liftoff in April.
Center: Shuttle pilot Robert Crippen doing acrobatics in zero gravity.

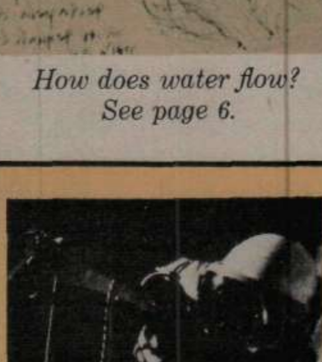
Picture Credits: inside front cover (left) NASA, (center) Rockwell International, (right) NASA; p. 1 Royal Library, Winsor Castle; pp. 2, 3 (top) Dr. Robert Heath, *J. of Neuroscience Research* 3 (1977) pp. 89-90; p. 2 (bottom) Christopher Sloan; p. 3 (right) Gregory Northrup and James Wolfe, University of Illinois; p. 4 NASA; p. 5 David Cherry, Sr.; pp. 6, 8 Royal Library, Winsor Castle; p. 7 A. Roshko, California Institute of Technology; pp. 10-11 NASA; p. 13 Boeing Aerospace Co.; p. 14 (from top down) NASA, NASA, Boeing Aerospace Co., NASA; p. 18 (top) Franklin, *Experiments and Observations on Electricty;* p. 19 NASA; p. 20 (drawing) Gary Genazzio, (photo) Carlos de Hoyos; pp. 21, 22 Carlos de Hoyos; p. 23 Christopher Sloan; p. 24 Alan Yue.

The Young Scientist (ISSN 0272-0876) is published five times a year (Sept., Nov., Feb., April, and June) by the Fusion Energy Foundation, Suite 1711, 250 West 57th Street, New York, N.Y. 10019. *The Young Scientist* provides news and features on the frontiers of science for students from 10 years and up. The views of the Fusion Energy Foundation are stated in the editorials. Opinions expressed in signed articles are not necessarily those of the FEF directors or advisory board. Subscriptions in the U.S. are $8 per year for 5 issues. School group subscriptions are $5 each. Write or call for other bulk rates. Second-class postage is paid at New York, N.Y. and additional mailing offices. Postmaster, send change of address to Suite 1711, 250 West 57th Street, N.Y., N.Y. 10019. Address all correspondence to *The Young Scientist*, Fusion Energy Foundation, Suite 1711, 250 West 57th Street, N.Y., N.Y. 10019. Or call (212) 265-3749.

The Young Scientist

September 1981 Vol. 1, No. 3

How does water flow?
See page 6.



About the cover

This NASA photograph shows astronaut Edward White taking the first U.S. walk in space June 3, 1965, on a tether outside the Gemini 4 spacecraft. Christopher Sloan designed the cover.

news...

Smoking marijuana damages brain cells

Normal monkey brain cells

New scientific experiments show that smoking just one marijuana cigarette a day for several months damages brain cells. The damaged cells lose their ability to communicate with each other. This causes abnormal brain waves and abnormal behavior.

Dr. Robert Heath at Tulane University in New Orleans, Louisiana, experimented with monkeys, giving them marijuana smoke equal to one cigarette a day, five days a week, for three months. He then examined slices of their brains with a powerful electron microscope and found damage in the region between brain cells called the communication space, or **synapse.**

The synapse is where the brain cells communicate with each other by electrochemical impulses. Each brain cell has a central body and many long extensions that look like tree branches. The tip of one cell's branch almost touches the tip of another cell's branch. When we are thinking or running or sleeping, our brain cells are controlling this activity through electrical waves, which constantly travel from cell to cell.

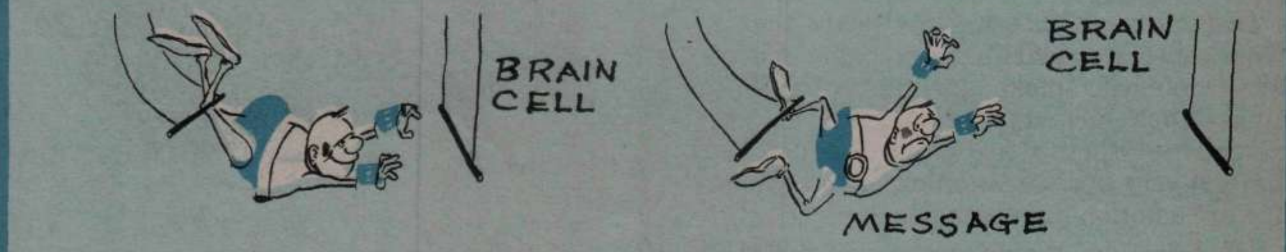
When a cell needs to send an electrical message to another cell, it produces a tiny amount of chemical called a **neurotransmitter** at the tip of a branch. This chemical passes through the synapse space between the cells and carries the message to the next cell. There the chemical message changes back into an electrical message again.

There are 10 billion nerve cells in the human brain, and each is connected to thousands of other cells. The millions of messages passing back and forth in this vast network of cells are the basis for normal mental activity. Any damage at the synapse "message lines" could therefore destroy the entire working of the brain.

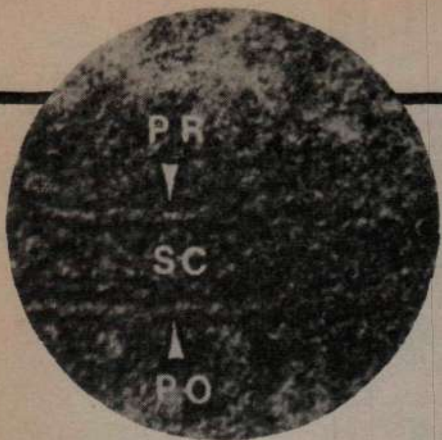
The marijuana damage

Dr. Heath found that the marijuana damaged the monkeys' brain cells at the synapse spaces. He found that the synapse spaces became larger. That is, the cells were more separated from their neighboring cells. The synapse space actually became one-third larger than normal.

Not all of the brain is affected equally. The marijuana damage in the monkey brain cells was mainly in the part of the brain called the **limbic system.** The limbic system is the part of the brain that is important for memory, attention span, and emotional stability. Most of the marijuana chemical collected in the limbic system, which was thus the part of the brain most affected by the marijuana damage.



The synapse is the brain communication space. To transmit a message, a brain cell produces a chemical that passes through the synapse to the next cell. Marijuana damages monkey brain cells making the synapse space one-third larger than normal.



Brain cells after treatment with marijuana

The monkey brain tissue shown here is magnified 80,000 times its original size. After a monkey is treated with moderate amounts of marijuana, the communication space between two nerve cells, called the synapse (SC in the photograph), widens and is filled in with unidentified dark material.

When Dr. Heath tested for the normal electricity in the monkeys' brains, he found that the electrical brain waves were not normal. He concluded that the abnormal brain waves were caused by the damage he found in the synapse spaces between the cells. The animals also acted abnormally, which Dr. Heath concluded was caused by the brain cell damage.

To test this idea, Dr. Heath measured the brain waves of some people who were given marijuana to smoke. Not surprisingly, he found that the electrical brain waves in these humans were also abnormal in the limbic brain area.

Even when the monkeys who were exposed to marijuana for six months were kept off it for another nine months, they still had the same widening of their brain synapse spaces. Dr. Heath has thus shown that the effects of marijuana on the brain can last for at least nine months, and possibly for years after a person stops smoking.

Doctors have observed for years that the mental effects of marijuana smoking are very bad. People who smoke marijuana often forget things—their memory is damaged. They can't concentrate—their attention span is damaged. They get very upset over unimportant things—they are emotionally unstable.

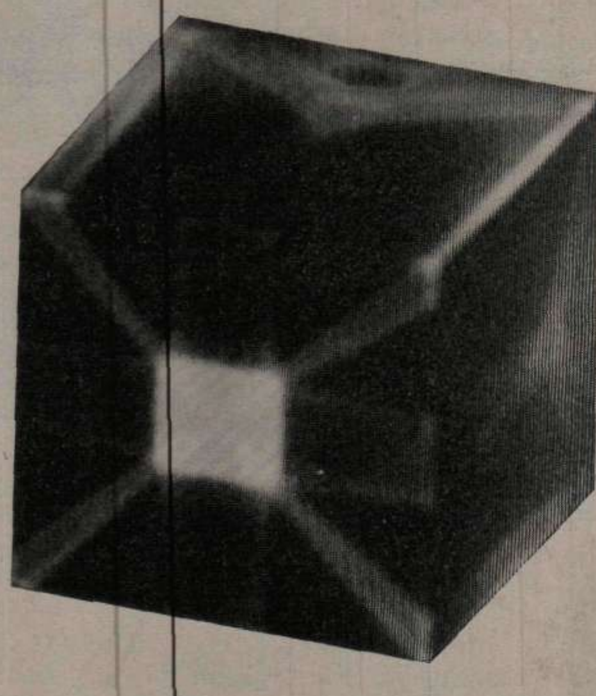
Dr. Heath's experiments with monkeys and his brain-wave experiments with humans give the probable reason for these mental changes from marijuana in the brain cells.

—by Ned Rosinsky, M.D.

Hot off the wire...

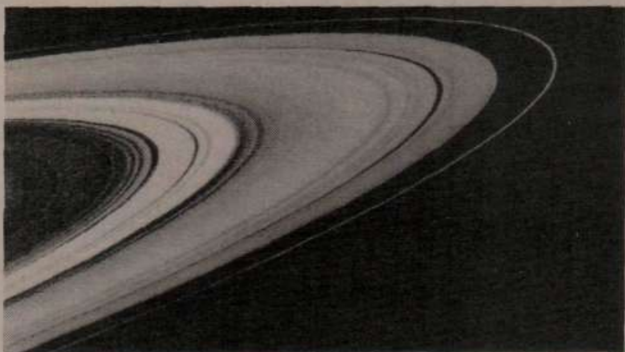
Heat transfer in crystals. You have probably heard that a basic law of the universe is **entropy:** the universe will eventually die because all the energy will be evenly distributed as the "random" vibration of molecules called heat. Now new experiments with heat transfer in crystals have challenged this assumption. Scientists at IBM Laboratory in Yorktown Heights, New York cooled a crystal of germanium to near absolute zero and sent a small pulse of heat through the crystal. Instead of the heat spreading evenly throughout the crystal as expected, it traveled in an ordered pattern, much like a beam of light.

