The Young Scientist

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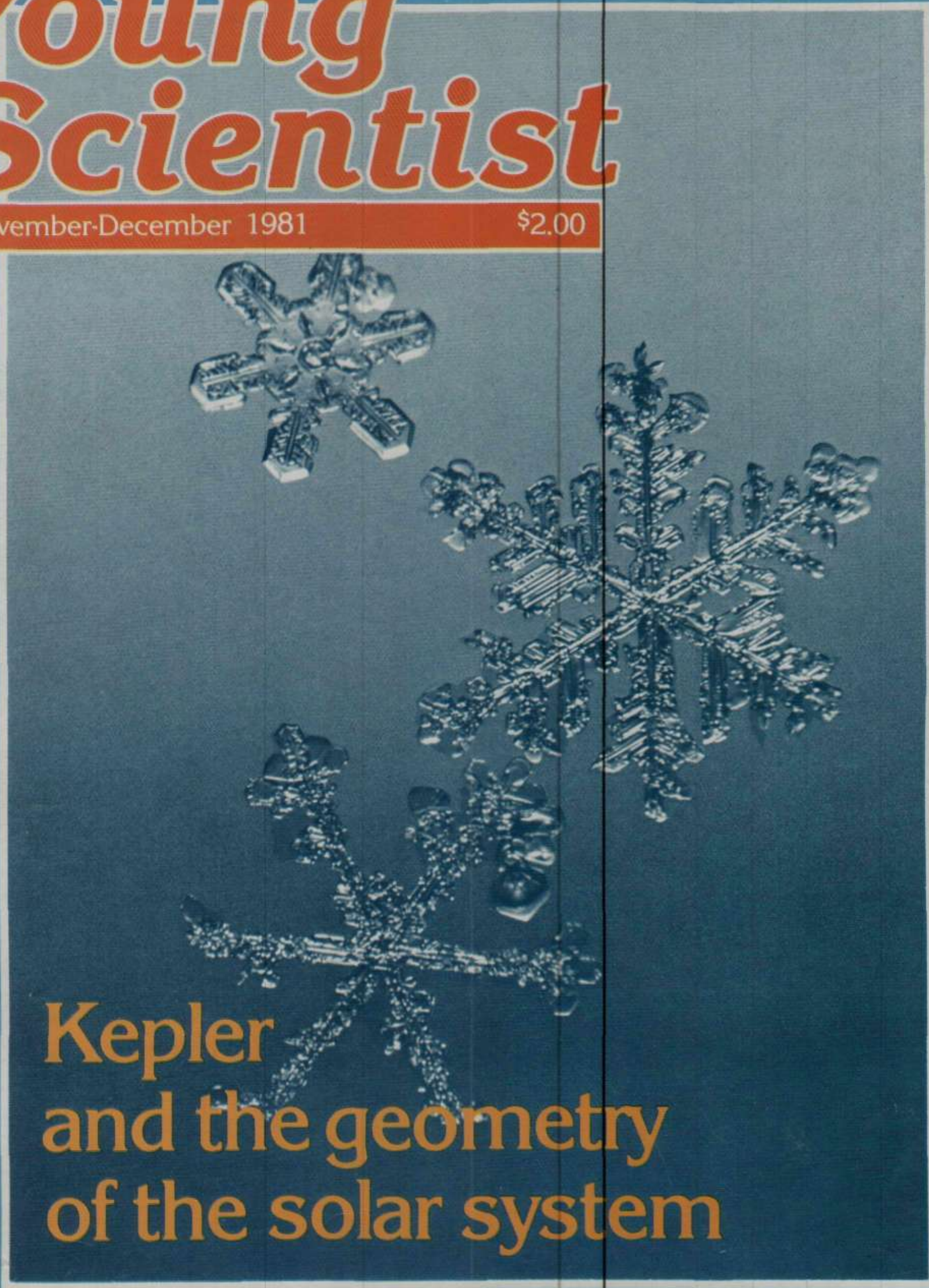


Kepler and the geometry of the solar system

From the editor's desk

The geometric laws of the universe

Johannes Kepler, the 17th-century astronomer, said that "God was certainly a geometer." The solar system, which Kepler was the first to explain scientifically, is a beautiful example of such geometry.

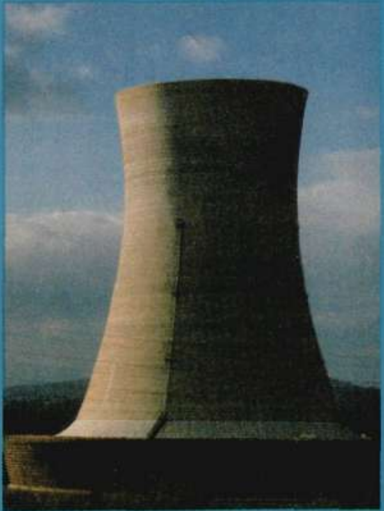
As our feature story on Kepler discusses, Kepler showed that this geometry is not merely a pleasing form or shape; it is the **cause** of things. Like all scientists who follow the geometric method of Plato, the Greek philosopher-scientist who lived 2,000 years before him, Kepler knew that the laws of the universe are geometric.

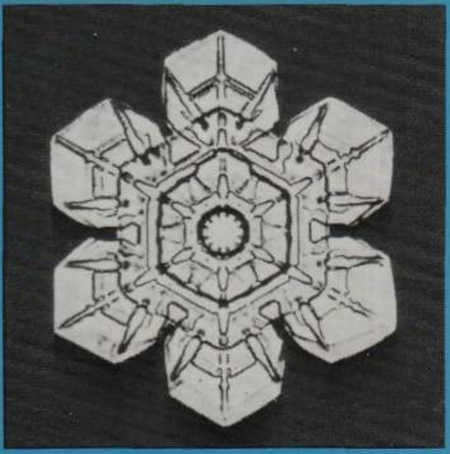
Kepler's study of the structure of matter in the solar system used the same geometric method as his study of the causes of things on the earth. Today's scientists are using this method to develop the power of the atom so that we can cheapen the cost of energy and make industry and transportation more efficient, as our feature story on nuclear power explains.

In Kepler's day, however, it was still a daring statement to claim that the laws of the heavenly bodies were the same as the laws governing things on the earth. Kepler went even further and said that the laws governing the microscopic world of snowflakes, water particles, and even the smallest pieces of matter were the same as the laws governing the vast solar system.

Kepler wrote a short essay called *The Six-Cornered Snowflake* explaining these ideas. This little book is undoubtedly one of the most profound pieces of scientific research ever published. It not only describes **how** the snowflake forms its six-cornered crystals, but delves into the reasons **why** water should form the delicate filigrees of ice.

This is the real question that scientists must answer—why? It is not enough to settle for the easy answers that just describe the world, or to answer only the questions of how things work. Scientists must know how to explain the world and to answer the question of why things are the way they are.





Kepler said that the same geometric laws govern the heavens and the smallest pieces of matter. Top: Saturn photographed by Voyager 1; left: a nuclear cooling tower; above: a snowflake taken by a photographic microscope.

Steven Bardwell

Dr. Steven Bardwell

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The Young Scientist

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Young scientists visit the Triga nuclear research reactor at Columbia University in New York.

About the cover

These photographs of real snowflakes were taken by Edward LaChappelle and appear in his book, *A Field Guide to Snow Crystals*, published by the University of Washington Press in Seattle in 1969. The cover design is by Virginia Baier.

news...

Voyager 2 results challenge scientists

Results from the Voyager 2 mission to Saturn in August have challenged existing theories of the solar system and suggest a new idea about the laws of the universe.

The latest data include exciting and unexpected results about Saturn's surprisingly complex ring system. Not only are there many thousands more rings than the traditional theories predict, but these rings are dynamic—changing—yet beautifully ordered. The conventional Newtonian gravitational laws cannot explain this ring structure.

Before the first Voyager satellite took photographs of Saturn from a distance of 78,000 miles in November 1980, most astronomers thought that there were only two rings around Saturn, separated by a gap called the Cassini division. But after the relatively close-up observation of Saturn by Pioneer 11, astronomers revised this estimate. Their general opinion was that there were perhaps 10 Saturnian rings, and a few daring scientists even suggested that there were as many as 50 rings.

These scientists were shocked when the photos taken by Voyager 1 showed that the rings of Saturn were composed of more than 1,000 small rings. They then predicted that there were no rings smaller than the ones already seen and that the gaps visible between the rings were caused by what scientists called the **scouring action** of larger particles in the rings, which cleaned out the gaps. These larger particles were called **moonlets.**

Saturn's moon Hyperion, photographed by Voyager 2 at 310,000 miles. About 220 miles by 130 miles, the hamburger-shaped moon is pock-marked with many meteorite impact craters.

Scientists were also puzzled that the large Cassini division predicted by the traditional theory was found to be only slightly less dense than the rest of the rings. It was filled with a different size particle that looked dark when lit from the front by the Sun, but was quite bright (and equally complex) when the Sun was behind them.

Based on the information from Voyager 1, NASA planned much of the data-gathering program for Voyager 2 to test the theories about the moonlets causing the gaps in the ring structure. Voyager 2 conducted a detailed scan of the ring plane to photograph the expected moonlets.

The Voyager 2 photographs of Saturn then created even more surprise. Not only were there no such moonlets, but there were many new puzzling details of the ring structure visible in the Voyager 2 photographs. As one of the Saturn imaging team scientists said, "The more we have seen of the rings, the less we know about them."

Saturn's 100,000 rings

The most important new finding was provided by Voyager 2's sensitive photopolarimeter, which measured the intensity of light from the star Delta Scorpii as the rings swept in between the satellite and the star. It was able to detect structures as small as 100 meters (300 yards). The 700,000 data points generated by Voyager 2 show new rings down to 100 meters wide. That is, there are rings on as fine a scale as the satellite could detect. There are at least 100,000 distinct gaps in the rings.

What accounts for this structure? Several scientists, including researchers at the Fusion Energy Foundation, think that this ring structure is caused by a breakdown of the standard gravitational equations by Isaac Newton that are used in calculating celestial mechanics. This breakdown is similar to that in the famous **three-body problem.** Scientists know that in the so-called three body problem, when more than two bodies of matter are interacting via gravitational forces, it sets up a complex and unstable gravitational field that can exhibit very strange behavior.

This idea was investigated by two researchers at Princeton University, J. Avron and B. Simon, who calculated the gravitational field around a planet like Saturn, its many moons, Jupiter, and the Sun.

The question of causality

The Princeton scientists predicted that the rings of Saturn would be infinitely divided into thinner and thinner rings, until the particle size is reached. Indeed, one NASA researcher said that now he expects to see rings "down to the individual particle."

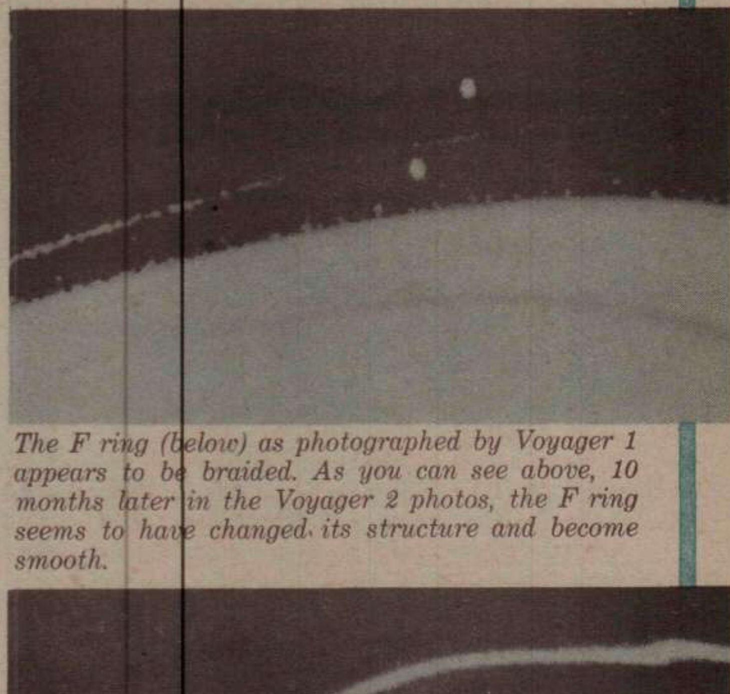
The results of the Princeton work show that the gravitational field in which Saturn's rings exist is **indeterminate** or mathematically unstable. This means that a small change in the way the rings appear at a given moment would, if the Newtonian equations were correct, result in a totally different appearance later on.

Like the three-body problem itself, the solutions of Newton's equations for this situation predict cause and effect to break down. But we know that neither the universe nor Saturn is indeterminate or without cause. The rings are not only real, but stable, lawful, and long-lived phenomena. If the mathematical predictions of Newton's equations were true, we would expect to see a violently disordered system. Since Saturn is obviously ordered, something is wrong with these equations.

The problem is not that the particles in the rings do not obey Newton's gravitational equations. It is rather that the causality of the rings as a whole is determined on a different level from that of the individual particles. What scientists call **collective interactions** in the rings as a whole have created a new structure, with new laws of cause and effect. These laws cannot be explained mathematically by looking at the millions of particles that make up the ring system. Although these new laws have yet to be discovered, Kepler's method applied to the new Voyager results on Saturn may point to a solution.

