The Young Scientist

February/March 1981 $2.00

Exploring the frontiers of the 1980s

Voyager 1 unveils secrets of Saturn

Genetic engineering

From the editor's desk

A new year of scientific challenges

1980 was a very important year for scientific progress. In all the areas of science that we report on in *The Young Scientist*, there were major discoveries or new developments. Two of the most important are described in this issue: the continuing improvement in the very useful branch of biology known as **recombinant DNA** and the observation of the unexpected and exciting features of Saturn's rings and moons by Voyager 1.

Although these two areas of science are quite different, they both demonstrate that the universe is organized on all levels—from the smallest to the largest—in very orderly and beautiful **geometric** patterns. Understanding how these geometries form, why they are sometimes preserved for long times, and why they sometimes change are among the important questions that science seeks to answer. The most important thing is to explain how the universe and man continue to develop.

Here are some other areas of science where important advances were made in 1980, which will be discussed in future issues:

Biological evolution: Many leading scientists have agreed that the evidence we have of changes in the forms of life over billions of years shows that new types of plants and animals do not occur as a result of many small changes. Instead, they occur because of large and rapid changes that transform the whole pattern of life.

Fusion energy: Scientists continued to improve all the many ways that are being developed to harness the process of nuclear fusion as an almost unlimited source of energy in the future. **Fusion** is the process by which energy is generated in the Sun and the stars. Numerous other advances occurred in astronomy, medicine, physics, and engineering that we will report on. But the real question is whether we will continue this progress and turn it into useful inventions fast enough to rapidly improve the lives of the world's growing population by filling their needs for materials, energy, food, housing, education, and health care. We can look back with satisfaction on the scientific year 1980, and look forward to many new and exciting discoveries in 1981.

Dr. Morris Levitt

The universe is organized on all levels—from the smallest to the largest—in very orderly and beautiful geometries, from the spirals of a seashell to those of a galaxy.

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The Young Scientist

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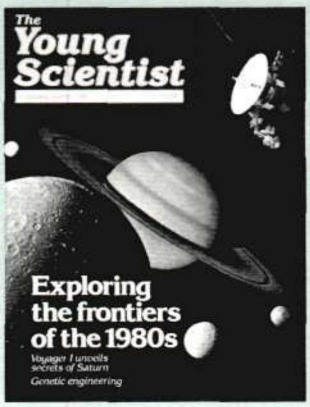
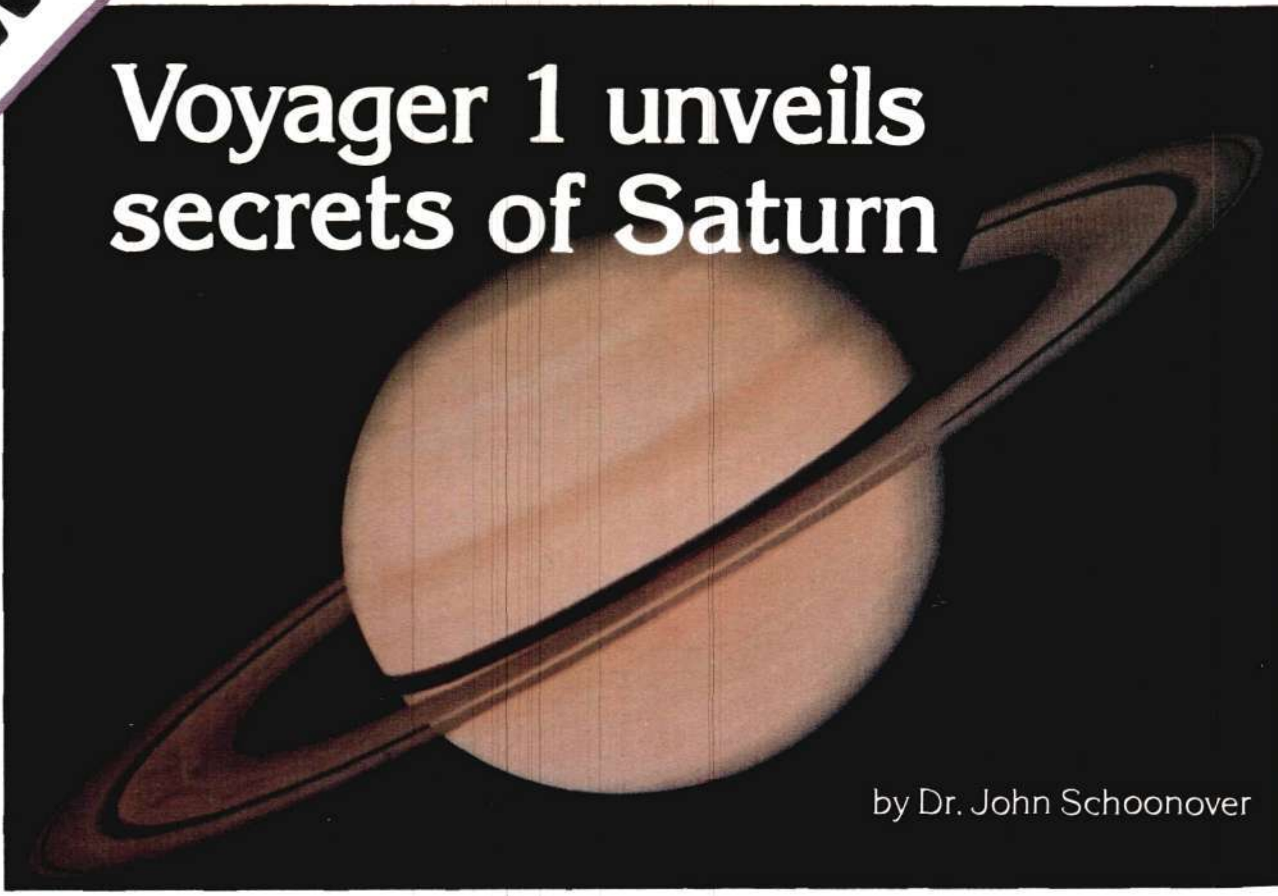
Unlocking the genetic code—see page 10.