The heat beam can be focused, diffracted, and reflected just like a beam of light! In fact, pictures show the energy bouncing back and forth through the crystal like light in a box of mirrors. This shows that not only is heat a more organized form of energy than had been thought, but that we must rethink our idea of a crystal as simply a set of springs (chemical bonds) and balls (atoms) connected together.



A photograph of a pulse of heat energy traveling through a crystal of germanium that has been cooled to low temperatures. The bright regions correspond to a temperature rise. The photo was taken by physicists Gregory Northrop and James Wolfe at the University of Illinois.

Return to Saturn. Voyager 2, the sister ship to Voyager 1, will make its closest approach to Saturn on Tuesday evening, August 25. Scientists have used the information supplied by Voyager 1 to reprogram Voyager 2's computers so that the robot spaceship will take a closer look at some of the most puzzling features of the Saturnian system that were discovered by Voyager 1, such as the braided F ring and the moon Enceladus, which is much smoother than the other moons.



The underside of Saturn's rings taken by Voyager 1, 740,000 kilometers from Saturn.

Pluto: the double planet. Scientists now believe that Pluto is actually two planets, not one, which raises new questions about the origins of the solar system. The planet farthest from the Sun, Pluto is so small and so far away that nobody could see it until about 50 years ago, when telescopes were made more powerful. But now we have a new telescopic method that shows that Pluto and its companion Charon are nearly the same size. Charon, which was discovered in 1978 and called a moon of Pluto, proved to be about one-half as wide as Pluto and almost one-eighth as massive. By comparison, Earth is 80 times heavier than its Moon.

Pluto and Charon form only a dim blob of light through an ordinary telescope. To get a better look, astronomers take time-lapse photographs. But during a long exposure, the turbulence in the Earth's atmosphere causes the image to wiggle around, making the picture blur.

Speckle interferometry uses a computer to overcome this blurriness problem. Many short-exposure pictures are fed into a computer. The blurriness can be partly removed, leaving a clearer image.

A team of French astronomers used this method to photograph Pluto and Charon. They found that they are really a system of two planets!

Space and fusion budget cuts. President Reagan's proposed budget for the fiscal year 1982 would set back the nation's space and fusion programs.

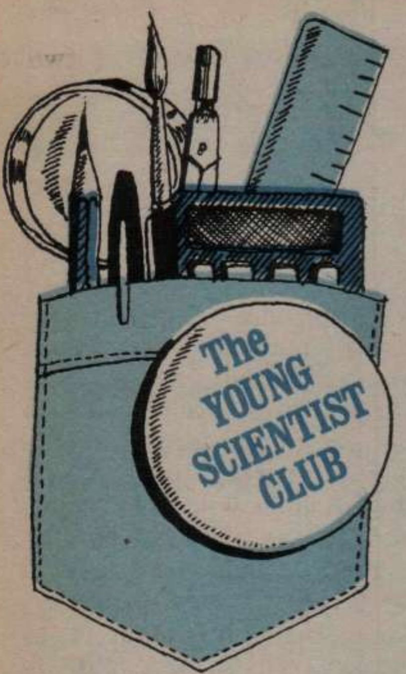
In space, the administration has proposed cutting the National Aeronautics and Space Administration (NASA) budget by $603.5 million, about 10 percent of the total budget of $6 billion. Unless Congress votes to add money to the NASA budget, the cuts will force cancellation or delay of several important projects:

The **Solar Polar Mission** will be canceled. This mission, planned jointly by NASA and the European Space Agency, would send up two spacecraft to observe the Sun at close range, one at each pole. The **Halley's Comet** probe has also been canceled. This is a once-in-76-years opportunity to learn more about the oldest material in the solar system. In addition, the **Large Space Telescope** and the **Gamma Ray Observatory** have been delayed from 1986 to 1988. These high-powered observatory instruments, to be flown on the Space Shuttle, would improve our observations of the universe by more than 200-fold.

There are also delays in the **Venus Orbiting Imaging Radar Mission** to map the clouded planet, the **Upper Atmosphere Research Satellites Experiment** to measure the chemistry and magnetism of Earth's atmosphere, and the **Galileo Mission** to send an unmanned probe to the surface of Jupiter. Other projects being cut include the **National Oceanic Satellite System**, the **Technology Transfer Program,** and programs in geology and agriculture.

At the height of the Apollo Project, which put a man on the Moon in 8 years, NASA's budget was $14 billion in 1981 dollars. This means that Reagan has proposed a NASA budget for 1982 that is less than half that of 1965.

The Reagan administration has recommended cutting the fusion budget from $525 million to $460 million. This will delay the beginning of the engineering phase of the fusion program and contradict the law passed in 1980, called the Magnetic Fusion Energy Engineering Act of 1980. This law tells the government to build a fusion engineering device by 1990 and a commercial prototype fusion reactor by 2000. The law also had a price tag for fusion in 1982 of $525 million.



This section of the magazine is reserved for your letters, news of Young Scientist Club activities, and the puzzles, experiments, and ideas you send us. Write to The Young Scientist, Fusion Energy Foundation, Suite 1711, 250 West 57th St., New York, N.Y. 10019.

From Erik Norris Olathe, Kansas:

Professor Von Puzzle, I have a puzzle for you. A millionaire died and in his will he said he would give all his money to anybody who could put 10 trees in 5 rows of 4.

Professor Von Puzzle:

Thanks. It's a good puzzle. For Erik's answer, see page 24.

From Jason Bosowski Tollana, Connecticut:

I am doing a report on nuclear energy. If you can, could you send me a diagram of a nuclear reactor, a nuclear pellet, or a picture showing how a nuclear reactor works?

From Anne Jungclaus Martinsville, Indiana:

I am interested in nuclear fusion as a Science Fair project. I have some idea of how it works. I am going to build a scale model of the Livermore nuclear reactor to illustrate the principle of how laser beams develop enough heat for the fusion process to take place.

I would like to simulate the process and the energy given off by using glowing radium, as used on watches and clocks. Bombarding the radium with a stream of bright light (to represent the laser beams) I believe would make the radium glow brighter, indicating the reaction. I know any true fusion reaction isn't possible to duplicate, but I believe using a mild radioactive substance to simulate the process would make a better project.

From Nader Hanna Huntington Beach, California:

My science class receives The Young Scientist magazine. We believe in the fusion energy movement. We also believe that progress is the only direction helpful to mankind. That is why we turn to you. My eighth-grade science class and I would like to build a fusion energy reactor in the simplest form.

The Editor:

You should all read this issue's Experiment section, in which we describe how two 13-year-old young scientists built a model tokamak. We'll continue to report on fusion research in every issue of **The Young Scientist.** And the next issue will have an article on nuclear power and how it works.

From Melissa Landis, 14 Kearney, Nebraska:

I really enjoy **The Young Scientist.** Science is my favorite subject, and I'm really glad to have a science magazine like this.

Some of the kids in my school are taking drugs. Could you have an article explaining more about how drugs can hurt you?

I also think it would be good to have a section on different careers in science, telling what you should study in school to become a scientist. I want to be a psychiatrist when I grow up, and I know I have to learn all about medicine and biology now. What do you have to do to become a fusion scientist, or an astronaut?

From Jamie Plouff, 14 Tulsa, Oklahoma:

I would greatly appreciate it if you could please send me information on nuclear fusion and what is currently going on to perfect this future power source. I have a great interest in fusion and have been considering it for a career.

David Cherry (upper left) demonstrating his model rockets.

From David S. Cherry, 10 Englewood, New Jersey:

Just recently there was a science fair at Lincoln Early School. My project was an exhibition of rockets. My hobby just happens to be building model rockets, so I thought that maybe I could enter a showing of rockets. The way I set my project up was by using dowels as stands for my rockets and wrote a little bit about each rocket. I won second prize in the physical sciences.

The names of the rockets were the Renegade, the Cruise Missile, Starlab, and the Space Shuttle. All of the models, except for the Space Shuttle, can actually be launched with solid fuel engines, and will go 1,000 feet in the air.

From Ethan Cerami, 10 Englewood, New Jersey:

On June 12, 1981 there was a Science Fair at Lincoln School.... My project was about human anatomy. I constructed a model of a human body. I wrote and illustrated a report about the senses and the systems in the body.

I studied the senses of hearing, eyesight, taste, smell, and touch. I also learned about the digestive, circulatory, respiratory, excretory, skeletal and muscular systems. I won second prize in the biological sciences. My prize was an electric microscope.

Drawings of Leonardo da

by Dr. Steven Bardwell

Leonardo da Vinci, who lived from 1452 to 1519, during the Renaissance, is one of the most famous artists in history. His fame as a scientist, however, is newer, because only in the last 20 years have his notebooks of scientific research been discovered.

Many people have doubted Leonardo's ability as a scientist because his drawings and paintings frequently show what they call "unrealistic" portrayals of objects. This is especially true of his drawings of water.

When my 12-year-old son saw the drawing of a waterfall shown in Figure 1 at a recent exhibition of Leonardo's work at the Metropolitan Museum of Art in New York City, he exclaimed, "But this isn't what a waterfall looks like!"

The waterfall in Figure 1 was drawn in about 1506, as part of Leonardo's design for a water-development project for the Italian city of Milan. Ten years later, near the end of his life, he used the drawing to complete a set of drawings called the "Deluge Series." Another drawing in this series, shown in Figure 2, is even more "unrealistic."

Several art historians have been perplexed by these pictures. One, for example, wrote that Leonardo's scientific side must have "been ashamed of anything so obviously untrue to natural appearances." As a physicist, however, I had the exact opposite reaction: Leonardo had discovered the basic features of fluid flow 450 years before they were discovered by modern hydrodynamicists!

Figure 1
A page from Leonardo's notebook, showing the results of several experiments with water. The two smaller diagrams above show two kinds of wakes (flow) made as the water moves past an obstacle. The lower diagram shows the complex wake made by a jet of water pouring into a pool of unmoving water.

Leonardo's hydrodynamics

Just three years ago, in 1978, scientists discovered that fluids (liquids or gases) flowing around obstacles form two types of wake: a flat, two-dimensional stack of vortices and a three-dimensional braid of larger vortices. It took very careful experiments to discover these facts and then elaborate the properties of these flows.

Figure 2
In this drawing from his "Deluge series," Leonardo shows the power and destructiveness of moving water. The rain and wind have sliced away a section of the sedimentary rock and thrown it into the lake below. Note the vortices that the rain, wind, and clouds form.

How real are they?