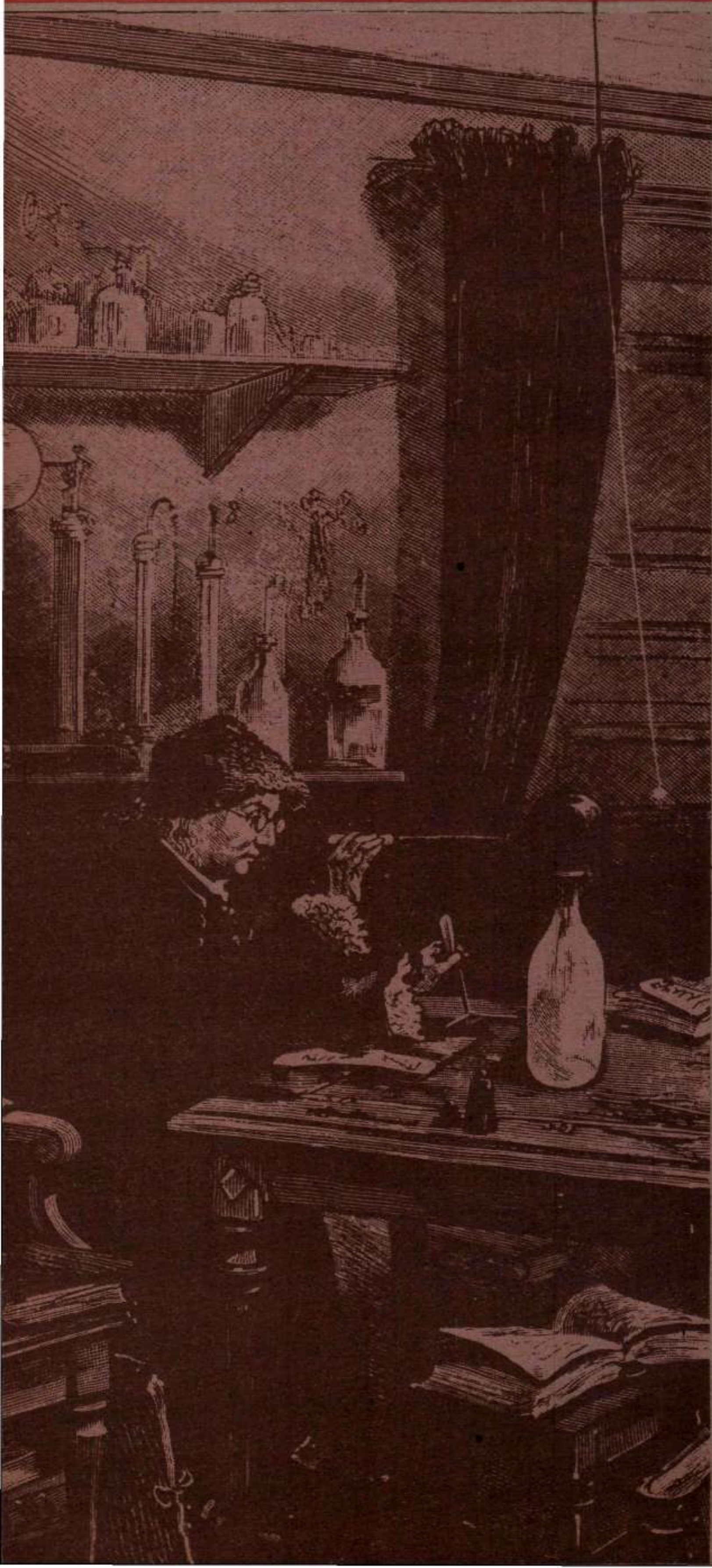
by Dr. Steven Bardwell

Several thousand of Saturn's rings (above) as photographed in Voyager 2's closest approach to the planet Aug. 25. The narrowest bands here are about 10 miles wide. Below: Saturn's F ring with two moons, photographed by Voyager 2.



The F ring (below) as photographed by Voyager 1 appears to be braided. As you can see above, 10 months later in the Voyager 2 photos, the F ring seems to have changed its structure and become smooth.

TALES OF SCIENCE



Benjamin Franklin did his most important scientific work in 1746 and 1747, when he was about forty years old. At that time he carried out a thorough investigation of the Leyden jar, a new electrical device that had been invented in Leyden, Holland, by Pieter van Musschenbroek, a Dutch professor. The experiments Franklin did to develop the theory of how the Leyden jar works cleared away many basic misconceptions and unclarity in the electrical theory of his time. Even today, more than 200 years after Franklin's work, the concepts and terminology that he developed have become the chief elements of modern electrical theory.

The jar, in fact, is the first electrical **capacitor,** or condenser. Today, almost every sophisticated electrical apparatus has many capacitors in its circuitry, all of which operate on the same basic principle as the Leyden jar, storing and releasing electrical charge. In an electrical circuit, a capacitor stores and releases charge at rates determined by the design of the circuit.

Musschenbroek had discovered the Leyden jar while doing another experiment. He set up his materials in such a way and charged them so effectively that he gave himself a huge electric shock. Realizing that he had found a new phenomenon, he redesigned the elements of his experiment into what we now call the Leyden jar.

(The Experiments section in the next issue will show how to build and test a Leyden jar. As preparation for the Leyden jar, this issue's Experiments section, page 15, explains how to build an electroscope, which detects an electric charge.)

Franklin's discoveries

Franklin spoke in terms of positive electrical atmosphere, or what we today call **positive charge**. He developed the concept of positive and negative charge as being a surplus or deficit of an electrical fluid that was present in everything. He also thought that something became charged either by adding or subtracting charge from it, not, as was previously thought, by rubbing wool, for example, on glass to create the charge. Franklin's hypothesis has survived to this day as the explanation for electrical charge.

Franklin and his Leyden jar.

Benjamin Franklin—Part II

Some of the things Franklin discovered about what he called "Musschenbroek's wonderful bottle" can easily be demonstrated using the simple experiments that he devised. The quotations here are from Franklin's book *Experiments and Observations on Electricity,* in which you can find these and many more experiments with the Leyden jar.

First, Franklin showed that **the inside and outside of the Leyden jar are oppositely charged:**

> *Place an electrised phial [Leyden jar] on wax; a small cork-ball suspended by a dry silk thread held in your hand, and brought near to the wire, will first be attracted, and then repelled: when in this state of repellency, sink your hand, that the ball may be brought towards the bottom of the bottle; it will be there instantly and strongly attracted, 'till it has parted with its fire.*
>
> *If the bottle had a* positive *electrical atmosphere, as well as the wire, an electrified cork would be repelled from one as well as from the other.*

With a slightly more complicated experiment, Franklin was able to show that **the glass itself carries the charge in the Leyden jar,** not the water or the metals. As he put it:

> *The whole force of the bottle, and power of giving a shock, is in the GLASS ITSELF; the non-electrics [conductors] in contact with the two surfaces, serving only to* give *and* receive *to and from the several parts of the glass; that is, to give on the one side, and take away from the other. Purposing to analyse the electrified bottle, in order to find wherein its strength lay, we placed it on glass, and drew out the cork and wire which for that purpose had been loosely put in. Then taking the bottle in one hand, and bringing a finger of the other near its mouth, a strong spark came from the water, and the shock was as violent as if the wire had remained in it, which shewed that the force did not lie in the wire. Then to find if it resided in the water, being crouded [crowded] into and condensed in it, as confin'd by the glass, which had been our former opinion, we electrified the bottle again, and placing it on glass, drew out the wire and cork as before; then taking up the bottle, we decanted [emptied] all its water into an empty bottle, which likewise stood on glass; and taking up that other bottle, we expected, if the force resided in the water, to find a shock from it; but there was none. We judged then that it must either be lost in decanting, or remain in the first bottle. The latter we found to be true; for that bottle on trial gave the shock, though filled up as it stood with fresh unelectrified water from a tea-pot.*

Frankenstein versus progress

There were some people in Franklin's time who were frightened by his experiments and frightened by the fact that he could solve the mysteries of electricity—just as some people today are afraid of nuclear energy. In 1818, a book called *Frankenstein* appeared, written by Mary Shelley, wife of the poet Percy Bysshe Shelley. Mary Shelley's character, Dr. Frankenstein, is none other than Benjamin Franklin, with his name slightly changed and his nationality shifted to Central Europe.

The point of the Frankenstein story is to portray science as releasing an evil genie from a bottle. Using a bolt of lightning—remember that Franklin first captured lightning with his kite experiment—Mrs. Shelley's character Dr. Frankenstein animates his evil monster. Since that time, many science fiction books and movies have had the same theme, that scientific development leads to evil and it's better to keep things the way they are.

But most people in Franklin's time looked to him as a great man whose scientific discoveries and political ideas had helped create the new American republic and change the world for the better.

by Dr. John Schoonover

Nuclear power:

by Jon Gilbertson

Jon Gilbertson is a nuclear engineer with degrees in civil engineering and nuclear engineering, specializing in nuclear safety design. He has 19 years' experience working as an engineer and consultant, and he has written many articles and lectured widely on nuclear power.

This article presents the scientific facts of nuclear power and how it works. In future articles, Mr. Gilbertson will discuss more about the history and politics of nuclear energy.

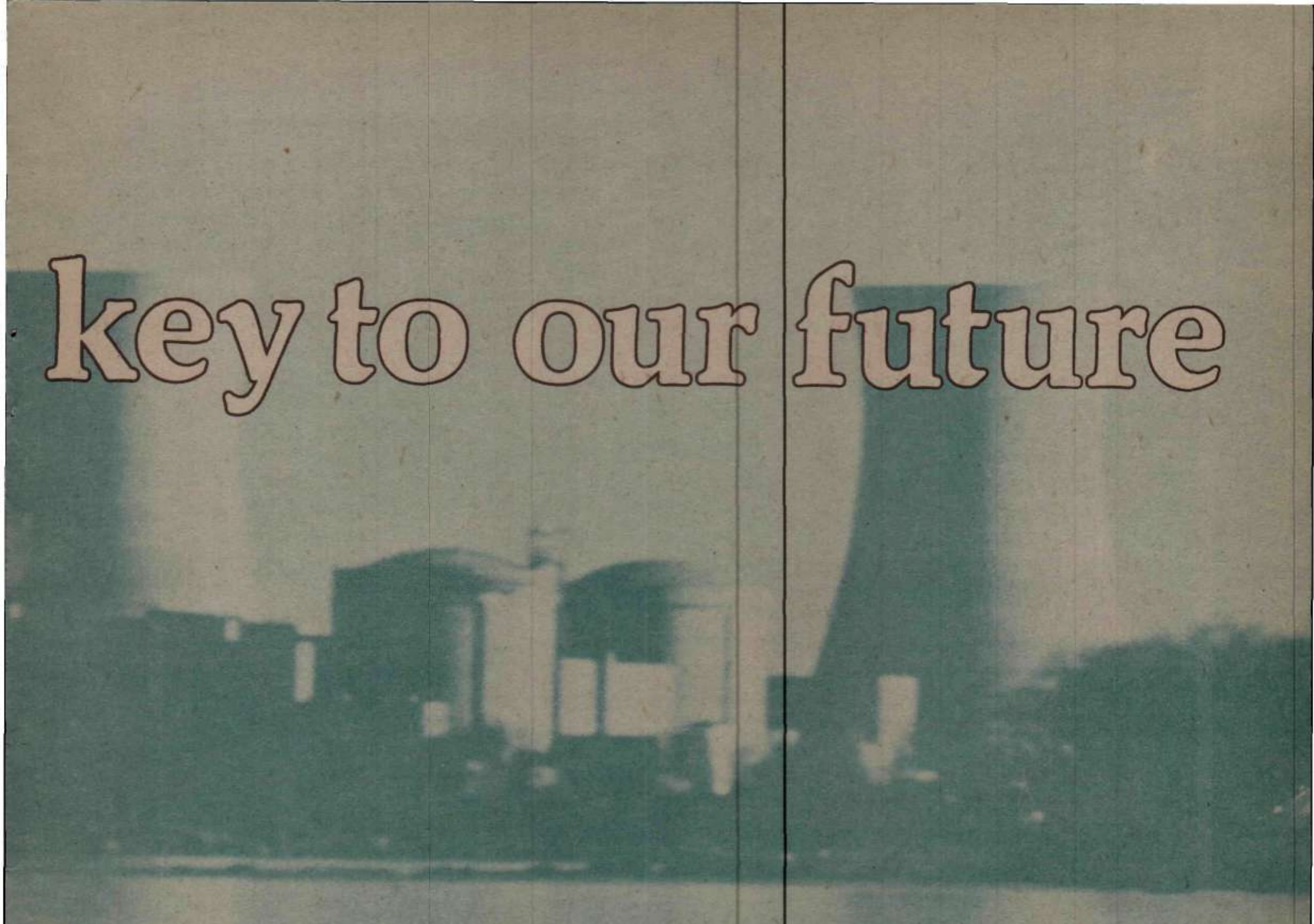
Panorama of Three Mile Island units 1 and 2 in Harrisburg, Pennsylvania. Inset: author Jon Gilbertson.