About the cover

NASA's Jet Propulsion Laboratory provided this composite of the Saturnian system from photographs taken by Voyager 1 in November 1980. The moon Dione is in the front, Tethys and Mimas are in the lower right, and Enceladus is at the left. We added the NASA painting of Voyager 1 in the upper right. Christopher Sloan designed the cover.

Voyager 1 unveils secrets of Saturn



by Dr. John Schoonover

Saturn, the sixth planet from the Sun, has held a special fascination for man ever since Galileo first viewed it through a telescope in the 17th century. Its perfectly smooth silver face and mysterious rings (which looked like "cup handles" to Galileo) made it seem the most unusual object in the solar system. Now, more than 300 years later, the space probe Voyager 1 has unveiled the secrets of Saturn.

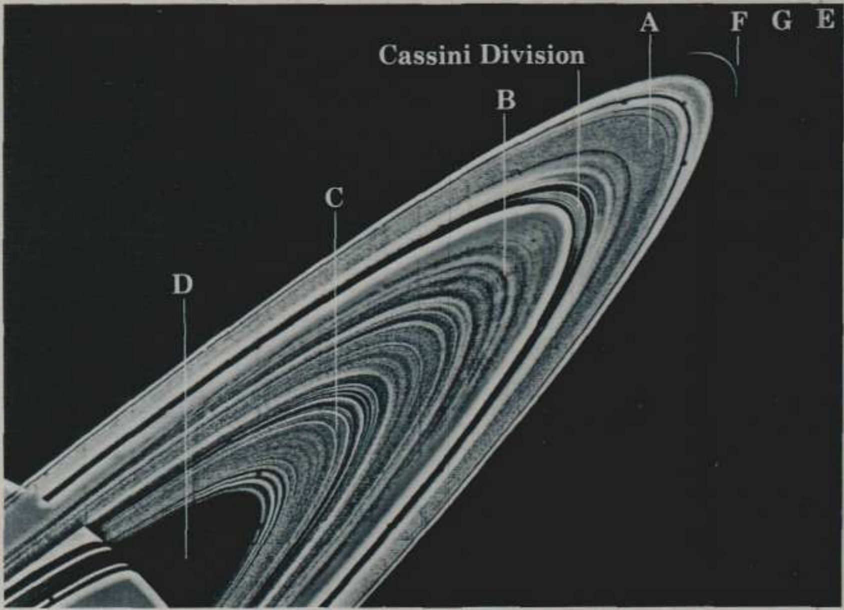
Launched from Cape Canaveral on September 5, 1977, Voyager 1 traveled 1 billion miles to carry out its mission. On November 12, 1980, 20 months after flying by Jupiter, Voyager 1 made its closest approach to Saturn, actually passing within 78,000 miles of the planet. The information returned by the robot spacecraft will challenge scientists for some time to come.

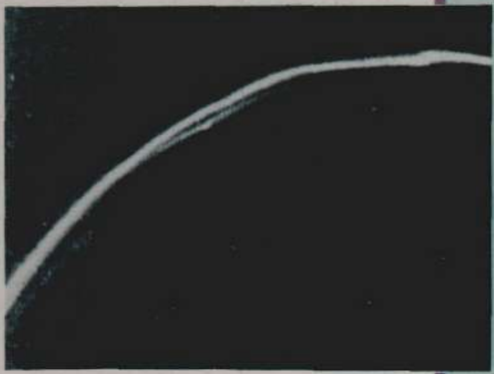
The team of scientists and engineers at NASA (the National Aeronautics and Space Administration) who designed Voyager 1 and guided it to its nearly perfect rendezvous are thrilled at the success of the mission. Voyager 1 missed its target by only 12 miles!