Look at the photographs of streams of helium and nitrogen gas flowing past each other in opposite directions in Figures 3 and 4. Figure 3 shows the gases flowing at about the same speed, producing a smooth interface of two-dimensional vortices. In Figure 4 these smooth, two-dimensional vortices are breaking up, at a much higher relative velocity. But note that a much larger, three-dimensional vortex is forming at the right of the photograph!

To a physicist familiar with these "new" results in fluid mechanics, Leonardo's drawings of water look very real. For example, look at Leonardo's drawings of water flowing around an obstacle in Figure 5 (next page). Leonardo made detailed studies of the flow of fluids around obstacles as preparation for constructing a vast canal, tunnel, and dam system for the region around Florence and Milan in Italy.

In Figures 5 and 6, Leonardo dissects the motion of a fluid wake caused by water flowing around an obstacle and discovers the two parts of this motion. In Figure 5 (a), he shows a two-dimensional stack of vortices, which is characteristic of water flowing at a slower speed with all of it traveling together. In Figure 5 (b), Leonardo draws a three-dimensional roll, braids of water curling off the edge of the barrier, in this case the wall of the canal. These three-dimensional braids of vortices, like the one photographed in Figure 4, are the wakes formed by more rapid, uneven flows—different parts of the water are flowing at different speeds.

Even more remarkable, Leonardo dissects these flows in the smaller diagrams shown in Figure 6. The two types of wake are shown several times. At the top, Leonardo shows a side view of the internal structure of the three-dimensional braid; at the bottom, he shows the same structure from above. His outline of the flow lines shows the characteristic loosening of the braid as the water flows farther from the barrier.

Leonardo remarks on the physics of this twofold division in the types of wakes: "Observe the motion of the surface of the water which resembles that of hair, and has two motions, of which one goes on with the flow of the surface, and the other forms the lines of the eddies; thus, the water forms eddying whirlpools one part of which is due to the impetus of the principal current and the other to the incidental motion and return flow."

Figure 3
This modern laboratory photograph shows the type of structure formed by relatively slow-moving fluids (here helium and nitrogen gases). The wake is called two-dimensional because it is flat.

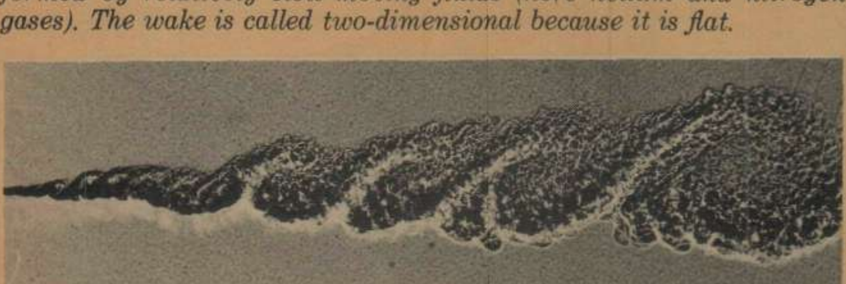


Figure 4
When these two fluids (helium and nitrogen) move more rapidly, they form a three-dimensional wake. The wake is now a twisted braid, made by twisting two streams of fluid (the top and bottom parts in Figure 3).

The question of causality

How could Leonardo have discovered the composition of fluid flow, when it has taken modern scientists years of so-

Figure 5

This page from Leonardo's notebook shows two kinds of wakes very clearly: The top drawing shows the flat, two-dimensional curls that form the slow wake, and the bottom drawing shows the braided, three-dimensional kind of wake. Leonardo understood how all fluid motions that we now call turbulent are a combination of these two types of wakes.

Figure 6

The experiments on this page of Leonardo's notebook show more complex wakes that are combinations of the two fundamental types. Leonardo says in his accompanying text that all fluid motion is "built up" out of the flat and braided kind of vortices.

phisticated experiments to discover it? Although the two types of wake are visible only in these very careful experiments, they are actually the mathematical and physical basis for all fluid flow. How did Leonardo know this?

What makes a drawing look "real"? Should it imitate a photograph, motion accurately frozen at one instant of time? Or should the drawing, to look "real," capture the causality, the reason behind the process? What happens when the instantaneous picture contradicts the causality? Is this how we "see" anyhow, by breaking processes up into tiny instantaneous pictures? It is not the eyes that see, but the brain, which is itself an ongoing process. How can the viewer "see" what never appears in any instantaneous picture? How can what is never there, the causality, be more real than what is there at each instant of time?

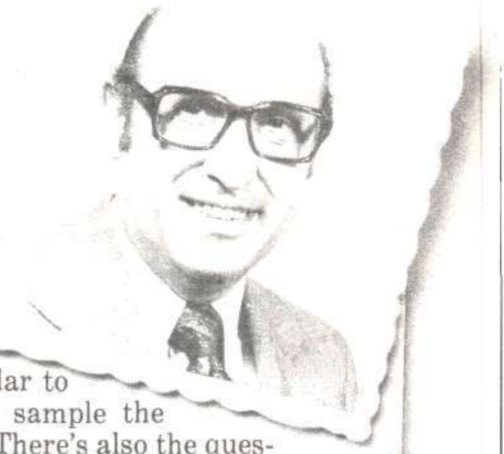
Elsewhere in his notebooks, Leonardo says, "If you understand the reason, you don't need experiments." The problem that every scientist faces is that without an understanding of the reason, you won't know what experiments to perform. In Leonardo's water studies he draws the results from very carefully prepared experiments. These are then combined with more typical wakes to show what is really occurring in the flow.

Leonardo brought this science and art of causality to great heights. The drawings derive their power from his ability to pose the paradox investigated by the Greek philosopher Plato in the fourth century B.C.: What is real—what the eyes "see," or the cause behind the process that is seen? Leonardo's drawings solve that paradox by forcing the viewer to form a hypothesis of underlying causality. They force the viewer to see reality as it really is, not as it looks.

A self-portrait of the great artist and scientist, Leonardo da Vinci

Interview

with Dr. Robert Frosch



Dr. Robert Frosch, now president of the American Association of Engineering Societies, was the administrator of the National Aeronautics and Space Administration (NASA) from 1977 until January 1981.

Question: What did NASA accomplish while you directed it?

Frosch: One obviously important accomplishment was carrying the Space Shuttle, or Space Transportation System, from the stage of initial testing through to launch readiness; that is, working out all the engineering problems of such a large-scale project. I think we did very, very well. NASA does very radical things in a very conservative way. The successful first flight of Columbia was extremely stable and right on target, with extra margins for safety and capability. A second important accomplishment was in the area of applications—communications, remote sensing, Landsat satellites, and so on.

Question: What NASA programs will be affected by the budget cuts?

Frosch: Even before the budget cuts, there were several things missing that we should have. We need a vigorous Halley's Comet mission. The rate of improvement in deep-space technology, such as solar electric propulsion systems, is inadequate. NASA doesn't suffer from not having important ideas. There are lists of things we wanted to do in X-ray and ultraviolet astronomy and planetary exploration. We wanted to have a Saturn program similar to the Galileo Mission to sample the atmosphere of Jupiter. There's also the question of what to do next with Mars. Now all sorts of things are being cut.

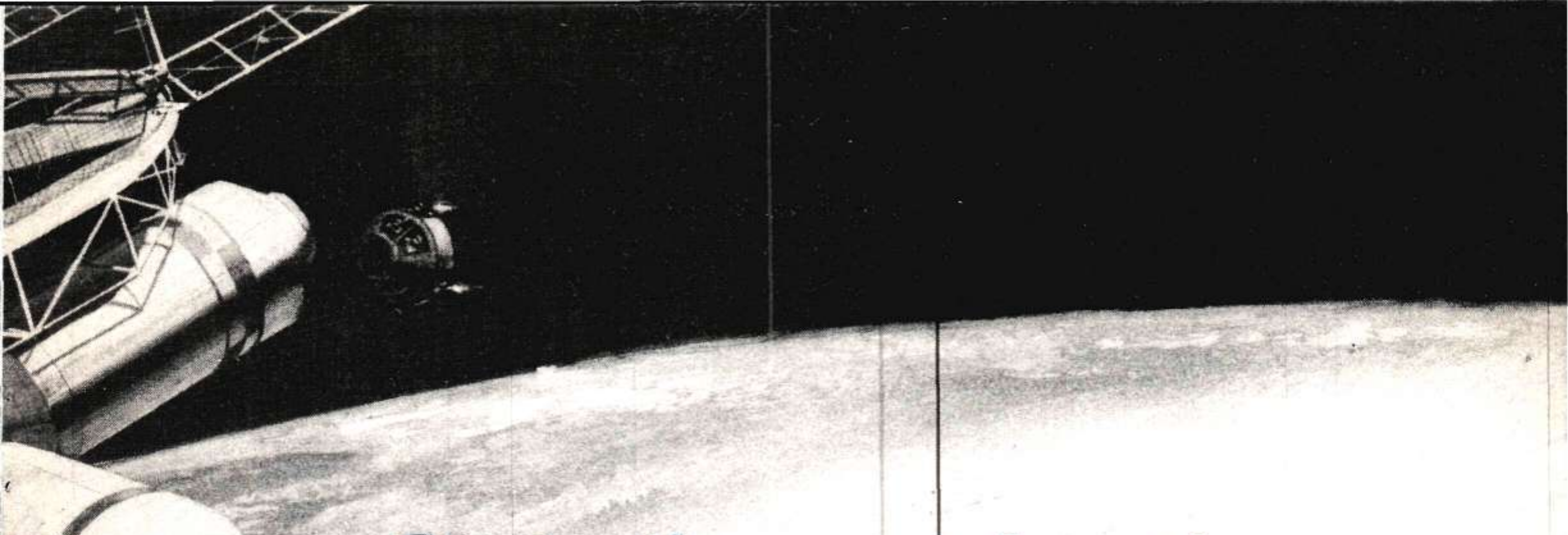
Question: What are your thoughts on the more distant future of man in space?

Frosch: The important next step after getting the Space Shuttle fully operational is building a permanently manned orbiting space station, the Space Operations Center or SOC. Given the Shuttle's limitation of 65,000 pounds for bringing cargo up to orbit, we should prepare for a manned planetary mission now by doing a lot of heavy construction and assembly in low-Earth orbit on the SOC with materials the Shuttle would deliver. You would also use this station for biomedical experimentation to learn the effects of long-term living in space.

Weight is the most important limitation for deep-space missions, and launching from orbit would overcome this. The most important question is how much fuel the spacecraft would have left to get back when it arrives at Mars or Jupiter, for example. So we could stockpile fuel and materials at the SOC to put together a more elaborate and satisfactory system than you could build on Earth. The SOC is a natural next step.