In the 1950s, when I was growing up and going to school, no one questioned the fact that nuclear energy was man's greatest discovery. We knew that mankind's development throughout history had depended on man's invention of new technologies and new resources to solve new problems as they came up. To us, developing the ability to use the power of the atom for the benefit of all mankind was the challenge facing our generation.

Because it was discovered in 1938, just before World War II, the first use for nuclear power had been for nuclear weapons—the atomic bomb. But after the war, scientists and engineers began putting together ideas and designs for hundreds of ways that nuclear energy could be put to work for the betterment of humanity. There were plans for everything from nuclear-powered trains, airplanes, rockets, and ships to electricity-generating plants, heating for industrial processes, power for heating and cooling entire cities, and power for making fresh water out of seawater.

Recognizing the importance of developing these projects for all mankind, President Eisenhower and his advisers fought hard to make

key to our future



this an international project. They succeeded, and in December 1953, Eisenhower gave his famous "Atoms for Peace" speech at the United Nations in New York City. The President stated why nuclear power must be developed and made available to the world:

"The United States knows that peaceful power from atomic energy is no dream of the future. That capability, already proved, is here—now—today. Who can doubt, if the entire body of the world's scientists and engineers had adequate amounts of fissionable material with which to test and develop their ideas, that this capability would rapidly be transformed into universal, efficient, and economic usage?"

The "Atoms for Peace" speech helped launch the development of nuclear energy programs throughout the world, including in some of the less developed nations like India and Mexico. One of the greatest needs was to educate more scientists and engineers so that research and development could be expanded. This meant providing money and scholarships to universities and students, which was done very rapidly in the United States. Nuclear physics and nuclear engineering programs were started all over the country, including the University of Wisconsin, which I attended.

Eisenhower's international "Atoms for Peace" program proposed a plan for exchanging technical information among all nations. This was accomplished at a series of historic conferences in Geneva, Switzerland, to discuss new results and progress in nuclear research. The Geneva Conferences on the Peaceful Uses of Atomic Energy, convened in 1955, 1958, 1964, and 1971, were a vast educational program to provide the benefits of nuclear energy to the entire world. Nothing like this had ever been done before.

In 1956, the British started up the world's first commercial nuclear power reactor. A year later, in 1957, the United States started up its first nuclear power reactor, which produced electricity for the people living around Shippingport, Pennsylvania, and in 1958 the Soviet Union opened its first commercial reactor. Thus began the era of the development of peaceful uses of nuclear power. Over the next 20 years, until the mid-1970s, much of the world's scientific and technological manpower was focused on this challenge.

Uranium fission

In 1938, two scientists in Germany, Otto Hahn and Fritz Strassman, split the uranium atom, releasing a tremendous amount of energy. Scientists began to study this splitting, or **fission,** of uranium, the heaviest element. They wanted to be able to control the fission process so that when they split a uranium atom it not only would release energy, but also would cause many more uranium atoms to split in a **chain reaction** (see box, page 9). With a tiny amount of uranium fuel, scientists could then release an enormous amount of energy.

During this same time, scientists also discovered that not all uranium would fission. In fact, they found that only a tiny fraction of **natural uranium,** uranium mined in the ground, would fission. This natural uranium contained two different kinds of atoms of uranium, and only one of them would fission.

The fissionable uranium atom has a weight of 235 mass units and is called uranium-235. The other kind of uranium atom has a weight of 238 mass units and is called uranium-238. It contains 146 neutrons in its nucleus, three more than the fissionable uranium atom.

Uranium-235 is only 0.7 percent of the total amount of uranium that is found naturally in the ground. The rest of the world's natural uranium, or 99.3 percent, is uranium-238. Both kinds of uranium are mixed together to make up the fuel material that is put into a nuclear reactor. The fissioning of some atoms of this uranium-235 within the larger amount of uranium-238 is what produces the energy in a nuclear power plant.

How a reactor works

The basic layout of a nuclear power plant is not very different from a coal-fueled power plant (see Figure 1). The coal plant burns coal, thousands of tons of it, to produce heat. This heat is transferred from the hot gases of the burning coal into steel tubes that contain flowing water. The water in the tubes begins to boil, producing steam, which flows into a steam turbine. This part of the power plant is called the boiler.

The steam enters the steam turbine at high pressures and velocities, and as it hits the turbine blades, it starts them spinning. This rotates the shaft on which the blades are mounted. At the other end, the shaft is connected to the rotor of an electrical generator. The generator has a strong magnetic field, and when the rotor spins in this field, it produces electric current. So the heat from the burning of coal, a **chemical reaction,** is turned into electrical energy and sent into homes, businesses, and factories.

The nuclear fuel is made up of small, ½-inch diameter pellets of uranium, stacked on top of each other inside hollow tubes of zirconium metal. The tubes are called **fuel pins** or **fuel rods,** and there are thousands of them in a nuclear reactor. Groups of the fuel pins are arranged in **fuel bundles,** and then these fuel bundles are arranged closely together in what is called the **reactor core** (see photo, page 10).

As in the coal boiler, water is used to transfer the heat produced to a steam turbine. In one type of nuclear reactor design, the **boiling water reactor (BWR),** the reactor core is immersed in water. As the water flows past the

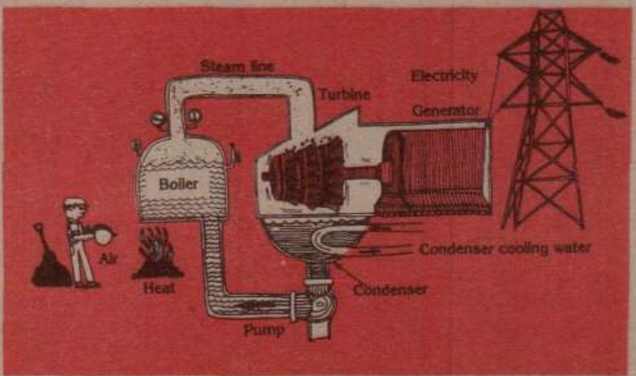


Figure 1
Fossil Fuel Power Plant
Heat produced by the chemical reaction of burning coal is used to make steam, which powers a turbine and generates electricity.

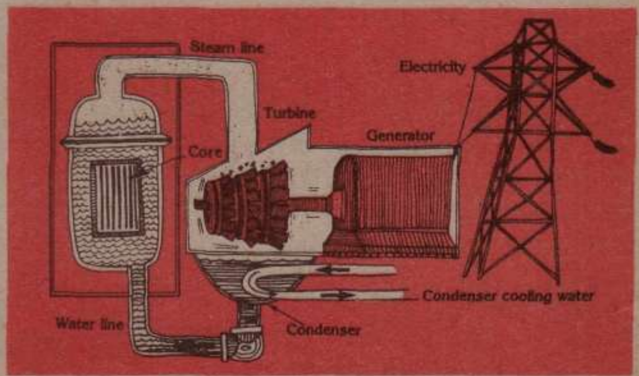


Figure 2
Nuclear Power Plant—Boiling Water Reactor
Heat produced by the nuclear reaction boils water surrounding the reactor core and produces steam, which powers a turbine and generates electricity.

How nuclear fission works

In nuclear fission, atoms of uranium, the heaviest element occurring in nature, are split apart into smaller pieces, releasing a tremendous amount of energy.

Atoms of all the elements are made up of a **nucleus,** which has smaller particles called **protons, neutrons,** and **electrons.** The protons and neutrons make up a tiny, very dense center of the atom, and the electrons are scattered around this nucleus at a great distance. The number of protons in an atom determines what kind of an element it is. Hydrogen always has 1 proton, for example. But the number of neutrons can change, without changing the identity of the element. These different forms of the same element are called **isotopes** (from the Greek word meaning "in the same place").

The protons have a weight of 1 **mass unit** each and have a positive electrical charge. Neutrons also weigh approximately 1 mass unit, but have no charge; as their name implies, they are neutral. Electrons are very small compared to protons and neutrons, weighing about 2,000 times less. However, each electron has a negative electric charge, which will balance a positive charge if both are put together. That is what happens in an atom. The number of electrons and protons are equal, balancing the electrical charges and making an atom neutral.

The weight of the atom is the total weight of all the protons and neutrons together. In a uranium atom, there are 92 protons and 146 neutrons for a total weight of 238 mass units. This is usually called the **atomic weight** of the atom.

During the 1920s, scientists discovered that new elements could be made by bombarding atoms with the nucleus of a helium atom, called an **alpha particle.** For example, if an alpha particle is shot into a nucleus of beryllium and stays there, the beryllium atom becomes a carbon atom—another element. The beryllium atom, which has 4 protons and 5 neutrons for an atomic weight of about 9, becomes a carbon atom, which has 6 protons and 7 neutrons and an atomic weight of about 13. The helium nucleus, or alpha particle, which has 2 protons and 2 neutrons and an atomic weight of about 4, is absorbed by the beryllium to make carbon.

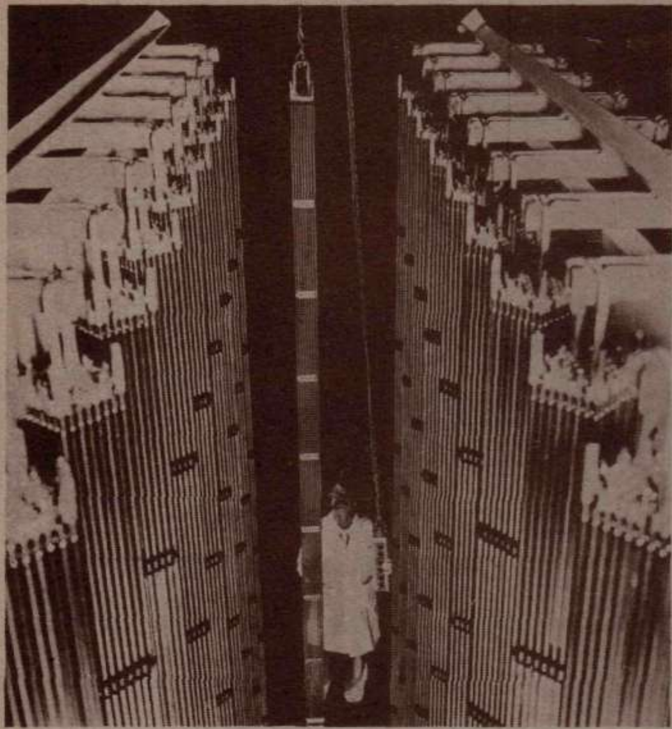
Figure 3
The Fission Process

When scientists bombarded a uranium atom with a neutron, they found that it split into two new elements, although not always into the same combination of new elements. One common combination is barium, which has a total of 137 protons and neutrons, and krypton, which has 84. These fragments are called **fission products.**

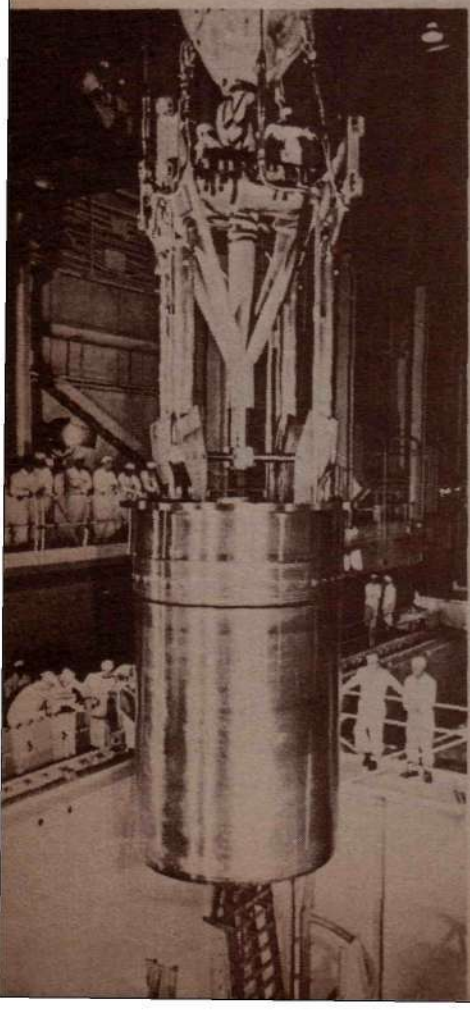
As the two new elements split apart, they repel each other because they each have large positive charges. They fly apart at tremendous speeds. This motion causes heat as these fragments are slowed down and stopped in the uranium.

In addition to the fragments that break off, chips—neutrons—also fly off the fissioning uranium. Perhaps two or three neutrons fly off every time a fission or split occurs in the uranium. This is the most fascinating thing about uranium fission. Not only does a uranium atom fission when a neutron is absorbed in its nucleus, but it gives off more neutrons during the fission. These new neutrons can then go on to produce more fissions in other uranium atoms, thus maintaining a chain of fission reactions—called a **chain reaction.** Sustaining this chain reaction in a controlled way is the basis for producing energy in a nuclear reactor.

Below: Fuel bundles containing fuel rods for a BWR at General Electric's nuclear parts manufacturing plant.



Below: Reactor core liner for the first U.S. nuclear power plant at Shippingport, Pennsylvania, being lowered into the reactor vessel.