This success came from the very advanced technology used in Voyager 1 and its Earth-based support systems. With 16 rockets using only 230 pounds of fuel and an electrical power source of 400 watts, Voyager 1 traveled to its precise goal at 50,000 miles per hour and sent back information at a rate greater than ever before achieved by any space probe. It sent back to Earth not only pictures, but also measurements of ultraviolet light, infrared radiation, radio waves, cosmic rays, the density of gases, and the strength of magnetic fields.

The space probe Pioneer 11, launched in 1973, was actually the first to approach Saturn. But it was a much more primitive vehicle. Nicholas Panagokas of NASA put it this way: "The difference between Pioneer and Voyager is like the difference between a Model T Ford and a sleek new Lincoln Continental."

Pioneer 11 came closer to Saturn than Voyager 1 did, but it provided little knowledge of the intricate ring structures revealed by Voyager's sophisticated computers and cameras, which photograph thousands of images through color filters to be reassembled by computers on





Saturn and its rings (facing page), taken by Voyager 1 from 11 million miles away. The hundreds of narrow rings are clumped together in seven larger bands, labeled A through G in the photograph above. Its mission accomplished, Voyager 1 (top right) will now journey through the galaxy. The braided F ring (bottom right) is perhaps the most fascinating mystery of Saturn. Note the rings twisted around each other and the "knots," which may be clumps of material or small moons.

Earth into a single color photograph.

What are some of the exciting discoveries made by Voyager 1? Voyager 1 discovered three new moons of Saturn's total 15 and gave us close-up views of the moons for the first time. The huge craters revealed on some of the moons indicate these moons were formed at the same time as the solar system. Even more exciting, Voyager 1 revealed that the rings of Saturn are much more complicated than scientists had imagined.

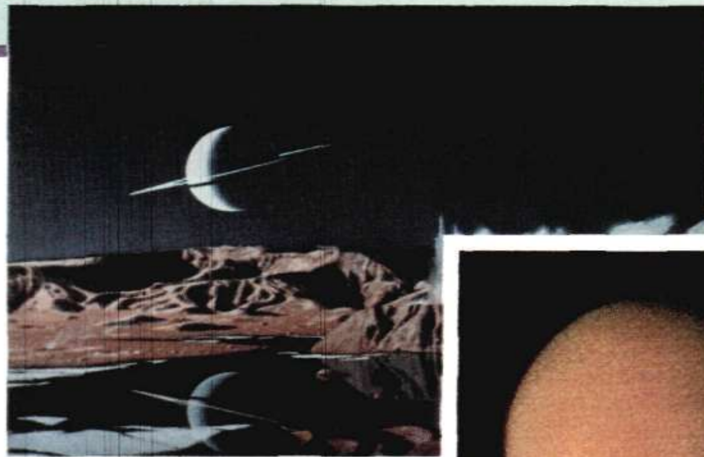
Saturn's braided ring

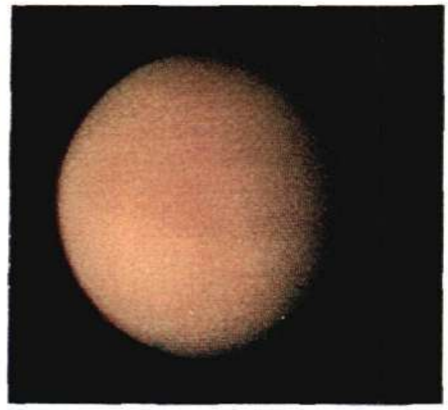
Rather than several large rings, each separated from the next by empty space, there are actually hundreds, perhaps thousands, of narrow rings. These rings are grouped together in clumps so that from a distance there seem to be gaps between clusters. One of these gaps is the famous Cassini Division. The rings are made of chunks of rock and ice ranging in size from tiny particles of dust up to huge boulders miles across. All of the matter in the rings is orbiting Saturn like billions of little moons.

The F ring, first discovered by Pioneer 11, now appears to be braided. It looks like several narrow rings twisted around each other like a braid of hair. Dr. Peter Goldreich of the University of California in Los Angeles has a hypothesis about the braids. He thinks that the two moons just discovered—one on each side of the braided F ring—act like shepherds to keep all the material in the ring from straying.