Going into space is the only way of solving the problems on Earth. There's a limitation of available energy and materials on the Earth. Looking at materials alone, to say nothing of room to grow, what we have available is the rest of the solar system.

Constructing a space station in space is the next step, once the Space Shuttle is in operation. Here is an artist's idea of what a space station might look like.



On to the next frontier—Colonizing space

by Carol White

During the early morning hours of April 12, millions of Americans sat thrilled before their television sets as Columbia, the first Space Shuttle orbiter, began its triumphant flight. More than a million people traveled to Cape Canaveral to be on the spot for the historic occasion. A new era had opened for man. Space was now an "airplane trip" away.

Twenty years before, President John F. Kennedy had demanded that America rise to the challenge of colonizing space. On May 25, 1961, he said to Congress:

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

Eight years later, on July 16, 1969, 600 million people—one-fifth of the world's population—watched the Apollo 11 astronauts, Michael Collins, Neil Armstrong, and Edwin Aldrin, lift off from Cape Canaveral. Four days later, on July 20, 1969, the world watched Armstrong and Aldrin step onto the surface of the Moon. Now we are on the verge of colonizing space. We are setting forth on the vast ocean of space to establish new living space and acquire new sources of wealth, just as Christopher Columbus and his crew set out on the Atlantic Ocean 500 years ago. Seeking a new route to India, they discovered America.

Colonization, then as now, is a four-stage process (see box on page 14), in which different sets of problems have to be solved:

1. Exploration and reconnaissance
2. Launching manned scouting parties
3. Establishing beachheads for planetary exploration
4. Expanding the economy and solving the technological problems to build self-sufficient colonies

Today we can confidently predict that by the year 2057, the centennial of the Space Age, man will have established colonies in space that will be sustained by their own agricultural production, where vast mining and manufacturing operations will go on.

Earth's seventh continent

Many space scientists have considered the benefits to be gained by space colonization. Dr. Krafft Ehricke, a pioneer in space science and astrophysics, calls the Moon "Earth's seventh continent." He says that the Moon "is an industrial sister ship of the luxury liner Earth," which will provide needed raw materials such as iron, titanium, chromium, nickel, manganese, and aluminum. It offers an environment of vacuum and low gravity in which we

The Space Operations Center

Now that the Space Shuttle has begun flying, the next step in colonizing space is to use the Shuttle to build a large space station, the Space Operations Center (SOC), in low Earth orbit. The Shuttle will carry the equipment and materials to construct the SOC and then serve as the "truck" to deliver food, fuel, oxygen, and equipment to the men and women living on the SOC.

NASA has begun designing the SOC, and several different plans are being developed. One would be to use the Shuttle's External Tanks, which are now discarded, as the main parts of the SOC. This is how Skylab, our first experiment in living in space, was built—from old Apollo parts. Another possible design is a huge wheel rotating to create artificial gravity at the rim. This station would be one-half mile in diameter and weigh about 500,000 tons.

The scientists, engineers, and technicians living in the SOC will perform experiments, build platforms for large telescopes and communications satellites, and set up factories to make chemicals and alloys that are either too expensive or impossible to make in the gravity and atmosphere conditions of Earth. For example, since a perfect vacuum is impossible on Earth, some of the molecules in the air always

Scientists at Boeing Aerospace Company are working under contract with NASA to develop designs for an SOC. Here is one of their designs for SOC living quarters.

can make important new advances in technology. It is also an ideal place for nuclear plants.

Ehricke says that the Moon not only will become a vast industrial complex, but also will have its own large farms to support large numbers of colonists. He concludes, "the Moon will be a springboard for extensive cultivation of other worlds in this solar system."

Well before the year 2000, we must be into phase three of our space colonization program. By that time, space flight should be almost as common as intercontinental air travel is today. By then we can expect nearby space to become the ideal location for scientific laboratory work and engineering testing because of the vacuum, gravity-free conditions.

The success of the Space Shuttle opens up this possibility because it vastly cheapens the cost of space travel, with parts that can be reused. Unlike other earlier spacecraft, the Shuttle does not burn up as it reenters the atmosphere. Its tiles absorb and redistribute the heat without letting the ship itself be damaged. In fact, Columbia has been planned to complete 100 space flights.

Yet at the same time that the Shuttle represents a great step forward, it illustrates one of the major problems in space flight. Although the Shuttle with its fuel and extra fuel tanks and engines weighs 1.99 million kilograms at liftoff, the orbiter itself weighs only 90,000 kilograms. The rest of the weight is taken up by the equipment and fuel needed to launch the ship, which is 20 times as great as the mass of Orbiter Columbia itself.

The problem: specific impulse

For man to travel deep into space and build colonies there, it will be necessary to develop spaceships that can overcome this problem of chemical rockets needing so much weight for fuel, with relatively small payloads. Today's rockets are inadequate for carrying the colonists and tons and tons of equipment that the thousands of people necessary to set up colonies will need. The first space colonies will not be self-sufficient, but will have to transport their tools, food, clothing, and even oxygen and water from Earth.

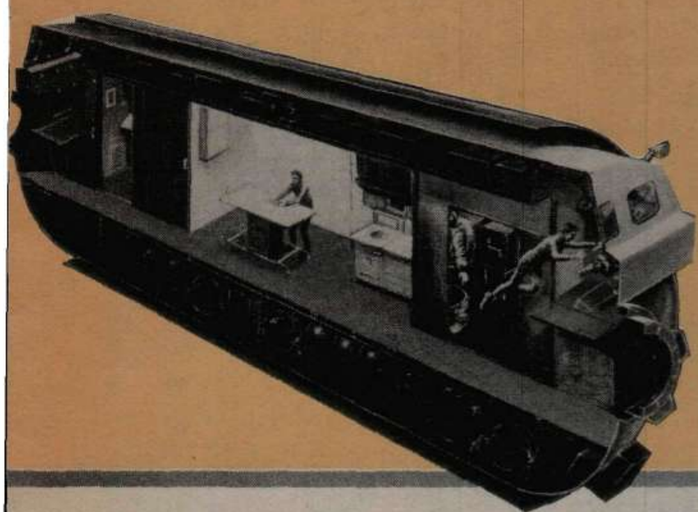
Not only is the need to carry bulk a problem, but time is also a problem. If we wish to colonize Mars, for example, with present chemically fueled rockets, the trip would take several years. We must develop propulsion systems that have greater thrust than the chemical rockets using hydrogen fuel.

Scientists use a measure called **specific impulse,** which is measured in seconds, to determine the speed at which a propulsion system can move a payload: the higher the specific sneak in to contaminate pure materials. In addition, gravity causes materials to sediment out of solutions and sets up convection streams ("winds") that stir gases or liquids, making certain chemical processes impossible. Experiments on Skylab and the Soviet Salyut 6 showed that in space we can make new metal alloys as well as separate the parts of the blood more perfectly through electrophoresis.

Another exciting area for space processing is crystals, which are needed for computers, lasers, and many other technologies. A single crystal grown free of gravity stress is more perfect and symmetrical.

The biomedical experiments performed on the SOC will be extremely important to test our ability to live in low gravity for extended periods of time—which will be necessary if we colonize the Moon or make long journeys to the outer planets of the solar system. Scientists must learn whether the changes in the human body caused by zero gravity are permanent or dangerous.

Finally, the engineers and construction workers on the SOC will build the huge fusion rocketships man will need to journey throughout the solar system, carrying all the supplies necessary to set up Earthlike cities everywhere he goes.



impulse, the faster and more efficient is the rocket. The maximum specific impulse possible from burning a mixture of hydrogen and oxygen as in the Space Shuttle is 456 seconds. A trip to Mars would take 2½ months at the maximum speed possible using chemical rockets, or 16,000 kilometers per hour—four times the speed of Apollo 11.

A reasonable goal, to make the entire solar system open to colonization, is a rocket propulsion system that would allow space travel at 320 kilometers per second, with a specific impulse of 32,800 seconds. At this speed, we'd reach Mars in 3 days! And Titan and the other moons of Saturn, which are prime candidates for colonization, could be reached in 45 days.

This is where industrial and technological developments here on Earth come in. We now have nuclear fission, which NASA research shows could be easily adapted to a rocket engine with a specific impulse of about 2,000 seconds. It would take about 40 days to reach Mars using a nuclear propulsion system.

The solution: fusion power

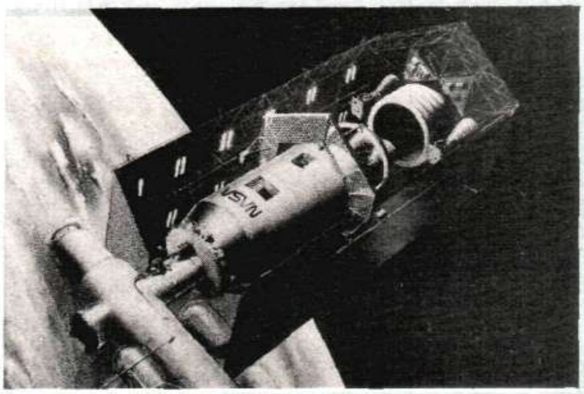
The real solution for the long term, however, is controlled nuclear fusion, which scientists predict should be available by the year 2000. Dr. Friedwardt Winterberg, a space and fusion scientist, predicts that we can reach Mars in a matter of only weeks, or even days, using the higher exhaust velocity possible only with fusion power. This means that the fuel that propels the rocket must have a much larger energy density. It must burn at a much higher combustion temperature than a chemical fuel, providing specific impulses as high as 1 million seconds!

Winterberg says this is why we must develop fusion power if we wish to explore space: "We need thermonuclear propulsion. In a thermonuclear reaction, the temperatures are not a few thousand degrees, as in chemical combustion; they are typically a hundred million degrees. Using fusion propulsion, we can get an exhaust velocity on the order of not just a few kilometers per second, but a few thousand kilometers per second."