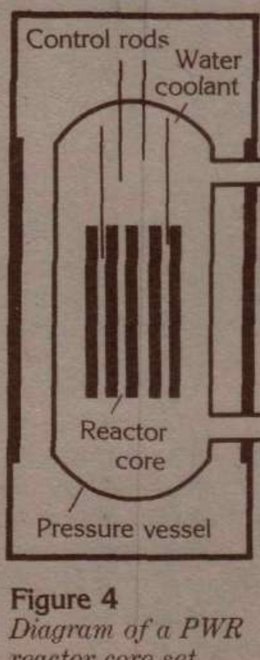


Figure 4
Diagram of a PWR reactor core set inside a pressure vessel. The control rods are shown in between the fuel rods.

hot fuel rods, it begins to boil. The steam produced from the boiling water is then sent to the turbine, where electricity is produced the same way it is in a coal plant (Figure 2).

In another type of nuclear reactor design, a **pressurized water reactor (PWR),** the water flows past the fuel rods, but it is not allowed to boil. Instead, the pressure is kept very high to keep the water a liquid. Then this very hot water flows through tubes that have a separate source of water running outside them. The hot pressurized water from the reactor heats them up, making the water outside the tubes boil. The steam produced outside the tubes in the steam generator is then sent to the turbine to produce electricity.

Although a nuclear reactor is more complicated than a coal or oil burner, the only basic difference between a coal plant (or an oil plant) and a nuclear plant is how the heat is produced.

Controlling the nuclear plant

In a coal plant, the heat produced is controlled by the rate at which fuel is fed into the boiler. In a nuclear plant, the amount of heat depends on the rate at which uranium atoms fission. And this depends on the rate at which **neutrons** bump into them. Neutrons are small particles of atoms that act like bullets, smashing apart the uranium atom.

Controlling this process is accomplished by putting rods containing a small amount of the element boron between the fuel rods. Since boron absorbs neutrons very easily, it can catch them before they cause a uranium atom to fission. The boron is put into metal rods called **control rods** that are inserted into the reactor core along with the fuel rods. The engineer who runs the reactor then can control the amount of heat produced by driving the control rods in or out of the reactor core (Figure 4).

The farther the control rods are pulled out of the core, the larger the amount of electricity generated—or the "higher the power level," as they say in reactor language. The farther down the control rods are inserted into the core, the lower the power level. The more the neutrons are absorbed in the boron and not available for uranium fissions, the less heat produced and the lower the power level.

Now, how do you think the engineers shut off a nuclear reactor? They push the control rods into the core even farther, until all neutrons are absorbed and fissioning stops. Nuclear engineers have designed reactors so that they can be shut off very quickly, if an emegency arises, or slowly, which is the usual way.

The control rods are driven in and out of the core by electric motors that are attached to the rods outside the reactor. Reactor operators control the power level simply by flicking a switch and turning on these motors. Shutting the power off slowly is done by turning on these motors and driving the control rods all the way in. The very fast way to shut off a reactor is by pushing the **scram button.** A computer is used to constantly check all the processes in a reactor, and it will automatically push the scram button if a problem is even suspected.

The scram button works this way: Control rods are attached to the electric motors by electromagnets, not by nuts and bolts. As long as the electricity to the magnets stays on, the magnets hold the rods to the motors. Hitting the scram button shuts off the electricity to the electromagnets, releasing the control rods. They immediately drop all the way into the

Radiation and radioactivity: Facts versus fiction

We live with radiation around us every day. Most of it comes from natural sources like the food we eat, the ground we walk on, or cosmic rays from outer space (as shown in the table). Some of it comes from man-made sources such as television, medical X-rays, or from flying in an airplane. This is usually called low-level radiation. More than 40 years of intensive scientific research into the effects of low-level radiation on human beings has concluded that it is not harmful.

Radioactivity, the kind of radiation produced in a nuclear reactor, is caused by the breakdown, or what scientists call **decay** of the unstable isotopes of some elements. Uranium-235, the fuel for nuclear reactors, is radioactive. It breaks up, or decays, as its atoms each give off an **alpha particle** (the nucleus of a helium atom) and become a new element. For uranium-235, this takes billions of years, since the atoms don't all give up alpha particles at the same time.

Other isotopes give off **beta particles** (electrons) or **gamma-rays** when they decay. Gamma-rays, which are similar to X-rays, have the most penetrating power and have been used to treat diseases like cancer.

After uranium fissions, the new elements formed, called **fission products,** are usually unstable. These fission products decay to a stable condition by giving off a combination of all three types of radiation, depending on which isotopes are involved. Furthermore, some decay slowly, over hundreds of thousands of years, while others decay very fast, within seconds, minutes, or days. These are the sources of radiation in a nuclear reactor.

Nuclear reactors are designed to contain the radiation from fission products. The reactors are built with several containment barriers—made out of concrete and steel—between the fuel pellets, where the radioactive fission products are absorbed, and the outside atmosphere. This keeps all but a tiny amount of the radiation inside the reactor during normal operation, and even during an accident, if one occurs.

The table here compares how much radiation a person living within 50 miles of a nuclear reactor receives from the reactor over one year. Radiation is measured in units called **millirems,** which show how much energy the body's tissues are absorbing from the radiation.

The normal background radiation in New York City (coming from the earth and the atmosphere) is about 100 millirems per person per year. At high altitudes there is less air above to cut down on radiation coming in from space, so a city in the mountains, like Denver, has normal background radiation of 200 millirems per person per year. A worker in a nuclear plant can receive up to 5,000 millirems per year without any harm.

During the accident at Three Mile Island in Pennsylvania in 1979, people living near the nuclear plant received on an average only 1.5 additional millirems of radiation.

Average doses of radiation

Per person, per year in millirems

Nuclear reactor (living within a 50-mile radius)	0.01
Natural background	
cosmic rays	35.00
air	5.00
building materials	34.00
food	25.00
ground	11.00
Man-made sources	
coast-to-coast jet flight	5.00
color television	1.00
chest X-ray (one)	50.00

core, shutting the reactor off in less than a second. It's almost as fast as shutting off the lights in your house!

Cheap electricity using nuclear power

The output of a nuclear power plant is electricity. And nuclear plants can do this better and more cheaply than any other kind of power plant. The reason is simple. The fuel is much cheaper. A tiny amount of nuclear fuel creates a huge amount of energy. It doesn't take much uranium fuel to run a nuclear reactor for a long time.

You can easily compare how much fuel it takes to run a modern power plant with coal or with nuclear energy (Figure 5). In one year, a coal-burning plant uses enough coal to fill a 260-mile-long train of coal cars—3 million tons of coal. But in the same year, a nuclear plant producing the same amount of electricity uses only 1 ton of uranium, an amount that could easily fit into a single truck.

Figure 5

The energy in one small nuclear pellet this size = the energy in 149 gallons oil =

To give you other comparisons: Each uranium fuel pellet is equal to about 1½ tons of coal. Only 20 pounds of uranium provides the power to light 25,000 American homes for a whole year.

Once it is in the reactor, the fuel lasts for three years or more before it has to be replaced.

Because a small amount of nuclear fuel produces so much power, the fuel costs for a nuclear power plant are much less than those for a coal or oil power plant. So although it costs more to construct a nuclear power plant, it is much cheaper to run it over the 30 to 40 years that it produces electricity. When these two costs are added together—the construction-equipment cost and the fuel cost—electricity produced from the nuclear plant is much cheaper. Today's nuclear-produced electricity costs about one-half what coal-produced electricity does. And oil is now so expensive that the electricity it produces costs more than five times what nuclear-produced electricity costs.

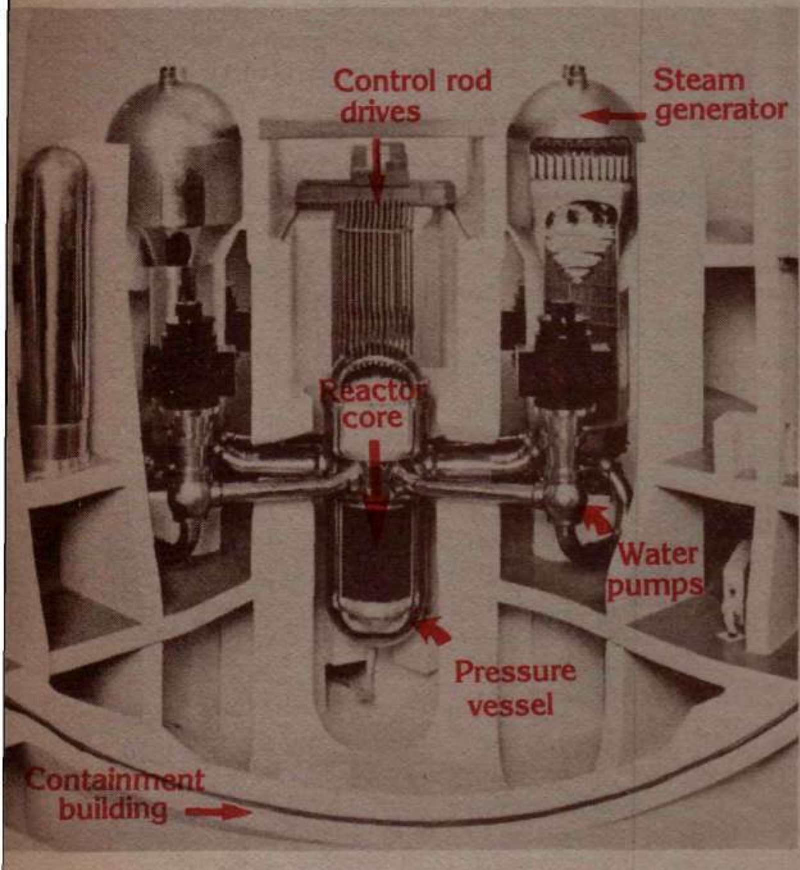


Figure 6

Cutaway view of a PWR model built by Combustion Engineering. At the center is the reactor core inside a pressure vessel. The pressure keeps the heated water around the core a liquid. This very hot water is pumped through tubes in the steam generators that have a separate source of water outside them and makes this water boil. The steam then flows to the turbine to generate electricity.

Man-made nuclear fuel

In the early 1940s, when scientists were working on the world's first nuclear research reactor in Chicago, named Chicago Pile One, they made a very important discovery about uranium and neutrons. When uranium-238 was hit by high-

Nuclear rockets and spacecraft

One of the first things that engineers recognized when they began to look at all the possible uses for nuclear energy was that since very little fuel produces a lot of energy, there would not be a storage problem. Therefore, it would be an ideal fuel to run ships, submarines, airplanes, and rockets. In fact, since a nuclear reactor could run a long time on one small fuel loading of uranium, a ship or plane could run a year or more without ever stopping to refuel.

The Defense Department immediately recognized this as a very important advantage for Navy submarines and ships, and they went to work on it. By January 1955, the clean, silent power of the atom pushed a sleek new vessel out of the harbor and onto the high seas. This nuclear submarine, the first of many more to come, *A small amount of nuclear fuel goes a long way.*

energy neutrons (neutrons traveling at high speeds), it absorbed the neutrons. But each uranium-238 atom that absorbed a neutron became unstable and radioactive (see box, page 11). Because of its radioactivity, it lost energy and eventually changed into another element.

This new element was entirely new. It did not exist naturally in the ground to be mined. It had 94 protons, weighed 239 mass units, and was also radioactive. Scientists named it **plutonium.**

Most important, scientists discovered that plutonium atoms fissioned, just like the atoms of uranium-235. Researchers quickly realized an astounding fact: By making U-238 into plutonium it would be possible to turn **all** uranium into nuclear fuel, not only the tiny amount of fissionable uranium-235 that exists naturally in the earth. This could make a supply of nuclear fuel that would last for hundreds of years.

The problem was how to design a nuclear reactor that would operate with high-energy neutrons, rather than the low-energy neutrons, or slow neutrons, used in ordinary nuclear reactors. Since the cooling water in a reactor is what slows down the neutrons released during fission, the obvious solution was to get rid of the water. But then scientists had to come up with another coolant that would transfer the heat from the uranium fuel but would not slow down the neutrons.

was named the *Nautilus* after the Jules Verne tale *Twenty Thousand Leagues Under the Sea.* The *Nautilus* could stay under water for months at a time. And it proved this by taking a three-month underwater journey through the Arctic Ocean, underneath the ice cap of the North Pole.

Nuclear reactors on submarines, although considerably smaller than those in power plants, operate in much the same way. Instead of producing steam to turn an electrical generator, the submarine reactor produces steam that turns a propeller shaft.

This propeller, of course, drives the submarine just like the propeller of any ship or submarine run by oil or coal. However, the nuclear submarine has no exhaust gases or fumes and, therefore, leaves no tell-tale signs in the water, whether it is on top or underneath the sea.

Scientists found two ways of doing this. The first was to use a gas—helium or carbon dioxide—to remove heat. The second way was to use a liquefied metal for a coolant, such as sodium, which melts at 208 degrees Fahrenheit. Both kinds of reactors were built, but the sodium-cooled system is the most developed today.