Dr. Goldreich thinks that these two moons exert a force on the dust and rocks in the F ring that tends to make them spiral about each other and form the braided structure. It may take years of work, however, before this scientific hypothesis can be proved or disproved. (A scientific **hypothesis** is a concept—sometimes mathematical—of how the system under study developed and works. We judge the validity of the hypothesis by how much it increases our power to understand and control nature.)

Voyager 1 also made new discoveries about Titan, Saturn's largest moon. Scientists thought Titan was the largest moon in the solar system, perhaps even larger than the planet Mercury. But Voyager's information shows that Titan is actually smaller. (Jupiter's moon Ganymede is now considered larger.) Titan looks large because it has a very dense, very deep atmosphere—500 miles thick. This atmosphere, mostly made of nitrogen, also contains some methane (swamp gas). The methane is partially converted into octane, a major ingredient of gasoline. So when it rains on Titan, it rains gasoline!





This photo of Titan was taken by Voyager 1 from 2.8 million miles away. The painting depicts how Saturn might look from the surface of Titan.

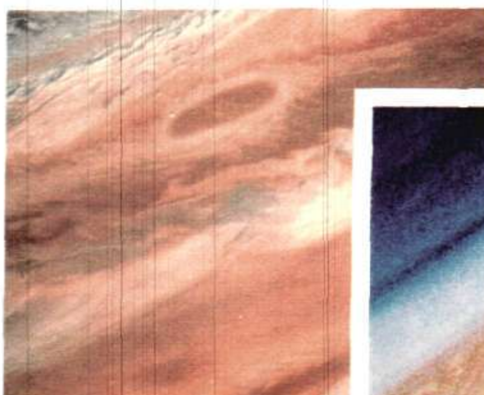
Scientists think that the atmosphere of Earth billions of years ago may have been similar to Titan's. If this is so, we may be able to get some clues as to how life began on Earth by studying Titan's chemistry.

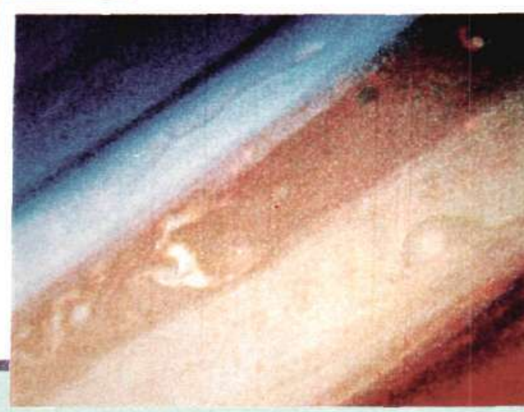
The dance of the moons

Two of the newly discovered Saturnian moons, Moon 10 and Moon 11, perform a very intricate dance as they circle the planet. One of Kepler's laws of planetary motion predicts that the farther a moon is from its planet, the longer the time it takes to go around it. For each distance from the planet, there is a special time for going around it, called the **period.** For Earth's moon, for example, the period is about 28 days—a lunar month.

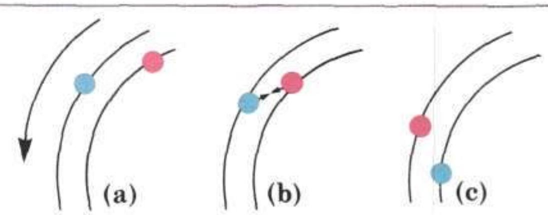
Moons 10 and 11 are in very nearly the same orbit, at almost the same distance from Saturn. You would expect the one closer to the planet to catch up with the farther one and pass it every now and then, because its period is shorter. But this is not what happens. The two moons are in such close orbits that they would collide if they tried to pass. But this doesn't happen either!

What does happen, as shown in the drawing, is that the inner (red) moon starts to catch up with the outer (blue) moon. As they approach each other, they pull on each other with gravitational forces so that the blue moon slows down and the red moon speeds up. But before they get close enough to collide, they have pulled each other into the other's orbit. The red moon is yanked up to the outer orbit, while the blue moon is thrust down into the inner orbit. The blue moon speeds ahead in its new, lower orbit, escaping the collision. And the red moon takes the path that the blue moon left. Then, when the blue moon is about to catch up with the red moon, they exchange roles again, completing their dance pattern. As indicated by the jaggedness of Moon 11





This color-enhanced photograph of Saturn's surface (right) shows that it has bands, spots, and swirls similar to those of Jupiter (left). Saturn's bands indicate winds traveling at 900 miles per hour, four times faster than the winds of Jupiter.



(a) The inner (red) moon approaches the outer (blue) moon. (b) They pull on each other gravitationally, exchanging orbits. (c) The blue moon speeds ahead on the inner orbit. Inset photo: Moon 11.

shown in the photograph, the dancing moons may once have been a single moon that split.