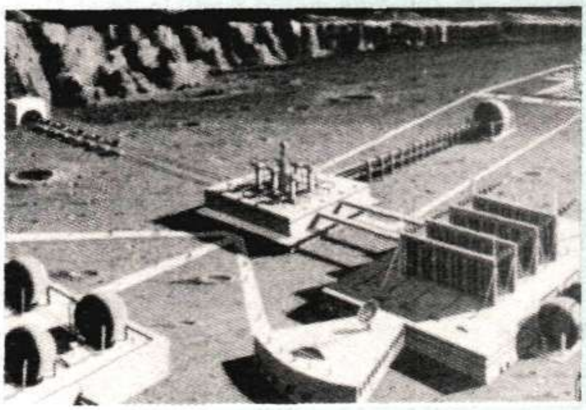
Winterberg's plan is to launch a fusion space rocket that would be assembled in orbit from parts that have been carried up by the Space Shuttle to an orbiting space station. Since the ship will be constructed in zero gravity, it can be built as large as necessary to carry all the supplies the colonists will need. Such a rocket can carry a payload of thousands or even millions of tons, which it would take from an Earth orbit into an orbit around Mars. Then man would descend onto the surface of Mars using chemical rockets.

Stage 1. *Monkeynaut Ham, who flew in the Mercury-Redstone 2 capsule in 1961.*

Stage 2. *Apollo 15 astronaut James Irwin setting up the lunar roving vehicle.*



Stage 3. *Artist's drawing of a spacecraft being serviced in the hangar of an SOC.*



Stage 4. *An artist's idea of an industrial complex on the Moon.*

The four stages of colonization

1. A necessary period of exploration and reconnaissance, such as the early trips of the Portuguese seeking to find a new route around the African continent to India. To do this, they had to develop technology for navigation such as the compass and the astrolabe. For the space program, this first phase was the period in which we launched unmanned, robot spacecraft such as the first American satellite Explorer I, which discovered the Van Allen Belts of radiation circling the Earth. Basic questions about meteor damage and radiation levels had to be answered. Could man survive in zero gravity? We learned that meteors could be guarded against with shields since they are fairly rare, but that the Van Allen Belts make it necessary to build space stations either below 460 kilometers or above 3,400 kilometers.

2. Launching of manned scouting parties, such as the 17 Apollo missions to the Moon and Columbus's trip to America. In this phase, man's ability to survive in space was tested, with more sophisticated experiments made possible by human control of the equipment.

3. Establishing a beachhead for planetary exploration by building manned space stations in Earth orbit. This would provide logistical backup for colonizing the Moon, just as the early colonies in America depended on supply lines from Europe.

4. Expanding our economy and solving the technological problems here on Earth in order to sustain the early stages of lunar or planetary colonization, at the same time that the first permanent colonists are building their cities. Just as the United States after the Revolution concentrated on mechanized agriculture and the development of an iron industry in order to provide the equipment and supplies for civilizing the Western frontier, so must we develop thermonuclear fusion energy here on Earth to supply the energy and equipment for our space colonists.

It is therefore essential that we have thermonuclear fusion power as a commercially viable energy source as quickly as possible, both to use as a rocket propulsion system and to create the unlimited amounts of energy from seawater here on Earth that are needed to supply electricity for industry, which will produce equipment and supplies for the colonists.

The technologies we must develop to enable us to domesticate and make habitable otherwise hostile environments are enormous. Without growth of our economy here on Earth, there is no way we can support the colonies on the Moon and Mars. But if we gear up to grow along with our space program, the possibilities are unlimited.

The stars our heritage

What will be the future of space travel? In the distant future, we may leave the solar system, seeking out Earthlike planets around distant stars. We should view the entire galaxy as our birthright.

It is even possible that in a few hundred years our great-great-great-grandchildren will make flights to other stars. Dr. Winterberg estimates that man will colonize the whole of our galaxy:

"The distance between the solar systems is about 10 light years, and a fusion craft would take perhaps 50 years to arrive at the next one. Suppose man migrates into the galaxy and travels from the first solar system in all directions to neighboring suns, taking 50 to 100 years to arrive at each. Man remains in each new solar system about a thousand years, building up a new technological civilization. Then he moves on to the next system.

"If we propagate about 10 light years each 1,000 years, then we would spread with a migration velocity of one-hundredth of the velocity of light. Since the galaxy has a diameter of 100,000 light years, that means that in 10 million years, man will have colonized the entire galaxy."

Why is it necessary for us to colonize space? After the initial success of the Apollo Project, many people attacked the space program as useless and a waste of money, claiming that the money should be spent on other more urgent needs. Many important projects were dropped from the space program. And even now, with the spectacular success of the Space Shuttle, budget cuts are planned for NASA.

Many answers could be given to this question. There are the technological spinoffs from the space program that have benefited the entire society, such as the development of the computer industry and life-saving medical equipment. There are the important mineral resources available in space—the entire planet of Mercury is a storehouse of heavy metals, for example. But these reasons don't go to the heart of the matter.

Man's mission

To conquer space is the lawful extension of man's mission to exert dominion over Nature. This is something that the early NASA leaders understood and put into practice in their plans. Scientists throughout history have also understood this. Man has always looked to the heavens to understand the universe and his place in it. The great astronomer Johannes Kepler in the 17th century described the stars as God's finger writing in the sky to awaken man to an understanding of science.

Some people write about space as if it would be an escape from the problems of industrial society on Earth to a simpler environment. This is ridiculous. Exploration and colonization of space can never work if it is thought of as an alternative to continued scientific and industrial development here on Earth. As we expand our frontiers in space, we will be reaching new scientific frontiers here on Earth as well.

Man cannot stand still. He either moves forward or civilization itself is destroyed. As Fusion Energy Foundation founder Lyndon H. LaRouche, Jr., said recently, the necessity for science is not just a practical question:

"Even if we had achieved such abundance that we needed no new scientific discovery, no new technological advances, in order to satisfy human needs to the full for an extended period of time, we would still need to conquer space. . . .

"We must commit ourselves at this present threshold of controlled thermonuclear fusion to the early, rapidly expanding mastery of space. We do this, not so much because of the benefit that scientific discoveries made there will greatly improve our life on Earth. We will and must do so because we have the means to undertake that challenge, and for reason of the moral effects upon mankind generally of committing our species in practice to looking up from the day-to-day mud of life on this our home-planet, to go forth from this home of ours to perfect our mastery of the lawful ordering of the universe, eagerly seeking the meaningful chores we find imposed upon us to do there."

NSTA has what you need...

- Publications for your professional interests
- Ideas for creative classroom teaching
- News on what's happening in science today.
- Opportunities to meet and share ideas with colleagues
- Continuing education programs
- Regional workshops on science-related topics

JOIN THE MORE THAN 40,000 professional science teachers and administrators who now belong to the National Science Teachers Association. As a member, you will receive 17 valuable member benefits, including . . .

- **PROFESSIONAL JOURNALS**—Choose from among NSTA's award-winning magazines.
  - **SCIENCE AND CHILDREN:** Published exclusively for elementary school science teachers and administrators (8 issues/year).
  - **THE SCIENCE TEACHER:** Designed to provide valuable laboratory and classroom information for the secondary teacher and administrator (9 issues/year).
  - **JOURNAL OF COLLEGE SCIENCE TEACHING:** Devoted to the teaching of science at the college level, especially introductory courses and those for non-science majors (6 issues/year).
- **SPECIAL PUBLICATIONS**—NSTA publishes books and booklets each year on special topics such as Measurement and Evaluation and Energy Games. Regular members receive these books at member discounts; Comprehensive members receive 2-3 publications at no extra cost.
- **ANNUAL CONVENTION** — Join over 5,000 colleagues to exchange ideas and hear noted scientists and educators each year. You save more than 30% off the registration fees.
- **DRIVE-IN CONFERENCES** — 25-30 regional workshops are held each year to discuss local issues and experiences in science education.
- **LOW-COST GROUP INSURANCE** — As a member, you and your family may apply for group life and hospital income insurance which are among the best plans available anywhere.
- **AND MORE** . . . including NSTA's employment registry, local chapter activities, international exchange, voting privileges . . . all exclusively for NSTA members.

SEND NO MONEY NOW!

To join NSTA, just fill out and return this coupon. No need to send money now — we'll be happy to bill you **after** your membership and subscriptions begin.

National Science Teachers Association
1742 Connecticut Avenue, N.W.
Washington, D.C. 20009

Check membership category:

☐ ELEMENTARY — for the elementary teacher. Includes a subscription to **SCIENCE AND CHILDREN.** **ANNUAL DUES: $20**

☐ SECONDARY — for the secondary teacher. Includes a subscription to **THE SCIENCE TEACHER** **ANNUAL DUES: $25**

☐ COLLEGE — for the college teacher. Includes a subscription to the **JOURNAL OF COLLEGE SCIENCE TEACHING** **ANNUAL DUES: $25**

☐ COMPREHENSIVE — includes 2-3 Special Publications as they are released at no extra cost, and subscriptions to the two journals I have checked below:
☐ **SCIENCE AND CHILDREN** ☐ **THE SCIENCE TEACHER**
☐ **JOURNAL OF COLLEGE SCIENCE TEACHING** **ANNUAL DUES: $45**

☐ COMPREHENSIVE PLUS — includes 2-3 Special Publications as they are released at no extra cost and subscriptions to **All Three NSTA Journals.** **ANNUAL DUES: $50**

NAME

ADDRESS

CITY STATE ZIP

Professor Von Puzzle

Welcome to the puzzle page. In the next issue of The Young Scientist, I'll give you the answers to these puzzles and explain some of the mathematical principles behind them.

If you have puzzles that you think other young scientists would enjoy, send them in with your answers. Send them to me, Professor Von Puzzle, Fusion Energy Foundation, Suite 1711, 250 West 57th St., New York, N.Y. 10019.

Kepler's Third Law

Given the time it takes for a planet to make one trip around the Sun, can you figure out how far that planet is from the Sun? And, given how far a planet is from the Sun, can you figure out how long it takes to make one trip around the Sun?

This puzzle would be impossible to solve if it weren't for the work of the great astronomer **Johannes Kepler,** who laid the basis for modern astrophysics in the 17th century. The most important hypothesis he made in his study of the planets' motions was that motions in the heavens should be in harmony with motions he could see on Earth. Kepler knew, for example, that the tones of a musical scale could be represented by simple ratios. He also knew that snowflakes form into highly symmetrical **hexagonal** (six-sided) shapes. Everywhere that he looked in nature he found simple ratios, symmetries, and proportions. He assumed that these same general types of simple proportions should hold in the heavens as well.

Based on his conviction, Kepler discovered three laws that describe the motions of all the planets quite accurately. To solve this puzzle, you will need to use Kepler's Third Law:

The ratio of the cube of the distance of the planet from the Sun to the square of the time it takes the planet to go around the Sun is the same for every planet.