These new reactors use the high-energy neutrons, called **fast neutrons,** to create or **breed** new fuel, plutonium, from the uranium-238. At the same time, some of the fast neutrons make fissions in the uranium-235 and the plutonium atoms. The reactors that combine both these processes—fission and breeding—are called **fast reactors** or **breeder reactors.**

A fast reactor produces electricity by transferring the heat from the fuel rods to the liquid sodium around the reactor core and from the sodium to tubes of flowing water. This water boils and makes steam to run the turbine and electric generator, just as in other power plants. The reactor also breeds more plutonium than the amount of fissionable fuel that was put in the reactor when it started up. Therefore, some of the plutonium can be taken out and used to start up other reactors, while part of it can be put back into the same reactor to keep it running.

The fast reactor is just now beginning to be built for commercial use in a few countries. To be able to meet the future energy requirements for the entire world, many more fast reactors, as well as ordinary, water-cooled reactors, will have to be built all over the world.

Building cities with nuclear power

Although there are many future uses for nuclear power, probably the most important will be for building new cities and new industrial parks. Nuclear energy is the most concentrated form of energy that man has ever known. Therefore, it has the potential of being the most efficient, most versatile, and least expensive energy source ever. But in order to make the most of this potential, scientists have to develop new types of nuclear reactors that can deliver the heat energy at even higher temperatures.

Work is already well along on a new reactor that will do just that. Called the high temperature gas-cooled reactor, or HTGR for short, it uses helium gas as a coolant to transfer the high-temperature heat. The idea is to use this very hot helium (between 1,500 degrees and

2,000 degrees Fahrenheit) to heat up other kinds of gases that are used directly in industrial processing. For example, natural gas or coal gas is used at high temperature to make iron and to make fertilizer. If a steel-making plant or a fertilizer plant were located right next to an HTGR, the hot helium gas could be piped in to provide the heat source.

Some of the hot helium could also be used to generate electricity with a gas turbine. This would eliminate the need for a steam generator and water system in a power plant. Instead, the helium would flow directly from the reactor through the gas turbine and back into the reactor again. The rotating gas turbine would drive the electric generator, producing electricity even more efficiently and therefore more cheaply than ordinary reactors do.

Finally, again because of its higher temperatures, the extra heat from the HTGR could be used more efficiently than the leftover heat from other power plants. It could be used to desalinate seawater by evaporating it and then recondensing the water, leaving the salt behind. Or it could be used to provide heating or air-conditioning for people who live nearby. Of course, it could do all of these things at the same time.

The nuplex

The Atoms for Peace program of the 1950s planned to use nuclear power plants as a central energy source for an entire city, including its surrounding industry and farms. This concept is called a **nuplex,** meaning a nuclear-powered industrial and agricultural processing complex. Nuplexes are designed to make the most efficient use of almost all the concentrated energy of a nuclear plant. Therefore, the cost of nuclear energy with nuplexes will be even cheaper than today's cost.

Although several countries—including India, Mexico, and the United States—have blueprints and designs for nuplexes, none has been built. Nuplexes, however, must become the basis for the city-building of the future. This is especially important for the developing nations, where a lot of progress must be made as fast as possible.

But even building many nuplexes around the world is not the final goal of the Atoms for Peace program. The next challenge is for us to develop nuclear fusion. Fusion, which is the energy process that goes on in the Sun and stars, promises an even more concentrated and therefore more efficient energy source. And the fuel for fusion is water. Fusion works by heating and compressing atoms of hydrogen until they fuse or join together, releasing a tremendous amount of energy in the process. This is the challenge of the 21st century.

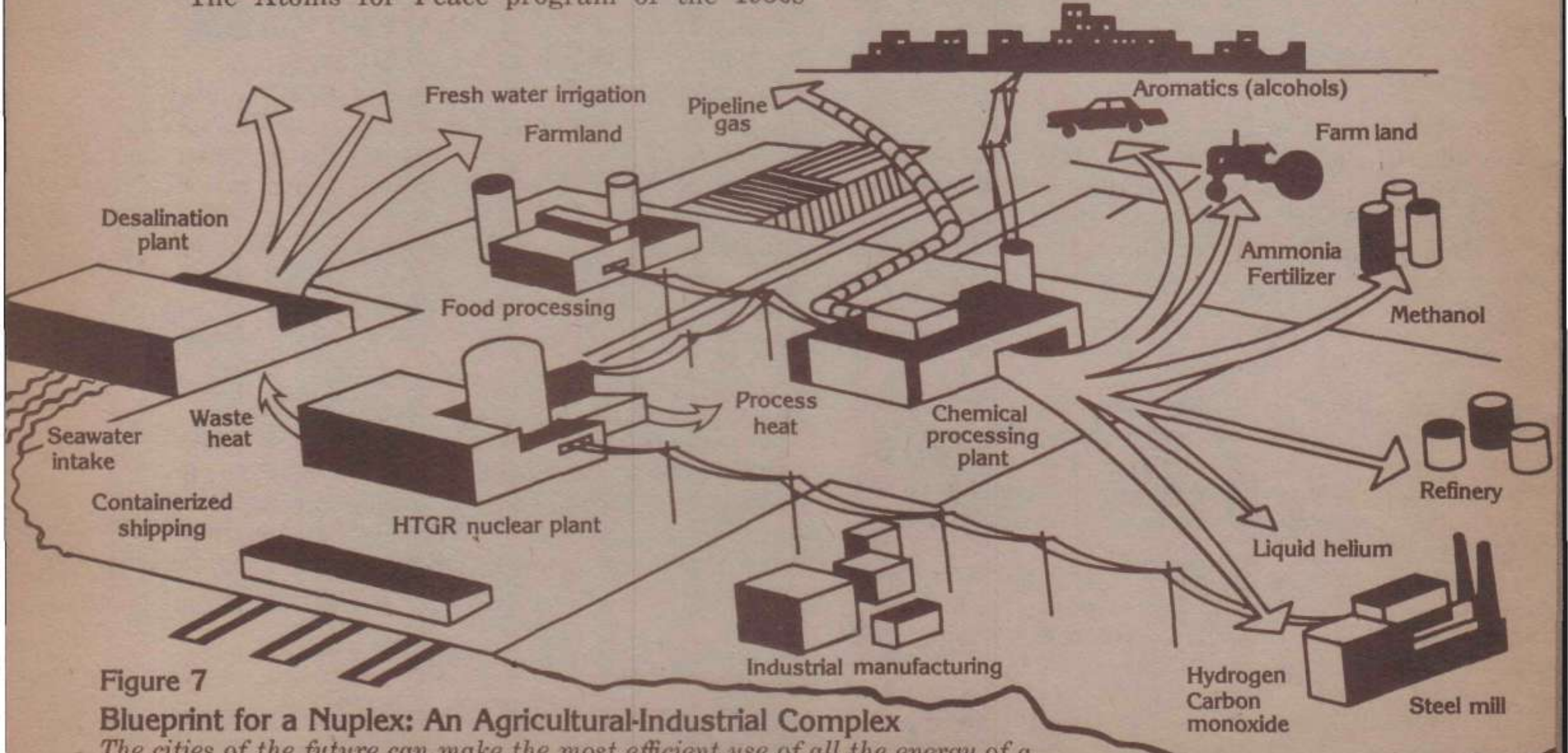
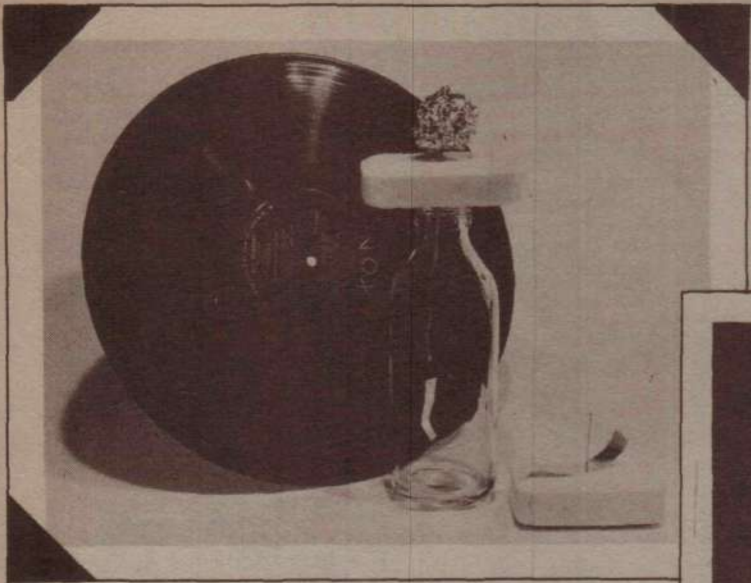


Figure 7

Blueprint for a Nuplex: An Agricultural-Industrial Complex

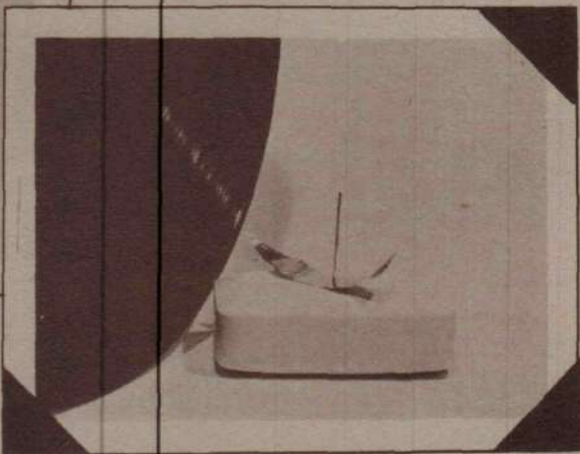
The cities of the future can make the most efficient use of all the energy of a nuclear plant by locating industrial and agricultural plants nearby. This blueprint shows the use of energy in the form of electricity, high-temperature process heat, and low-temperature waste heat.

Experiments



Left: A "gold foil" electroscope and a versorium.

Below: The versorium pointing toward the charged record.



Making an electroscope

An electroscope is a device for detecting an electric charge. It can also be used to distinguish between positive and negative charges, and to compare amounts of charge. The earliest model of the electroscope was built by a great English scientist, William Gilbert (1540-1603), who called his device the **versorium,** a Latin word for **rotating needle.**

Materials you will need:

- aluminum foil (thinnest available)
- scissors
- bar of soap or paraffin wax
- a few inches of heavy copper wire or large paper clip straightened out
- a piece of appliance cord (the sort used in ordinary extension cords)
- a pint or quart jar
- silk thread

Cut a strip of aluminum foil 4 inches long and ⅜ inch wide; cut one end to a point. Push a needle through the middle of the strip and into the bar of soap or paraffin wax. Bend the ends of the strip slightly upward, so the strip can revolve with little friction.

Now develop an electric charge on a record or a ruler and bring it near the foil arrow. You can build up an electric charge on a discarded phonograph record by rubbing it vigorously with a piece of wool. Or you can use a hard-rubber comb or a ruler (wooden or plastic), rubbing with wool or fur.

When you bring the charged object near the versorium, the foil arrow should swing around and point toward the object. The charged object is "inducing" an opposite charge on the end of the foil arrow, which moves toward the object, and it is inducing a like charge on the other end. This means that some electrons already on the arrow are being shifted to one end.

A "gold foil" electroscope

The "gold foil" electroscope was first built by Abraham Bennet in 1787. For this experiment, however, you will use aluminum foil instead of gold.

Cut two strips of foil ⅜ inch by 1½ inch. Use a needle to pierce a hole near one end of each strip.

Take off the covering from about 5 inches of appliance cord. Separate and cut a single strand. Run the strand through the holes in the foil strips and twist the strand to make a double loop or figure 8. The strips must hang freely.

Bend one end of a 5-inch or 6-inch piece of heavy copper wire or paper clip wire into a hook shape. Then drive the straight end of the wire through a bar of soap or paraffin wax. Now suspend your strips from the hook in the wire.

Continued on page 16

Experiments
Continued from page 15

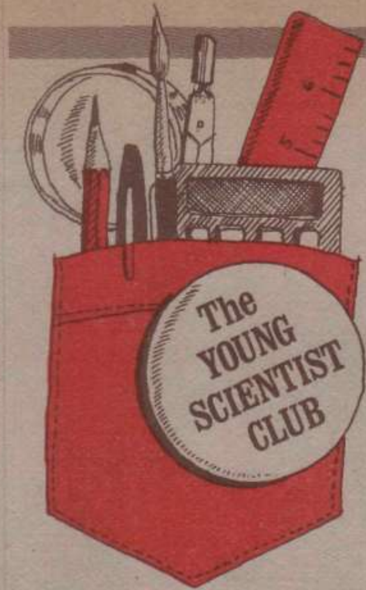
Lower the apparatus into a jar, letting the soap or wax bar cover the opening. The jar protects the foil leaves from air currents. If you wrap silk thread a few times around the wire where it meets the soap or wax on both sides, it will reduce the leakage of electric current out of the apparatus. You can also bend the end of the wire sticking out of the bottle and enclose it in a ball of aluminum foil, which may help reduce leakage. (As Benjamin Franklin discovered with his lightning rod, current discharges into the air most readily from a sharp point.)

Now charge an object as you did before and bring it near the ball of foil. The foil leaves should spread apart. Why?

The foil leaves in the electroscope spread apart when you bring a charged object near the ball of foil.

When you remove the charged object, the leaves will fall again. You can actually transfer a charge to the ball, wire, and leaves by **touching** a charged object to the ball. (You are adding or subtracting electrons.) When you remove the object, the leaves should fall only part way.