Kepler's harmony of the spheres

Scientists use the laws of gravitational attraction between two bodies to explain the new organizations of matter seen in the Saturnian system. But this approach, which was developed by Isaac Newton in the 17th century, cannot fully account for the complex motions and structure observed. With three or more bodies, the mathematical calculations get very difficult and often unsolvable. Yet in nature, the bodies do arrange themselves in perfectly orderly geometries.

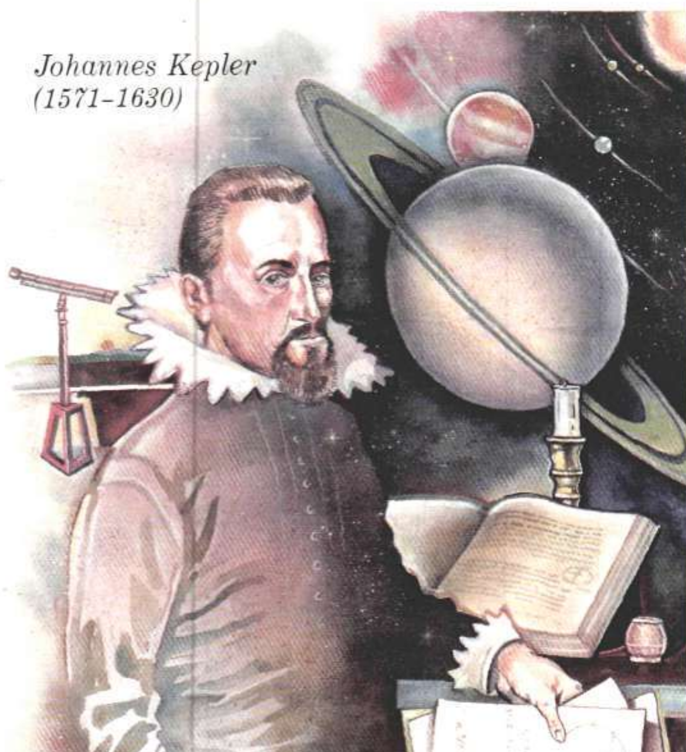
It was this physical reality that the astronomer Johannes Kepler sought to understand when he developed his laws of planetary motion in the 1600s. Kepler's approach was to look at the solar system as a whole. He insisted that there had to be an explanation for why just these planets, no more and no less, traveled in certain orbits and not others.

He knew that there had to be a reason why the whole solar system fit together just the way it did, what he called the **harmony of the spheres.** He found the first clues in the effect of the Sun's action on all the planets. From this, Kepler discovered that the orbits of the planets were ellipses, not circles, and he discovered the relationship between period and the distance of the planet from the Sun. Kepler's laws of planetary motion totally revolutionized mathematics, physics, and astronomy.

But today, Kepler's question—why does the solar system fit together harmonically—has still not been answered fully. The system of Saturn with its rings and moons gives us some more clues to the answer. Although the Saturn system appears to be more complicated than the rest of the solar system, it is actually explainable in terms of the basic ideas behind Kepler's discovery of the laws of planetary motion. Instead of looking at individual planets or moons, we must view the system as a whole and investigate how it came into existence. Its birth created the conditions reflected in the particular celestial bodies and orbits that we see today.

The answers to these questions will probably come as we learn more about how matter and energy organize themselves through scientific research here on Earth. For example, this question of organization is equally important in fusion energy research. The answers will give us the power in the near future to begin to explore and colonize the solar system and the stars beyond.

Johannes Kepler (1571-1630)



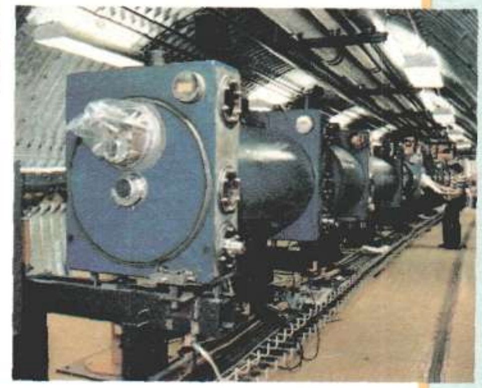
news...

TECHNOLOGY

Superconductors get warmer

Researchers at the U.S. Army Benet Weapons Laboratory and at Rensselaer Polytechnic Institute, both in New York, have discovered that a material called cadmium sulfide superconducts electricity at 77 degrees above absolute zero. The previous high temperature for a superconductor was only 23 degrees above absolute zero.

Superconductors are materials that can carry an electric current without losing any of its electrical energy. Ordinary electrical conductors like copper wires lose some of the electrical energy because the atoms in the wire resist the flow of current through them. The material heats up from this electrical "friction" (called resistance), changing the electrical energy into heat energy. This is how toasters and electric ovens work. But generally, it is better to have conductors that do not change electrical energy into heat energy, because then the electricity can be carried in large amounts for long distances.