The cube of a number is the product of multiplying it by itself 3 times, or $N^3 = N \times N \times N$. So, in mathematical terms, Kepler's Third Law says, for example,

$$\frac{\left(\text{distance of Earth from Sun}\right)^3}{(\text{Earth period})^2} = \frac{\left(\text{distance of Mars from Sun}\right)^3}{(\text{Mars period})^2}$$

Scientists use astronomical units, or A.U.s, to measure distances. The distance of Earth from the Sun, the Earth's **orbital radius,** equals 1 A.U. And the time it takes a planet to go around the Sun one time is its **period,** which is measured in Earth years. So, for Earth, Kepler's ratio is

$$\frac{(1\ \text{A.U.})^3}{(1\ \text{year})^2} = \frac{1 \times 1 \times 1}{1 \times 1} = \frac{1}{1} = 1$$

Now you can answer the puzzle by filling in the blanks in the following table. Does the ratio hold for the planets where both orbital radius and period are supplied?

Planet	Orbital radius (A.U.)	Period (Earth year)
Mercury	.387	______
Venus	.723	.615
Earth	1	1
Mars	1.523	______
Jupiter	5.202	______
Saturn	9.541	29.46
Uranus	19.19	______
Neptune	30.09	______
Pluto	______	284.4

Is Kepler's ratio also true for the Galilean moons of Jupiter, where Jupiter replaces the Sun? Use the following table to see:

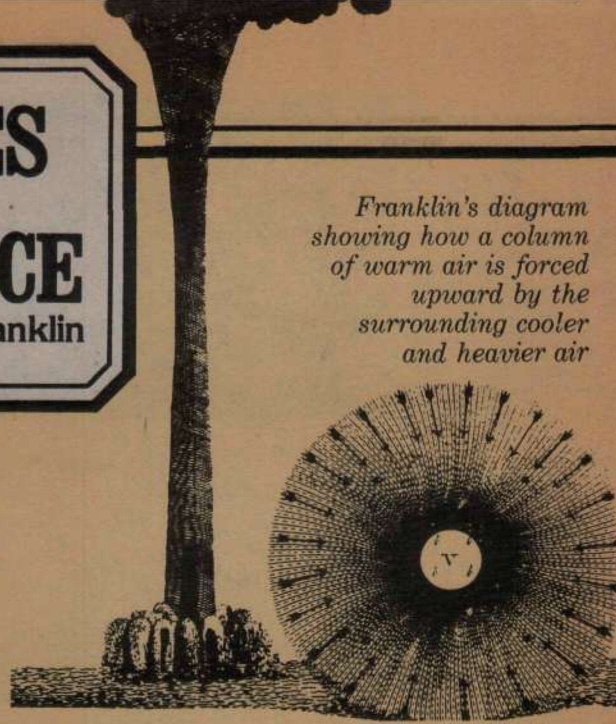
Moon	Orbital radius (A.U.)	Period (Earth year)
Io	4.219	1.529
Europa	6.712	3.068
Ganymede	10.71	6.182
Callisto	18.83	14.42

What is the value of Kepler's ratio here? Can you think of a reason for such an invariant ratio?

Turn to page 24 to find the answers to the puzzles in the last issue.

TALES OF SCIENCE

Benjamin Franklin
Part I



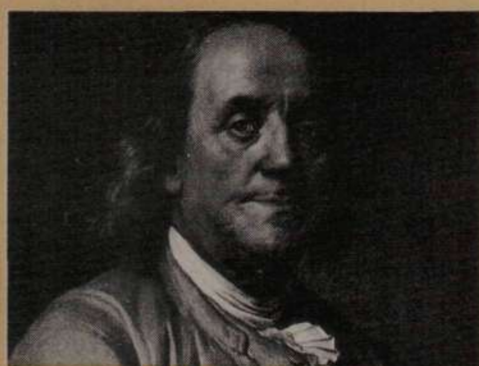
Franklin's diagram showing how a column of warm air is forced upward by the surrounding cooler and heavier air

Benjamin Franklin, a founding father of the American republic and a hero of the American Revolution, was one of the most advanced thinkers and scientists of his day. In fact, his contributions to the science of electricity are still useful.

From his youth, Franklin was intrigued by what was then called Natural Philosophy, so much so that he formed a scientific society when he was a young man. The Junto held discussions on scientific and philosophical topics, built up a scientific library, and collected scientific apparatus, which the members used to perform experiments. Eventually the Junto became the American Philosophical Society, the first scientific association in this country.

Franklin retired as a printer in his early forties to devote his time to science and public service. During 1747 through 1749, he concentrated on electricity and laid the foundations of the modern science of electromagnetism. For many years his book *Experiments and Observations on Electricity* was the standard textbook.

Franklin's discoveries were not due to trial and error; his ability to turn scattered knowledge and physical observations into a science were based on the way he looked at the world. Since Franklin knew that everything in the world is coherent, that is, is organized with an underlying unity, he knew that man's reason is capable of understanding and shaping the universe. His method was to make hypotheses, to imagine how something must work, and then to compare this with the evidence from experiments in order to improve the original hypotheses.



Franklin's hypotheses were not always correct, but his scientific method was.

A real scientist must have understanding of how the human mind works, in order to make better and better hypotheses. This method is well demonstrated in Franklin's book of electrical experiments. One example is a letter Franklin wrote on "Observations and Suppositions, towards forming a new Hypothesis, for explaining the several Phaenomena of Thunder-Gusts." Franklin knew that lightning was electrical, just like the "electrical fire" he could produce in his laboratory.

Franklin asked how it could be that so much electrical fire could be stored in clouds and appear as lightning. He also asked how water vapor could form into raindrops and fall to Earth. The answers Franklin arrives at, his hypotheses, are not completely correct in the light of modern knowledge. However, the important thing is that the method he used to develop these hypotheses *is* correct.

Franklin's unifying conception in explaining thunderstorms is the role the electrical fire plays, both in the formation of clouds and their subsequent interactions. First, Franklin points out the basic electrical phenomena that come into play:

- *Non-electric bodies, that have electric fire thrown into them, will retain it till other non-electrics, that have less approach;*

and then it is communicated by a snap, and becomes equally divided.

- *Electrical fire loves water, is strongly attracted by it, and they can subsist [exist] together.*
- *Air is an electric* per se *[in itself], and when dry will not conduct the electrical fire. . . .*
- *Water being electrified, the vapours arising from it will be equally electrified. . . . Every particle of matter electrified is repelled by every other particle equally electrified.*

Franklin then proposes that seawater, because of its salt content, is more easily electrified than fresh water. He concludes that:

- *Hence clouds formed by vapours raised from fresh waters within land . . . more speedily and easily deposite their water, having but little electrical fire to repel and keep the particles separate. So that the greatest part of the water raised from the land, is let fall on the land again; and winds blowing from the land to the sea are dry. . . .*
- *But clouds formed by vapours raised from the sea, having both fires, and particularly a great quantity of the electrical, support their water strongly, raise it high, and being moved by winds, may bring it over the middle of the broadest continent from the middle of the widest ocean. . . .*
- *If they are driven by winds against mountains, those mountains being less electrified attract them, and on contact take away their electrical fire (and being cold, the common fire also;) hence the particles close toward the mountains and toward each other. . . . If [the air is] much loaded [with water vapour], the electrical fire is at once taken from the whole cloud; and, in leaving it, flashes brightly and cracks loudly; the particles instantly coalescing [uniting] for want of that fire, and falling in heavy shower. . . .*
- *If a country be plain, having no mountains to intercept the electrified clouds, yet it is not without means to make them deposite their water. For if an electrified cloud coming from the sea, meets in the air a cloud raised from the land, and therefore not electrified; the first will flash its fire into the latter, and thereby both clouds shall be made suddenly to deposite water. . . . The concussion or jerk given to the air, contributes also to shake down the water, not only from these two clouds, but from others near them. Hence the sudden fall of rain immediately after flashes of lightning.*

This exciting hypothesis is just a sample of the riches there are in Franklin's book, which can be found in local libraries. The book shows a truly great mind working out a plausible explanation for one of the most awe-inspiring displays in nature. Undaunted by the scantiness of the knowledge he had at hand, Franklin applied it in an attempt to bring the fury of the storm under the control of human reason.

(The next Tale of Science will be on Franklin's hypothesis about the workings of the Leyden jar.)

Today scientists are on the threshold of controlling storms. Here at the University of Chicago scientist Theodore Fujita demonstrates his tornado machine, which simulates the motion of a cloud that creates a tornado's funnel.