If you transfer a charge that you know is negative to the apparatus (for example, rub a stick of wax or candle with wool), how would you use the electroscope to tell whether another charged object has a positive or negative charge? Try a plastic ruler and a wooden one (rubbing with wool); rub a balloon against your hair and try it also.



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 Street, New York, N.Y. 10019.

Many of you have asked us to suggest books to read and places to visit to learn more about subjects in **The Young Scientist.** The Young Scientist Club has sponsored tours of fusion experiments, nuclear plants, science museums, and high-technology industries. If you are interested in a tour in your area, please write to us.

Here are some books suggested.

On Kepler

The Harmonious World of Johannes Kepler, by Sidney Rosen (Boston: Little Brown and Co., 1960).

On Nuclear Power

Man and the Atom—The Uses of Nuclear Energy, by Frank Barnaby (New York: Funk and Wagnalls, 1971).

Nuclear Power by R.W. Deutsch (General Physics Corporation, 1000 Century Plaza, Columbia, Md. 21044, $3.50 postpaid).

Our Friend the Atom, by Heinz Haber, A Walt Disney Book (New York: Simon and Schuster, 1956).

Unlocking the Atom—A Hundred Years of Nuclear Energy by Michael Longstaff (London: Frederick Muller Ltd., 1980).

Applied Atomic Power, by R. Tom Sawyer and others (New York: Prentice-Hall, Inc., 1946).

Man and Atom—Building a New World Through Nuclear Technology, by Glenn T. Seaborg and William R. Corliss (New York: E.P. Dutton & Co., 1971).

Answers

The puzzle in the September issue was about 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. Part of the answer appears on page 22 in the article on Kepler.

The puzzle also asked if Kepler's ratio holds true for the Galilean moons of Jupiter, where Jupiter replaces the Sun. It does. The ratio in this case is about 32, a constant ratio for each of Jupiter's moons, Io, Europa, Ganymede, and Callisto.

The fact that Kepler's ratio in the third law holds for the planetary systems of Jupiter and Saturn as well as the entire solar system is a beautiful demonstration of Kepler's idea that the whole universe obeys harmonic laws.

Nuclear scientists have also found that the same laws of orbital mechanics hold for the electrical force between subatomic particles. These particles influence each other with a force that depends on the inverse square of the distance between the particles. Nuclear particles have the difference, however, that their interaction can be either **attractive** (like gravity) or **repulsive.** In the case of repulsion, the orbits of the particles take the form of the other conic section, the hyperbola.

We will discuss more about this in future articles.

Welcome to the puzzle page. 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.

Elliptical shortcuts

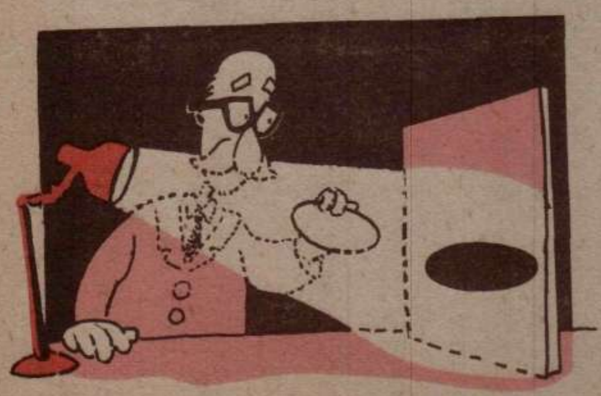
An ellipse is a very common sight, for every circle, seen from an angle, is an ellipse. I am lying on my couch looking up at the bottom of a flowerpot hanging at my window. When I walk up close and look directly up at it, I find it is a circle, but from here it looks like an ellipse. Artists know this and always draw circles as ellipses in perspective drawings.

The Greeks at the time of Plato knew the ellipse and all of its properties. They called it a **conic section curve.** A section is a cut, and the ellipse is one of four curves that can be cut from a cone by a single slice. The other three are the parabola, hyperbola, and circle.

To cut a circle from a cone, we merely slice it parallel to the base. (Roll up a cone out of clay and try it yourself.) Now turn the angle of the blade slightly, make sure your hand is out of the way, and cut again. You should see an ellipse.

You can also make an ellipse with shadows by holding a cut-out circle in a light beam. Tilting the angle of the circle cutout will give you different shape ellipses, just as tilting the angle of the knife does with the clay cone.

There is another way to make an ellipse, of any size or shape you like, using paper, pins (or thumbtacks), a pencil, and a piece of thread.



Light Cut-out circle Shadow ellipse

We'll start by making a circle with a pin and a thread and comparing it to the ellipse. Place your piece of paper on something soft like a telephone directory. Stick the pin in the center and tie the end of the thread to it. Make a loop in the other end, and put the pencil point in it. Now, if you swing the point around, keeping the thread taut, you will trace a circle. (You could also do this with a compass, the tool used to draw a circle.)

The circle is the **locus** (Latin for "place" or "position") of points equidistant from a center point. The pin is the center point, and the taut thread maintains the pencil at an equal distance as you swing it around.

Now, we know from the above experiments with cone and shadows that the ellipse is related to the circle. But how is it different? Well, aside from its appearance, the ellipse has two "centers," not just one. Each is called a **focus** and together they are called the **foci** (the Latin plural).

To draw an ellipse, place your two pins an inch or two apart near the center of the paper. Now take the thread and tie a loop big enough to fit around both pins. If you now place your pencil point in the loop, pull it taut, and swing your arm around as you did with the circle, your pencil will trace an ellipse.

At any point on the ellipse, the sum of the dis-

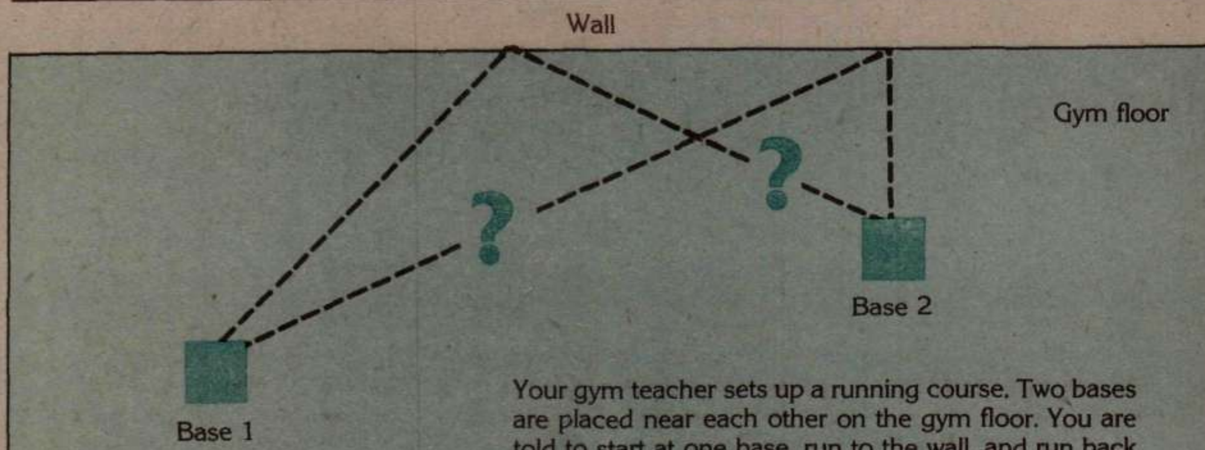
tances to the two foci is always equal. We have ensured this condition by the loop of thread. When we pull it taut and swing it around, the distance from each focus changes, but the sum of the two distances remains constant. It has to, so long as the loop doesn't get bigger or smaller.

Now, if you tie a bigger loop, you can draw a new ellipse surrounding the first one. The orbits of the nine planets and the asteroids are ellipses like these two. They all have the same two points for foci, one of which is the Sun!

The ancient Greeks knew that the planets revolved around the Sun, but until the time of astronomer Johannes Kepler (1571-1630), everyone thought the orbits were circles.

(You can read more about this in the series of articles on Kepler.)

There are many interesting properties to be learned about the ellipse before we know as much as Kepler did. The puzzle for this month is based on one of the properties that I have already told you about, but you will have to use your ingenuity to realize it.

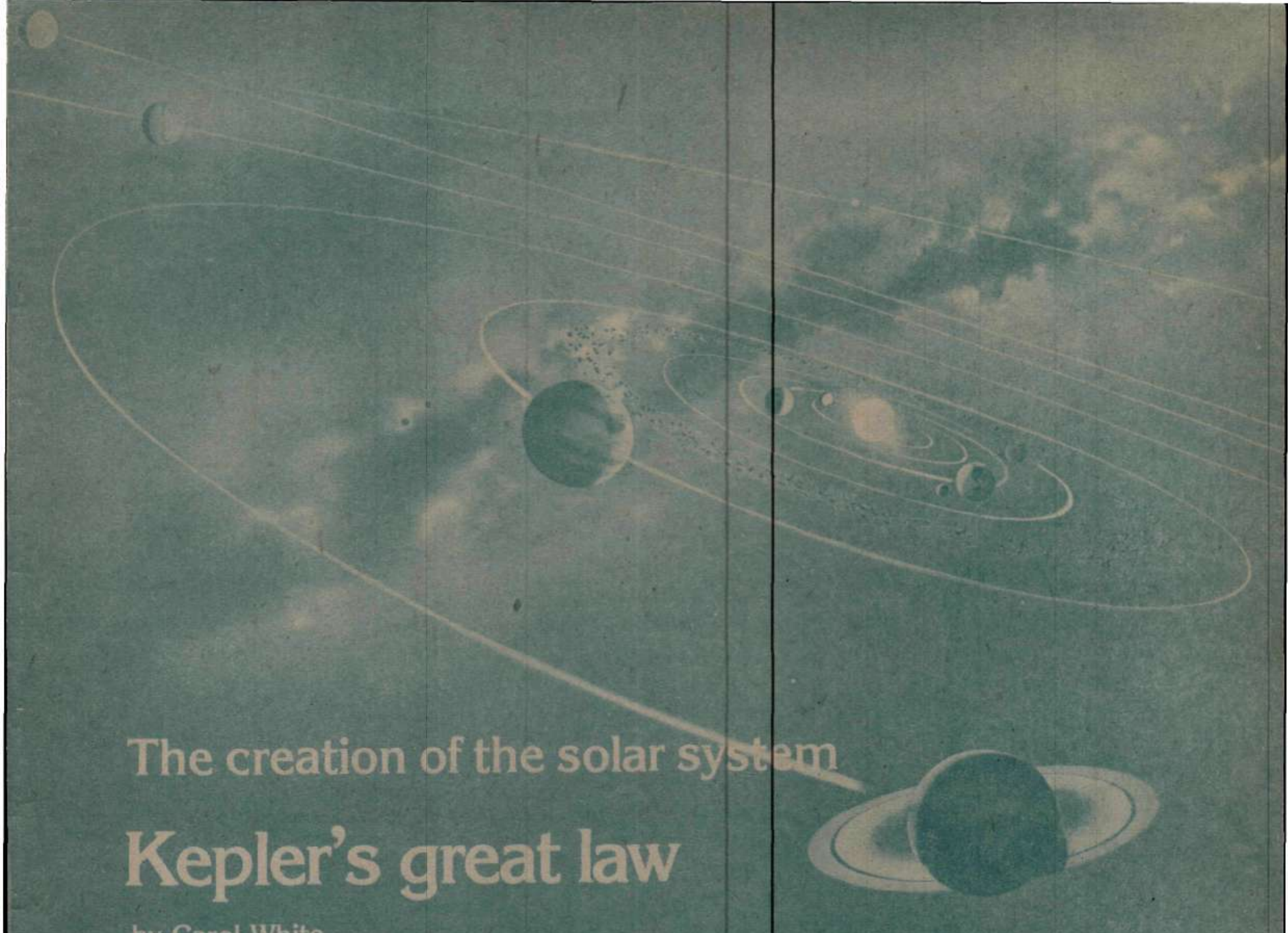


Your gym teacher sets up a running course. Two bases are placed near each other on the gym floor. You are told to start at one base, run to the wall, and run back to the second base. You know that to run the course the fastest, you should take the shortest route. But how do you know what that is? Where should you tag the wall to ensure the shortest course? You can use your ellipse maker to find the answer.

There are many different courses, but only one is the shortest.

The answer to this issue's puzzle will appear in the next issue.

Turn to page 16 to find the answer to the puzzle in the last issue.



The creation of the solar system

Kepler's great law

by Carol White

This is the first of three articles on Johannes Kepler, 1571-1630.

If you were to ask the typical person "Who was the father of modern astronomy?" you might get the reply "Johannes Kepler." But chances are that most people would be more likely to answer with the name of Copernicus or Isaac Newton.

It's true that Copernicus's restatement of the heliocentric hypothesis—that the planets orbited around the Sun—was a significant advance over the Earth-centered hypothesis of Ptolemy, which was popularly accepted in the 16th century.

But Copernicus had a problem. In principle he was correct, but because he thought that the planets traveled in **circles** around the Sun, he was unable to describe their paths without making complicated adjustments. These adjustments, called **epicycles,** made his calculations of the planetary orbits just about as unworkable as they were with Ptolemy's second-century theory that the planets and the Sun traveled around the Earth.