Antarctica, the coldest spot on Earth (−88.3° C), is warm compared to the −270°C superconducting magnets in the Isabelle accelerator at Brookhaven National Laboratory.

Scientists first discovered superconductivity in very cold mercury early in this century. The most recently developed superconductors use special materials that can carry very large amounts of electricity without melting or losing any of the energy. A current in a superconductor loop could flow forever. But superconductors have been possible only at very low temperatures, near absolute zero. **Absolute zero** (or 0 degrees Kelvin) is 273 Celsius degrees below the temperature at which water freezes into ice (or 0 degrees Celsius). It is considered to be the state in which matter contains a minimum of heat.

Superconductors have many important uses. For example, the magnets needed to confine the hot electrified gas (plasma) in a fusion reactor must use superconducting wires to carry the huge currents without melting down. These magnets must be cooled to just a few degrees above absolute zero. But if scientists could use superconducting wires at higher temperatures or even normal, room temperatures, it would be much easier and cheaper to build a commercial fusion reactor.

The new superconductor, cadmium sulfide, is a commonly used dark orange dye. Since it became superconducting only when subjected to a tremendously high pressure, it is not likely to become a practical superconductor. But its superconductivity at high temperatures is very important in helping scientists discover why some materials become superconducting.

A **theory** is a concept of how something works that involves a mathematical description. The present theory of superconductivity cannot account for the cadmium sulfide example. So if scientists can use this new superconductor to make a better theory, they may find superconducting materials that work at even higher temperatures.

SCIENCE & GOVERNMENT

U.S. science education declining. According to a report commissioned by former President Carter and presented to him in June 1980, called *Science and Engineering Education for the 1980s and Beyond*, America is becoming a nation of scientific illiterates. The report states:

"While students who plan scientific and engineering careers are receiving an adequate educational foundation, more students than ever before are dropping out of science and mathematics courses after the tenth grade. . . . [These students] have effectively eliminated, by the age of 16, the possibility of science or engineering as a career. . . . Today people in a wide range of nonscientific and nonengineering occupations and professions must have a greater understanding of technology than at any time in our history. Yet our educational system does not now provide such understanding."

Preliminary indications are that the incoming Reagan administration will be taking this report very seriously. The next issue of *The Young Scientist* will review the science and energy policies of President Reagan's administration, and what must be done to upgrade U.S. science education.

SPACE & ASTRONOMY

Six months in space. Cosmonauts Leonid Popov and Valery Ryumin of the Soviet Union recently returned to Earth after spending 185 days—more than 6 months—in space. They lived aboard the Soviet space station, Salyut 6, as it orbited the Earth.

Doctors report that the two are in good health and that they actually gained weight. Popov gained more than 6 pounds while Ryumin gained 11. Most surprising, the cosmonauts grew taller! The doctors say that the good condition of the cosmonauts was maintained by their daily exercise routine and a balanced diet of foods very similar to what they would eat on Earth. Robot cargo ships supplied them with fresh food from Earth regularly.

The cosmonauts spent their time taking photographs of the Earth and examining its atmosphere, to supply information for scientists on Earth. They also did experiments with manufacturing crystals and metal alloys in a gravity-free perfect vacuum to see if such very pure materials might have special properties important for industries here on Earth.

For leisure, Popov and Ryumin watched color television broadcast from Earth, read, and listened to music.

The Soviets are planning a much larger space station that will house a crew of 12 scientists and cosmonauts. They hope eventually to have space factories orbiting the Earth, where spaceships to explore the solar system can be built.

(The next issue will feature an exciting proposal by a leading U.S. space scientist to launch human colonies into the solar system and then throughout the galaxy.)

Commander Leonid Popov (top left and bottom right) and Pilot Valery Ryumin in training.

Vaccinations help protect people against diseases like hepatitis B by stimulating the defense system of their bodies.

BIOLOGY & MEDICINE

New vaccine for hepatitis. Hepatitis is a disease that attacks the liver. The most common kind, hepatitis B, is very serious. About 100,000 people in the United States get hepatitis B every year, and of them about 2,000 will die from the disease.

Hepatitis B is caused by a virus that is often passed through contact with the blood of an infected person. For this reason, hospital workers and people who receive blood transfusions have a high risk of getting the disease. In some cases practices that are not hygienic are also to blame.

Researchers from the New York Blood Center have now invented a new vaccine that greatly helps prevent people from getting this disease. Of the volunteers who tested the vaccine, 96 percent had formed antibodies to protect them against hepatitis B within 6 months. The new vaccine is being tested now in several U.S. cities and should become available for general use when its complete safety has been demonstrated.