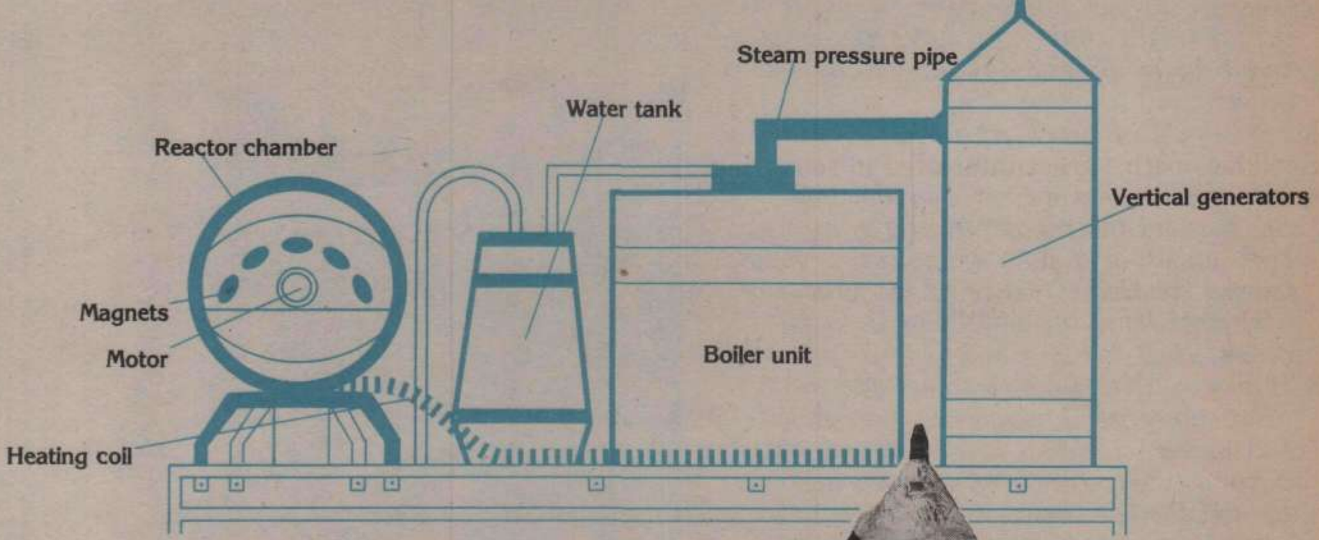
Building a model tokamak

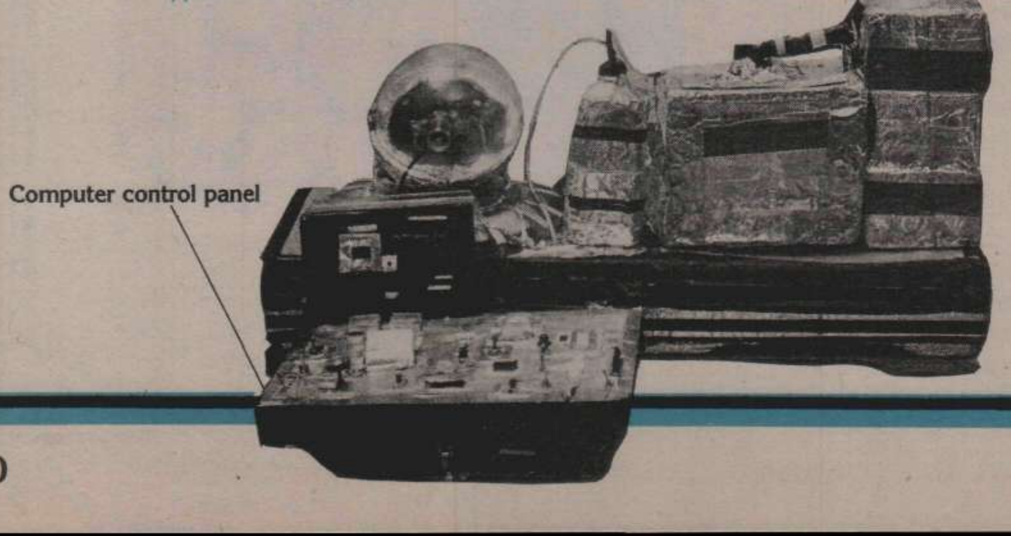
"How can I build a model fusion reactor?" is a frequent question from our readers. This issue's Experiment section describes how two boys built a simulated tokamak and used it to test out many basic hypotheses.

Michael Masterov and Yaroslav Shoikhet first learned about tokamaks and fusion power in December 1980, when their seventh-grade science teacher at New York City Intermediate School 187, Mr. Herb Friedman, taught a class on fusion energy based on the cover story in the premier issue of *The Young Scientist.* They were intrigued by the idea that man could create a source of unlimited, clean energy using seawater as a fuel and duplicating the process that goes on in the Sun and the stars to produce light and energy.

After reading more about fusion research and the problems scientists are near solving to develop power-producing reactors, Michael and Yaroslav decided to build a model fusion device. Their idea was not just to make a stationary model reactor, but to make a working model that would simulate (imitate) the operations of a tokamak fusion reactor and solve the same kinds of problems that fusion scientists are

A schematic and photograph of Michael and Yaroslav's tokamak project.





When the heat in the reactor builds up to 450 degrees, the computer control system turns on the heating coil. The coil heats the water in the boiler system to steam, and the steam powers a generator to make electricity.

solving. They set out to heat simulated fusion fuel in a reactor system that would achieve **breakeven**—producing more energy than the energy it takes to get the fusion reaction going. The energy is produced when two atoms of hydrogen combine, or fuse, to form a single atom, releasing energy in the process.

Since December, Michael and Yaroslav have spent all their spare time building a simulated tokamak power plant, constructing a computer to monitor the whole system, and modifying the components as they got new ideas to make the model perform better.

Their latest model is a 3-foot, 2-inch tokamak power plant with a dome-shaped reactor chamber, a computer control panel with 1,050 switches and probes connected to the various plant operations, and a heating coil connected to a boiler and vertical generator system. It is actually two projects in one: a simulated fusion reactor that produces heat and a steam power generating plant. Like a real power reactor, the heat produced by their reactor turns water into steam, which in turn drives a turbine to produce electricity. Earlier versions of the model were 6 feet long, but they found that the shorter system was more efficient.

The project is impressive. First, Michael and Yaroslav have mastered the principles of fusion energy and easily explain to anyone how fusion can solve the world's energy problem. In the introduction to their experimental notebook they write: "Throughout history, the human race developed different fuels for different reactions for the same purpose: energy emission. But throughout history the energy output was inefficient compared to the Sun. Not anymore, for fusion is at the doorstep. . . .

"Fusion, being the power source of the stars is not new at all, but it is new to our planet Earth and the human race. Fusion is better than anything else we have for many reasons. . . ."

Second, Michael and Yaroslav used their

Meet the experimenters

Michael Masterov and Yaroslav Shoikhet, both 13, got interested in science when they were very young. Michael became fascinated with a microscope he saw in a shop window, while Yaroslav started off his scientific interest when his father took the back cover off a radio. "I thought before that that there was a little person inside," he said.

Both boys emigrated to America from the Soviet Union with their families when they were 8 years old, and they met for the first time at school in science class. As a team they work well together; Michael tends to be more theoretical, while Yaroslav is the electronics expert.

So far, their tokamak project has won first prizes in five competitions—the school science fair at Intermediate School 187; the school district science fair; the Manhattan borough science fair; a metropolitan New York fair called SEER (Student Exposition on Energy Resources) sponsored by the National Energy Foundation; and, most prestigious, the nationwide SEER science competition June 3.

Among their prizes from the SEER competition is a shared $1,000 scholarship and a three-day trip to Cape Canaveral Space Center, the St. Lucie nuclear power plant, and Disneyworld.

Yaroslav (left) and Michael during a visit to the tokamak experiments at the Princeton Plasma Physics Laboratory in New Jersey.

To get more information about entering the SEER competition, write the National Energy Foundation, 366 Madison Avenue, New York, N.Y. 10017.

knowledge of fusion and simpler physical processes to hypothesize and then test out the major components of a working model of a steam-producing power plant. That meant, as they put it, "rigorous experimentation."

"Every one of the units was redone many a time," their notebook says. "This entire system, part by part, was built and put together with one principle in mind: No such thing is good enough, every single thing must be the best possible. . . ."

"It isn't enough that we build a model of the tokamak," they wrote, "we also modified it. It wasn't easy. Most of the time was spent not on the finished pieces anyone ever saw but on the ones with the mistakes we had to learn to do things right from. . . . Even when we had a good working solution we didn't stop there. And several times we found our previous solution was obsolete. There were many other times when the improvements alone changed some things beyond recognition. And then it was back to the experimentation and the scientific method."

How much did all this building and rebuilding cost? Michael and Yaroslav estimate that they spent a total of $100, scavenging many parts from the trash—a toaster, hairdryer, iron, Christmas lights, for example—and buying others at New York City's famous Canal Street industrial junk shops.

The experiment

In a real tokamak experiment, strong magnetic fields are used to form a "bottle," confining the hydrogen fusion fuel to keep it in the center of the reactor chamber while it is being heated to temperatures of millions of degrees.

To simulate this magnetic confinement, Michael and Yaroslav first embedded a 110-volt motor (from a hair dryer) inside a plastic sphere (their modified tokamak machine) with plaster of paris. Then they placed five magnets on the inside wall of the sphere. Because the motor is an electromagnet, it reverses polarity as the current alternates. Therefore, when they turned the motor on, they could measure the magnetic force caused by the alternating attraction and repulsion of the motor's electromagnet. They did this by balancing this fluctuating magnetic field against the steady magnetic field of the permanent magnet.

Yaroslav working on the tokamak model display. The inset shows the sparking device in the tokamak chamber.

Michael and Yaroslav note that it was not possible for them to create a strong field like that in a real reactor, but they did determine how to control the weak field they created by moving the magnets around and measuring the vibrations.

The next step was to heat their "fusion fuel." To ignite a fusion reaction in a tokamak requires heating the hydrogen fuel to at least 44 million degrees Celsius in an experimental reactor and about 100 million degrees in a working commercial reactor. (So far, experimental tokamaks have achieved temperatures of 82 million degrees.) At these temperatures, the hydrogen gas is a **plasma**—a gas that is electrically charged.

Michael and Yaroslav used two heating methods in their model, simulated lasers and simulated tesla sparking. They got the laser idea reading about laser fusion, although lasers are not used to heat the fuel in real tokamaks. The tesla idea came from an article Yaroslav read in *Radio Electronics* magazine about experiments in the Soviet Union using a huge spark—called ball lightning—to ignite a fusion reaction in the laboratory.

In order to approximate a laser, which makes light coherent, they focused seven small lights (Christmas lights) through crystals (from a chandelier) to concentrate the watts of power in one place. To simulate tesla heating, they used the motor shaft in the sphere as a connection with a contact plate to rub against, creating a shower of sparks. Later they modified this, interweaving the wires to make a cable and thus bigger sparks.

The flame from the the sparks was their simulated fusion fuel plasma.

The power used to start the heating in their reactor is 5 watts from the simulated lasers and 2.5 watts from the sparking device per minute. When the heat builds up in the reactor chamber of their tokamak to 450 degrees, a temperature probe connected to the computer control system turns on the heating coil. The probe is a round disk with two extended plates that screw on to the sphere.

Later they added a fan to the sphere to prevent a fire from starting from the sparks, and metal plates to ground the extra sparks. These plates reemitted the energy in heat, raising the temperature in the heating coil from 440 degrees to 450 degrees.

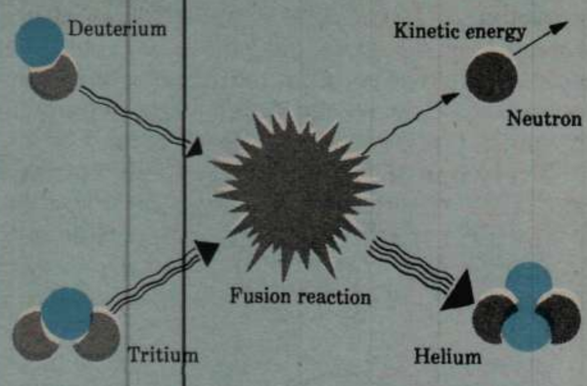
Generating electricity

To convert the heat created in the reactor into electricity, Michael and Yaroslav made a model of a conventional power plant where heat is used to make steam, which turns a turbine to create electricity. The insulated heating coil in their tokamak runs to a boiler system where it heats water to steam and the steam powers a generator. Much experimental work went into perfecting an efficient boiler system and generator.