It was Kepler who first discovered the fact that the planets traveled in elliptical, not circular, orbits.

Many claim that Isaac Newton (1642-1727) was the father of modern astronomy because he discovered the law of universal gravitation, but, as I shall show, his theory was taken directly from Kepler's "Three Laws." Newton merely restated them. It is an interesting question historically, therefore, how Newton came

Orbit of an imaginary planet

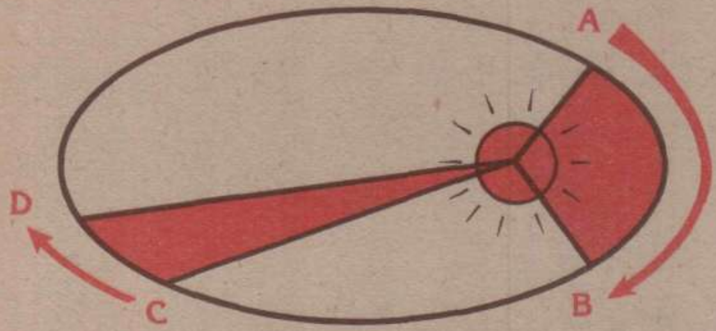


Figure 1
Kepler's First Law

Kepler's first law (usually called his second law) says that a planet sweeps out equal areas in equal times, no matter how far it is from the Sun. Shown here is a greatly exaggerated elliptical orbit (the orbits of the planets are actually within 1 percent of being circles), along with two of the areas swept out by a line connecting the imaginary planet and the Sun. The time it takes the planet to travel from point A to B is the same as it takes to travel from C to D. The planet travels just enough faster between A and B to make up for the shorter distance between C and D.

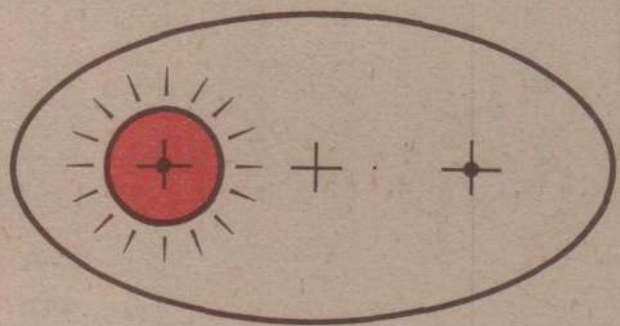


Figure 3
Kepler's Second Law

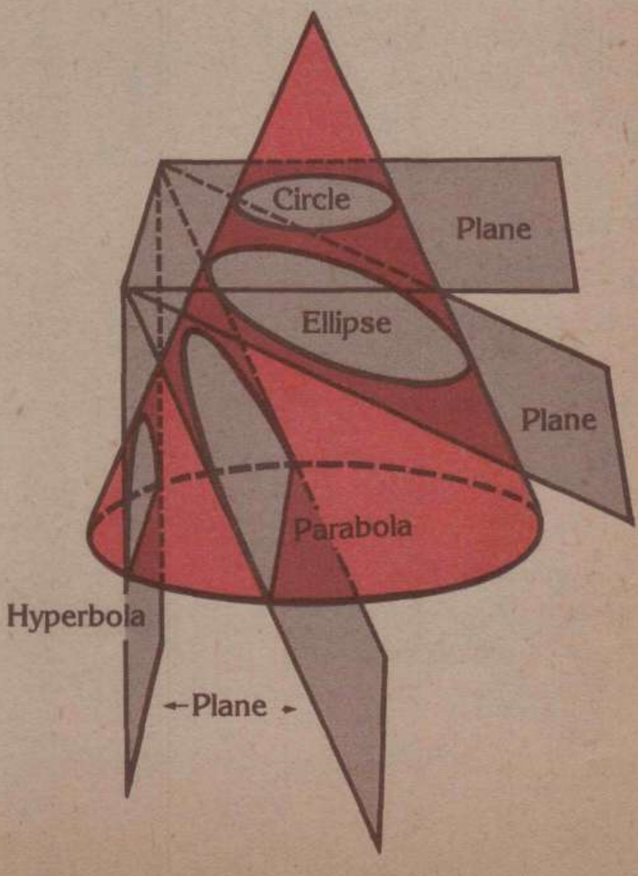
Kepler's second law (usually called his first) states that the orbits of the planets are ellipses with the Sun at one focus of the ellipse. Since the first law applies equally to all conic sections (circles and ellipses, for example), Kepler's second law specifies which conic section is to be used, and, more important, that the Sun is at one focus of the ellipse.

This conclusion was the difficult part of the second law. Kepler had tried before to use elliptical orbits to explain the motion of Mars, but had mistakenly put the Sun at the **center** of the ellipse instead of the focus. Kepler's insight that the Sun must be at one focus of the elliptical orbit came from his reading of William Gilbert's treatise on magnetic forces. This convinced Kepler that there was a force field pushing the planets through space, and Kepler knew that for the orbit to be an ellipse implied that the source of this ellipse was at its geometrically significant point—the focus. Figure 4 shows why the focus is significant.

Figure 2
The Conic Sections

The ancient Greeks discovered that the most important plane figures were the conic sections—the two-dimensional figures that could be made from the intersection of a plane and a cone. There are four different types of conic sections, as shown here. The **circle** is the simplest, made when the plane cuts the cone parallel to the base. The **ellipse** is made when the plane cuts the cone at a small angle. The two open conic sections, the **hyperbola** and the **parabola,** are made when the plane is at more of an angle. Only the circle and ellipse are closed curves, and each of them is a possible orbit for a planet in the solar system. Some comets have parabolic orbits.

You can make the conic sections using a clay cone and cutting it with a knife.



to be considered such a genius, while Kepler is consistently undervalued, since Newton made at best a modest contribution to Kepler's tremendous discovery. But that's another story.

Kepler's three laws

Kepler's most famous discovery in astronomy is his "Three Laws of Planetary Motion." All of modern astronomy is based on the physics contained in these three laws.

Kepler's thinking as he discovered these laws can be easily understood if we begin with what is usually called the second law, although it was actually the first of the laws he developed. This law states that the line connecting a planet to the Sun sweeps out equal areas of space in equal times. That is, if we connect the Earth to the Sun with an imaginary line, in the three months between December and February, this line would sweep out the same amount of area that the line would sweep out in the three months between June and August (see Figure 1).

This is true even though the Earth is farther away during the summer months than in the winter months. Kepler's law says that, in effect, the closer a planet is to the Sun, the faster it moves—with just enough increased speed to always be covering the same area.

Kepler knew that this law applied to any orbit whose shape was a conic section, one of the geometric shapes, like a circle or an ellipse, that can be made by "slicing" a cone (Figure 2).

The second law that Kepler developed (usually called his first law) was the discovery not only that the orbits of the planets were ellipses, but, more important, that the Sun was at the **focus** of the ellipse, not its center (see Figure 3). In fact, before Kepler had understood the law of equal areas, he had tried to analyze the orbits of the planets as if they were ellipses. But at the time he did not yet understand what made the orbit an ellipse—that it was the motion of the planet that made it a conic section, not just the orbit's form. Therefore, he tried to put the Sun at the center of the ellipse. It did not work, and Kepler gave up this idea.

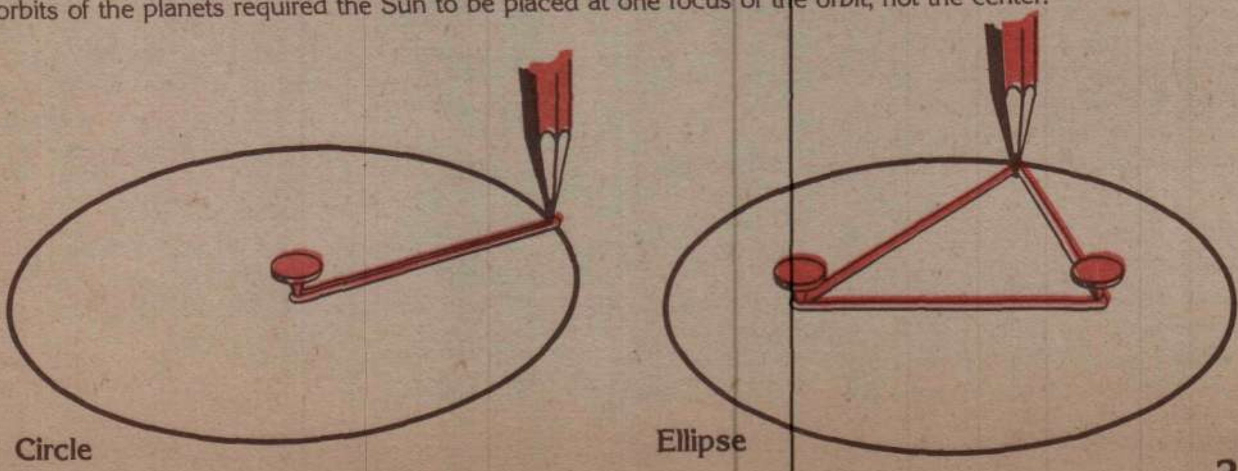
The law of elliptical orbits follows closely after the law of equal areas because the law of equal areas shows that there is a force moving the planets that determines the shape of their orbit. Since it was well known at that time that an ellipse is generated by its focus, not by its center, it was a natural conclusion for Kepler to put the Sun at the focus of the ellipse once he knew what caused the motion of the planets (see Figure 4).

Kepler was most proud of his third law, a law of harmonies of the motions of the orbits. This law states that the ratio of the cube of the planet's distance from the Sun to the square of its period (the amount of time it takes for the

Figure 4
Generating a Circle and an Ellipse

Two of the conic sections can be generated by simple machines that demonstrate the physics of the orbits of the same shape. A circle-making machine (called a **compass**) can be made with a thumb tack, string, and a pencil, as shown. The pencil traces out a figure that has the same radius at any point on the circumference.

An ellipse-making machine can be made using a loop of string, two thumb tacks, and a pencil, as shown. The thumb tacks are the two foci for the ellipse. As a circle's center generates a circle, the foci "generate" the ellipse. The pencil traces out a figure where the sum of the distances from the two foci to the pencil is the same at any point on the circumference of the ellipse. Kepler discovered that the elliptical orbits of the planets required the Sun to be placed at one focus of the orbit, not the center.



planet to circle the Sun) is the same for all planets (see Figure 5).

Kepler versus Newton

The best way to understand why Kepler's scientific method is so important is to contrast the approaches of Kepler and Newton (who lived 100 years after Kepler).

Newton is famous for stating "I do not make hypotheses." Of course, he did not mean that he would not put forth theories to explain how things work. His law of gravitation is a hypothesis that states that two objects exert an attraction upon each other that is calculated by taking the product of their masses and dividing that by the square of their distance from each other.

What Newton meant by his statement about hypotheses was that he felt that a scientist was under no obligation to explain **why** such a relationship should exist.

Kepler, had he lived to reply to Newton, would have dismissed him with scorn as a pretender. For Kepler, a scientist's first obligation is precisely to address the question "Why is this so?" To merely describe **how** something seems to work might be useful, but it is not true science, according to Kepler.

For Kepler it was not sufficient to determine the orbits of the planets, or even to show how they were related to each other as well as to the Sun. Kepler was looking for a physical geometry that would explain **why** the planets orbited around the Sun as they did.

It is sometimes said that Kepler's planetary theory was a geometric or kinematic theory to which Newton added the physics. This is far from the truth. In fact, Kepler criticizes Copernicus on precisely this account, saying that Copernicus's theory was merely geometric.

Nor, as is sometimes said, did Kepler stumble upon his law of the elliptical orbits merely by studying the star charts prepared by the 16th-century astronomer Tycho Brahe and then arriving at an empirical induction. The charts, which showed various positions of the planet Mars with great precision, indeed allowed Kepler to verify his hypothesis, but that hypothesis was itself grounded in theoretical considerations.

Only after studying the field theory of the English scientist William Gilbert, published in his book on magnetism, was Kepler satisfied that he could account for planetary motion. If the Sun was the energetic center of a magnetic-like force that "turned" the planets, then its position must be determinate, established at a definite place. Figure 4 shows the determinate position for an ellipse, called the focus. The two foci of the ellipse are the fixed points used to draw an ellipse on paper, and, in the solar system, to fix the orbit of a planet.

It was these considerations that led Kepler to his correct assumption that the Sun has a determinate position, the focal point of a series of ellipses that are the planetary orbits.

Figure 5
Kepler's Third Law

Kepler's third law says that 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. This law holds also (with a different constant ratio) for the moons of Jupiter and the moons of Saturn.

In mathematical terms, the law looks like this:

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

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. The time it takes a planet to go around the Sun one time is its **period,** which is measured in Earth years.

Here is a table showing the orbital radius and period for each planet. The constant ratio in each case according to Kepler's third law is 1. (This is part of the answer to Professor Von Puzzle in the last issue.)