SPACE & ASTRONOMY

Continent-wide telescopes. Astronomers from the California Institute of Technology and NASA's Jet Propulsion Laboratory plan to build two radio telescopes as big as the United States! How? The telescopes will be two networks spread across the continent, with 10 identical radio-telescope "dishes" in each network. The dishes will be located at observatories across the country, one string of telescopes ranging from Alaska to Texas, the other from Hawaii to Massachusetts.

Radio telescopes can "see" better and farther than telescopes using visible light because radio waves can pass through the dust between stars without being absorbed. Also, most of the atoms in stars and in the gas between the stars give off more energy as radio waves than as light waves.

With radio telescopes, scientists can see through the dark areas in the sky. They have found that the galaxies are much larger than we thought and that the "empty" space between the stars is actually full of gas and dust. They also discovered quasars—invisible sources of enormous amounts of radio waves.

Karl Jansky of New Jersey first discovered radio waves from the galaxy in 1931, while he was investigating radio static for the Bell Telephone Laboratories. The source of radio static that he discovered later proved to be located at the center of the galaxy.

The new continent-wide telescopes will be a great advance because the amount of detail to be seen with radio telescopes is limited by the size of the dish. Radio waves are very long and so the larger the telescope, the smaller the details that can be picked out from the radio source. In each new telescope, all 10 dishes will observe the same object at the same time, from several different angles. Then a central computer will combine the results to produce a map showing details as small as those you could see if you had one huge telescope dish 5,000 miles wide!

The 27 dishes of the Very Large Array radio telescope network near Socorro, New Mexico, make this the largest and most powerful in the world. Researchers can move each dish to track distant objects and change the size of the total network telescope as needed.


ERNIE! WANT TO GO TO THE PLANETARIUM
Pete Progress
NO THANKS
PETE I'VE DECIDED TO STOP GOING FORWARD AND START GOING BACKWARDS!
I'M RETURNING TO THE SIMPLE LIFE OF THE CAVE MAN!
I'VE GOT FURS AND I'M CONSTRUCTING MY OWN CAVE!
PUFF PUFF
I DIG UP ROOTS TO EAT FOR SNACKS!
GRUNT GRUNT
HERE'S MY SPEAR AND ALSO SOME FLINT ROCK FOR STARTING FIRES! SEE! NO MATCHES!
I SEE.
AND NOW IT'S TIME FOR THE BIG HUNT, THERE ARE BISON ROAMING FREE ON THE RANGE OUT THERE! SEE YOU LATER PETE!
HOURS LATER
NO LUCK.
I'VE GOT A FROZEN PIZZA AND A MICRO WAVE OVEN AT HOME!
GREAT! I'M STARVED! RETURNING TO THE SIMPLE LIFE IS TOO COMPLICATED!
ZIMMERMAN

Genetic Engineering

Exploring the frontiers of biology

by Dr. Richard Pollak

Recombinant DNA is a new technique that has revolutionized biological science. Just what is this new science, and how will it affect your life in the future?

When the first space travelers begin to colonize distant planets, one of their missions will be to establish agriculture. The conditions they will find for farming on other planets will be very different from those on Earth. The amount of sunshine and water, the temperature, and even the soil will not be the same as that on Earth. So the seeds that these space pioneers bring with them probably will not work on other planets, even after the planets are made more Earthlike.

But the space travelers will not worry. Part of their crew—perhaps including you—will be a team of genetic engineers. **Genetic engineers** are biological scientists who can change the characteristics of plants and animals. These genetic engineers will have the task of creating new varieties of plants that will grow well in the new frontier.

There may also be new diseases that arise under the unique conditions on other planets. But the same genetic engineers will develop new cures, just as scientists are now developing new cures for diseases here on Earth. In fact, in the not-too-distant future, when this space exploration is going on, scientists will probably have cured diabetes. This major disease today is the leading cause of blindness in the United States. Scientists may even have cured most forms of cancer too.

Just think, by then most of the diseases that

frighten us today will be found only in books. Your children will ask you, "Did you ever know anyone who had that disease?"

What makes this possible is the science of genetics and the practice of genetic engineering. The science of genetics has been around for many years, but today genetic engineering is a more powerful tool than ever before. This is because of a new technique known as **recombinant DNA** or gene splicing, which I will explain in detail in this article.

What is genetics?

Most of you already know something about genetics. If I ask you, "What happens if you cross an orange with a tangerine?" and you answer, "You get a tangelo," you are telling me that you know certain facts about genetics.

Genetics studies how the seeds of plants or animals grow into new plants or animals.

Farmers have known about genetics for hundreds of years. For example, farmers understood that if they crossed a horse and a donkey, they would produce a mule, a sturdy animal used for transportation.