Michael and Yaroslav are particularly proud of their generator design—a vertical stacked generator with 11 parts. The turbine in the bottom generator produces 20 watts; the other 10 generators produce 10 watts each.

Conventional generators are assembled horizontally. Their hypothesis was that steam rises because its specific gravity is lighter than air and, therefore, if the generators were stacked vertically on top of each other they would be more efficient. They tested their hypothesis and learned that the generators put out 5 watts more power when they were vertical than when they were horizontal with the same steam input.

Through more experimentation, Michael and Yaroslav decreased wattage consumption by the boiler apparatus by using a siphon instead of a 10-watt pump to pump the water. They also modified the boiler to keep the water level in check, saving 3 minutes in heating time, and they added a secondary coil around the boiler to stop the heat from dissipating.



How Fusion Works

In nuclear fusion two different atoms of hydrogen fusion fuel are compressed (squeezed together) and heated to very high temperatures in the fusion plasma. The neutrons and protons mix together and turn into an atom of helium plus one neutron. This leftover neutron leaves the fusion reaction at a tremendous speed, providing most of the energy released in the fusion process.

By putting the entire system on a perfectly balanced "evening" table (which took three days), Michael and Yaroslav were able to save 5 watts from the total amount of power required to run the system. Altogether, it required 180 watts of power to run their tokamak system, and the tokamak power plant simulation produced 175 watts of electricity. This is just 5 watts short of "breakeven." They wired the 175 watts of electricity output from the generators to power the various accessory units of the apparatus—the water pump (1.5 watts), the computer circuit (30.0 watts), and the cooling fan (13.0 watts), for example.

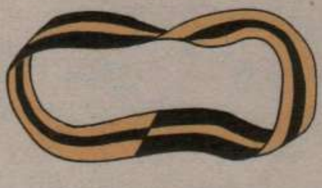
Is the fusion experiment finished? "Of course not," said Michael and Yaroslav. The boys are discussing a continuation of the project, perhaps going on to build a bigger reactor with a simulated direct energy conversion system using magnetohydrodynamics (MHD) that would eliminate the need for a steam turbine.

—by Marjorie Mazel Hecht

Answers

The ant race

The puzzle was an ant race: two ants moved at the same speed around two paper loops of the same length. But one ant got back to the starting point twice as fast as the other. The solution lies in the design of the loops. One was a **Moebius strip!** To see what a Moebius strip looks like, take a strip of paper, give it a **half-twist,** and then use tape to make it into a loop:



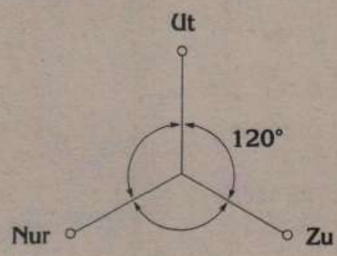
Now, if you trace a path down the center of this loop, you'll find that after one trip around, you end up at the original position, but on what seems to be the other side of the paper, just like the puzzled ant who lost the race. Keep going around, and you'll arrive back at the starting point. This is what happened to the ant who lost the race.

Actually, there is only one side to the Moebius strip, not two as in an ordinary loop. The Moebius strip is the simplest example of a one-sided surface. Another of its properties is that you can cut it in half and it will remain a loop.

Trace a line down the length of the strip before making it into a Moebius loop. Now cut down the length of the line. Do you think the same thing would happen if you put a full twist in the paper strip?

Roadbuilding in Flom

The problem was to find the shortest road system connecting the three cities of Nur, Zu, and Ut in the plain of Flom. The answer looks like this:

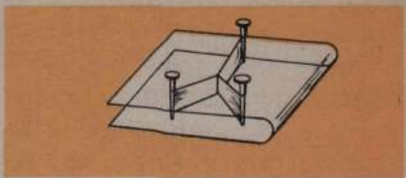


The three lines meet at the point where they form three equal angles of 120 degrees. This is called Steiner's problem after the German mathematician who found this solution. (A full geometric proof can be found in the book **What Is Mathematics,** by Richard Courant and Herbert Robbins, Oxford University Press paperback, 1968.)

One way to find the solution is to use soap bubbles! The soap film will form this solution for you. This is what is called a "minimal surface problem." Soap films always form in such a way as to use the least possible surface to cover a given space.

Mix a solution of soap (not detergent) and water, and add a few drops of glycerin, which you can buy at a drug store, to add stability to the soap films. Now get a sheet of bendable plastic and bend it into the shape of a U. The idea is to fix two planes a few inches apart from each other. (Any thin, flexible plastic will work. I used .060 gauge, low-density polyethylene obtained from a plastic supply store.)

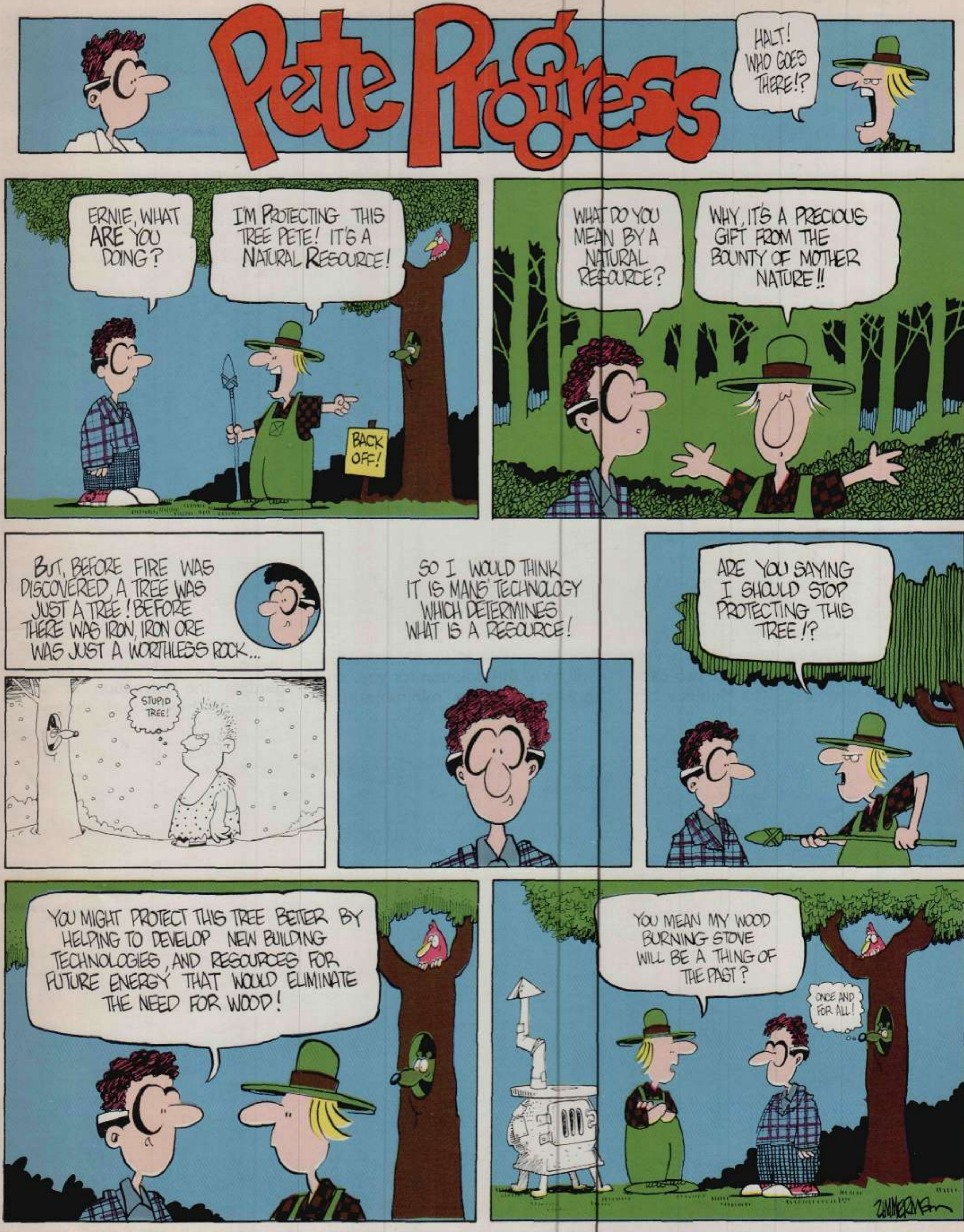
To make each of the three points representing Nur, Zu, and Ut, grasp a thin nail with pliers and heat it slightly. Then puncture the plastic by sticking the nail all the way through both sides of the U. The bubbles will intersect in 120-degree angles.



You can also arrange four and five nails to find the shortest road system connecting these sites.

Although scientists know that the soap film arranges itself in such a way as to form the minimal surface solution to the problem, they don't know why. The astronomer and mathematician Johannes Kepler asked a similar question regarding the formation of snowflakes in hexagonal shapes. A complete answer has not yet been found. Write to me if you think you know why.

Answer to Erik Norris's puzzle on page 5: a 5-pointed star


Pete Progress
HALT! WHO GOES THERE!?
ERNIE, WHAT ARE YOU DOING?
I'M PROTECTING THIS TREE PETE! IT'S A NATURAL RESOURCE!
BACK OFF!
WHAT DO YOU MEAN BY A NATURAL RESOURCE?
WHY, IT'S A PRECIOUS GIFT FROM THE BOUNTY OF MOTHER NATURE!!
BUT, BEFORE FIRE WAS DISCOVERED, A TREE WAS JUST A TREE! BEFORE THERE WAS IRON, IRON ORE WAS JUST A WORTHLESS ROCK...
STUPID TREE!
SO I WOULD THINK IT IS MANS' TECHNOLOGY WHICH DETERMINES WHAT IS A RESOURCE!
ARE YOU SAYING I SHOULD STOP PROTECTING THIS TREE!?
YOU MIGHT PROTECT THIS TREE BETTER BY HELPING TO DEVELOP NEW BUILDING TECHNOLOGIES, AND RESOURCES FOR FUTURE ENERGY THAT WOULD ELIMINATE THE NEED FOR WOOD!
YOU MEAN MY WOOD BURNING STOVE WILL BE A THING OF THE PAST?
ONCE AND FOR ALL!
ZIMMERMAN