Planet	Orbital radius (A.U.)	Period (Earth year)
Mercury	.387	.241
Venus	.723	.615
Earth	1	1
Mars	1.523	1.88
Jupiter	5.202	11.87
Saturn	9.541	29.46
Uranus	19.19	88.77
Neptune	30.09	165.1
Pluto	43.25	284.4

Newton's calculations

Newton's claim to preeminence is associated with his asserting the inverse square law of gravity and then applying it both to the celestial orbits and to the effects of gravity on Earth. Newton successfully calculated that the force of gravity between the Earth and the Moon, in his terms, accelerated the Moon onto an elliptical orbit rather than letting it fly off into space like a slingshot. He said that this was the same as the force that an object experiences when it falls to the Earth at an accelerated rate of 32 feet per second squared. This is an interesting calculation, but it is not original. Kepler had already assumed the universal character of his gravitational force concept when he associated it with magnetism.

Indeed, it was Kepler who first stated the inverse square law in his book *Optics*, where he showed that the light from a central source diminishes as the square of the distance from the source.

Kepler also recognized that the Earth acts upon the Moon in the same way that the Sun acts upon the Earth. In fact, he was the first to formulate a modern explanation for the ocean's tides, which rise and fall according to the combined gravitational action of the Sun and the Moon.

What generates the solar system?

For Kepler, a physical theory that accounted for how the Sun caused planetary motion was only a beginning. He demanded to know **why** this was so. He searched for a theory that would explain how the solar system was generated.

Surprisingly for those of us trained to accept the Newtonian notion that description is primary and that scientific theories are merely plausible explanations of observable data, Kepler arrived at an essentially correct hypothesis about the generation of the planets before he discovered his three laws.

Kepler supposed that the distances of the planets from the Sun had to be ordered according to definite laws. He discovered that by looking at the planetary orbits as geometrically determined circles inside spheres of the same size, he was able to account for the orbits in terms of a series of solid figures called **Platonic solids.**

In part two of this article I will discuss Kepler's great law of the formation of the solar system, and I will discuss the Platonic solids. Here I conclude with two quotations that will allow you to compare the spirit of Kepler with that of Newton.

Kepler's spirit

Both Newton and Kepler referred to a Creator when they discussed the universe, although Newton stated that any discussion of how the universe came to be was outside the realm of science—a point of view with which Kepler vehemently disagreed. Yet, see how differently Newton and Kepler saw that God.

Isaac Newton (from the *Mathematical Principles of Natural Philosophy,* Book 3):

This most beautiful system of the sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being. . . . This being governs all things, not as the soul of the world, but as Lord over all; and on account of his dominion is wont to be called Lord God *or* Ruler; *for* God *is a relative word, and has respect to servants; and* Deity *is the dominion of God not over his own body, as those who fancy God to be the soul of the world, but over servants. . . . As a blind man has no idea of colors, so have we no idea of the manner in which the all wise God perceives and understands things. . . . What the real substance of any thing is we know not.*

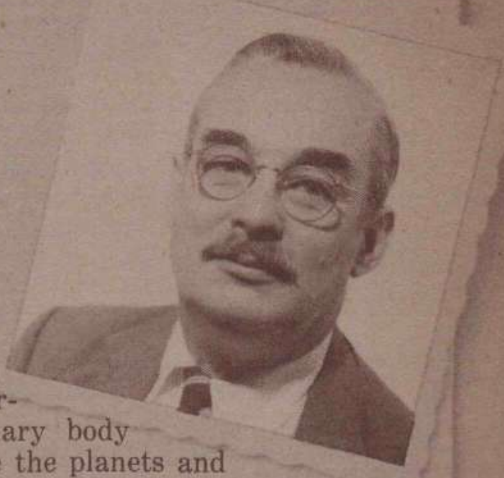

Isaac Newton


Johannes Kepler

Johannes Kepler (from the *Mysterium Cosmographicum* [*The Secret of the Universe*]):

For would that excellent Creator, who has introduced nothing into nature without thoroughly foreseeing not only its necessity, but its beauty and power to delight, have left only the mind of man, the lord of all nature, made in his own image, without any delight? . . . For the reason why the mind was joined to the senses by our Maker is not only so that man should maintain himself . . . but also so that from those things which our eyes perceive to exist we should strive towards the causes of their being and becoming, although we should get nothing else useful from them.

Interview with Dr. Alan Cook



Dr. Allan Cook, an astronomer for 35 years, is participating in NASA's Voyager Saturn project. He works at the Smithsonian Center for Astrophysics at Harvard University in Cambridge, Massachusetts.

Question: How did you become interested in astronomy?

Cook: I started in that direction at a very early age. When I was a child the great excitement was aviation. I had read all the books in our local public library in Cleveland Heights, Ohio, on aviation that were out in the front room, so I was sent to the back room where there were more. There I found a book on astronomy and, wondering what the word meant, I took it out and became interested. To go into astronomy or astrophysics today, I'd advise a young person to study physics, chemistry, and geology.

Question: Have our ideas about astronomy been changed or upset by the results of NASA's Voyager mission and the earlier Pioneer missions to Jupiter and Saturn?

Cook: Our ideas about the orbits of the planets haven't been upset. But the new information on the rings both of Uranus and Saturn does force us to look beyond just gravitational effects. Saturn's rings, by the way, are the only accumulations of celestial fossils that are still around to look at. They were part of the formation of the many celestial and satellite systems in the solar system that formed out of what is called an **accretion disk**. This is a flat region where bits and chunks of matter collected that surrounded the primary body out of which came the planets and then the satellites [moons] of the various planets.

Question: What do you consider the most important space exploratory programs?

Cook: The top priority among the projects being planned is the Galileo mission. It would put a satellite in orbit around Jupiter that would send a probe down into Jupiter's atmosphere. The cameras on this mission would take pictures of the fireballs entering Jupiter's atmosphere. These are large meteorites that cause craters when they hit. The mission would also study lightning, auroras, and volcanos on Jupiter.

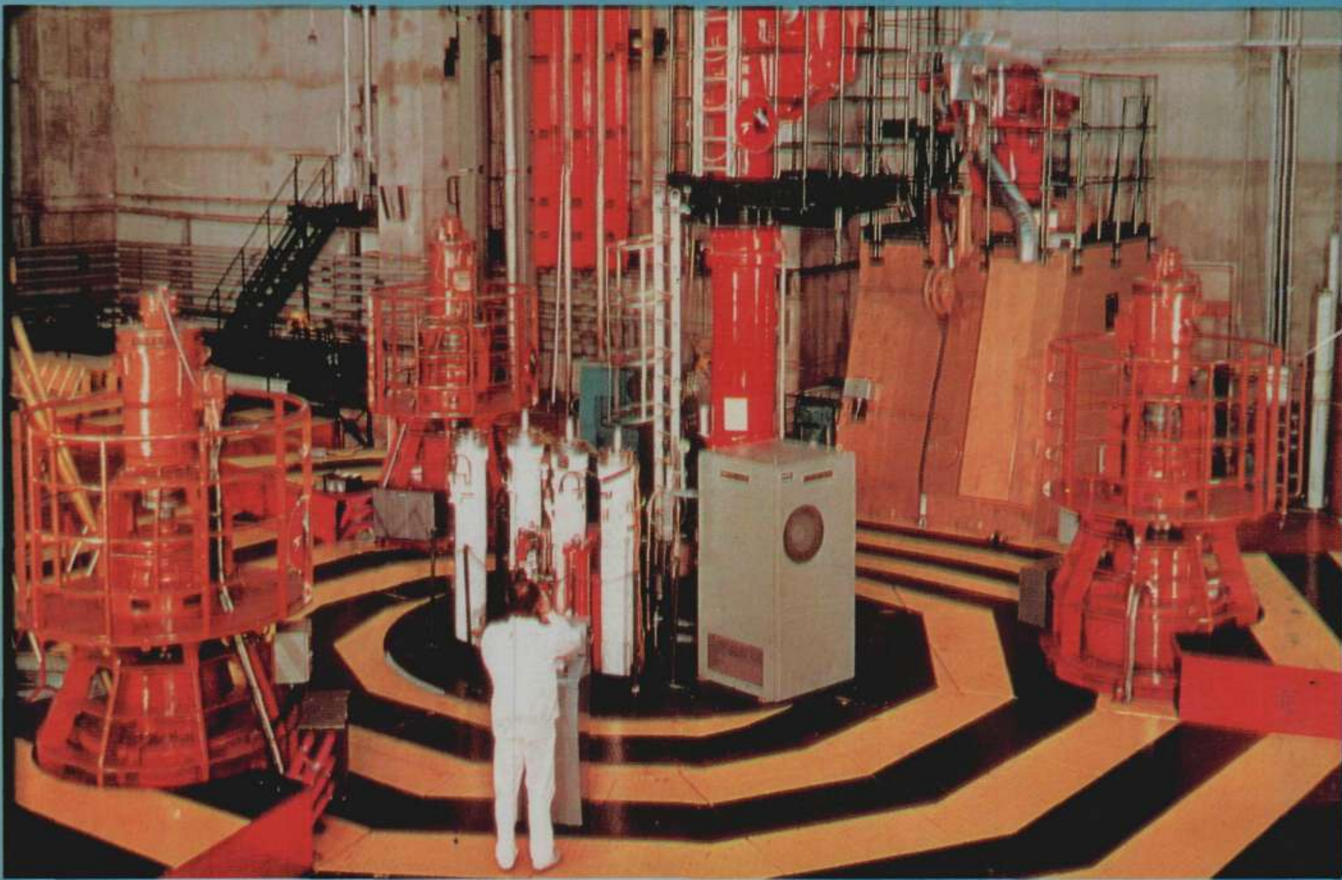
After that we would still like to go out to Halley's Comet. It passes near the Earth only once about every 75 years, and 1986 is its next visit. Next on the list should be an orbiter around Saturn in the 1990s, like the one for Jupiter. Then there's the plan for a Space Telescope to go into Earth orbit. Because it would not look through the layers of Earth atmosphere, this telescope would see stars even 14 billion light years away. This is the most exciting point in my life, as it is for everyone in the program. It's like the excitement over Antarctic exploration when I was young.

Question: What do you say to people like Senator Proxmire who don't want the government to fund these projects?

Cook: The solar system exploratory programs play a role in creating the atmosphere necessary for progress, and at most they cost a few dollars per person per year.


HEY, ERNIE! WHAT ARE YOU DOING?
Pete Progress
I'M PROTESTING NUCLEAR POWER!
NO NUKES
WHY ARE YOU AGAINST IT?
ISN'T EVERYBODY?
NO NUKES
NO! SOME PEOPLE THINK IT'S THE SAFEST, CHEAPEST, AND CLEANEST FORM OF ENERGY IN EXISTENCE!
SAFE! HAVEN'T YOU HEARD ABOUT RADIATION?!
YES, I HAVE- BUT MANY THINGS IN OUR EVERYDAY LIVES GIVE OFF MORE RADIATION THAN A NUCLEAR PLANT!
BUT HAVEN'T YOU HEARD WHAT IT COSTS TO BUILD A NUCLEAR PLANT?!
YES, I HAVE-BUT THEY PRODUCE MORE ENERGY PER DOLLAR INVESTED THAN ANY OTHER ENERGY SOURCE!
BUT HAVEN'T YOU HEARD ABOUT RADIOACTIVE WASTE?!
YES, I HAVE-BUT WE ALREADY HAVE WAYS OF RECYCLING WASTE TO PRODUCE NEW FUEL!
WELL... I'LL BET YOU HAVEN'T HEARD THAT NUCLEAR POWER CAUSES HOMESICKNESS!
NO, I HAVEN'T...
NO NUKES
... BUT I CAN SEE THE EFFECTS ALREADY!
ZIP!
SLOAN 7-81

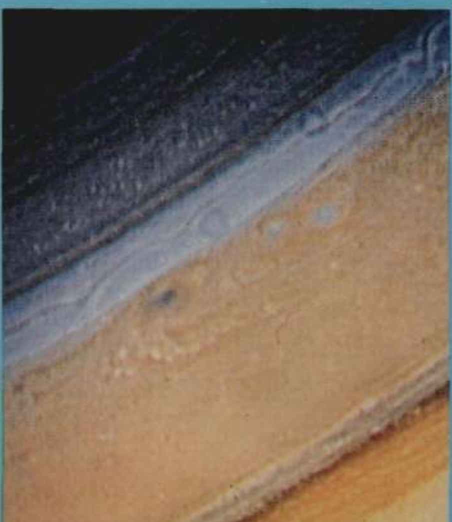
Commissariat a l'Energie Atomique



The challenge of nuclear energy

In this issue Jon Gilbertson describes the 20th-century challenge of developing the power of the atom for the benefit of mankind. He tells how the Atoms for Peace program was designed, how nuclear fission works, and how nuclear energy can be used not just to produce electricity cheaply, but also to produce power for industry, space, transportation, and city-building.

Pictured above is the operating floor of the Phenix, a fast breeder reactor in France. The reactor vessel is beneath the floor level. In the center is the fuel-handling device.



NASA

Saturn's surprises

The spectacular photographs of Saturn taken by Voyager 2 have upset the traditional theories of how the solar system works. Dr. Steven Bardwell explains why, and he suggests a new theory that takes its inspiration from the 17th-century astronomer Johannes Kepler.

Here is a color-enhanced photograph taken by Voyager 2 showing the different composition of two of Saturn's rings. The bright blue is the C ring and the yellow is the B ring.