This knowledge became more scientific in the late 1800s when Gregor Mendel, an Austrian monk, showed that plants contain genetic elements called **genes**. Mendel's experiments with pea plants showed that these genes contain important biological information about

To colonize planets throughout the galaxy, we will need new plants and animals as well as cures for any new diseases that may arise. The painting above depicts the gradual transition to an Earthlike colony. The new species and cures required will be made by genetic engineers like this scientist, shown here adding human DNA to test tubes of bacteria.

A horse and a donkey produce a mule.

each plant, such as the color of its flowers or the shape of its seeds, and about the daughter plants that grow out of its seeds.

Mendel also showed that these genetic elements are transmitted almost totally unchanged from generation to generation. In other words, the genes from mothers and fathers carry the messages for the development of their sons and daughters. In turn, these sons and daughters will pass the same messages on to their children. The genes are responsible for the way the offspring develop.

Genetic engineering, changing the genetic information, has been taking place ever since humans began agriculture. Genetic engineering changes the varieties of plants and animals around us (the ecology) so that the plants and animals that are best suited to meet human needs are most plentiful.

For example, when a farmer keeps the calves from the cow that produces the most milk or the colts from the horse that runs the fastest and sells the others, he is practicing genetic engineering. The farmer is changing the balance of nature in a way best suited to society's needs. Similarly, a farmer is using genetic engineering when he gets seeds for next year's crops only from the plants that survive a disease that wipes out the rest of the crop.

Genetic engineering today

Genetic engineering today is more scientific and deliberate than these agricultural practices. This is because it is based on a more thorough understanding of genetics. In fact, in recognition of contributions to this new knowledge, Dr. Paul Berg just received the Nobel Prize in chemistry, a world-renowned science award given each year by the Swedish government.

Dr. Berg, who is a professor of biology at Stanford University in California, is sometimes called the "father of genetic engineering." He carried out the first successful experiments to show that the genetic material of one species could be inserted into a second species and then function in a normal manner.

In doing these experiments, Dr. Berg and his fellow workers changed the biochemical processes that determine growth and development in an organism—its **physiology**—by changing its genetic makeup.

For example, scientists like Dr. Berg were able to take a type of bacteria and change its genetic makeup into a "new" bacterium that could produce the human protein insulin. Then scientists could use the new bacteria like a biochemical "factory" to produce human insulin in large quantities for the treatment of the human disease of diabetes. Until now, the insulin used by doctors to treat diabetes came from pigs and cattle. This animal insulin is expensive and not as good as human insulin.

The technique that Dr. Berg used to "create" new bacteria is known as recombinant DNA. Basically, **recombinant DNA** involves chang-

Dr. Paul Berg won the 1980 Nobel Prize in chemistry for his work in recombinant DNA.

ing the biochemical processes in a living cell by changing the genetic makeup of the cell—its genes. The DNA from one organism is "recombined" with the DNA of another.

The **cell** is a fundamental unit of life. Some simple forms of life, such as bacteria, consist of only a single cell. More complex organisms are made up of billions of cells, each working together as a "building block." In complex organisms, the cells become specialized and are often very different from one another.

The **genes** are biochemical molecules that contain the "master plan" for the cell's characteristics—how it grows, what it looks like, and what it does.

DNA: The master molecule

The biochemical molecules that contain the genes for almost every living thing are called **deoxyribonucleic acid**, or DNA for short. DNA is the "director of operations" for an animal, plant, or bacterium (*bacterium* is singular for the plural *bacteria*). This master molecule contains the instructions for the development and functioning of all cells and organisms. Almost every living cell contains DNA; the DNA is found in the cell's nucleus (see Figure 1).

DNA is a very long, thin molecule that has two parts (see Figure 2). The backbone of the DNA molecule is two very long strings twisted around each other in a double spiral or "helix." Connecting these two spirals are its other parts, little steps of biochemical molecules called **bases**. You can think of DNA as a very long spiral staircase supporting the steps of genetic information.

There are four different kinds of bases: adenine, cytosine, thymine, and guanine. Each base is a "letter" of the genetic code. Each combination of three bases is like one word of the code. So the genetic code has an alphabet of four letters that make up three-letter words. Sentences of these three-letter words are called genes. There are millions of genetic sentences in every human cell.

For example, if we imagine the genetic sentence telling how to make an insulin protein is PET THE CAT, it is in a long string of sentences like this:

SKY IS RED **PET THE CAT** WET THE DOG

A living cell has special machinery to read these DNA-encoded messages and translate them. Other parts of the cell then carry out the instructions in the message to produce a new molecule called a **protein.** The new molecule or protein becomes part of the cell's physiology

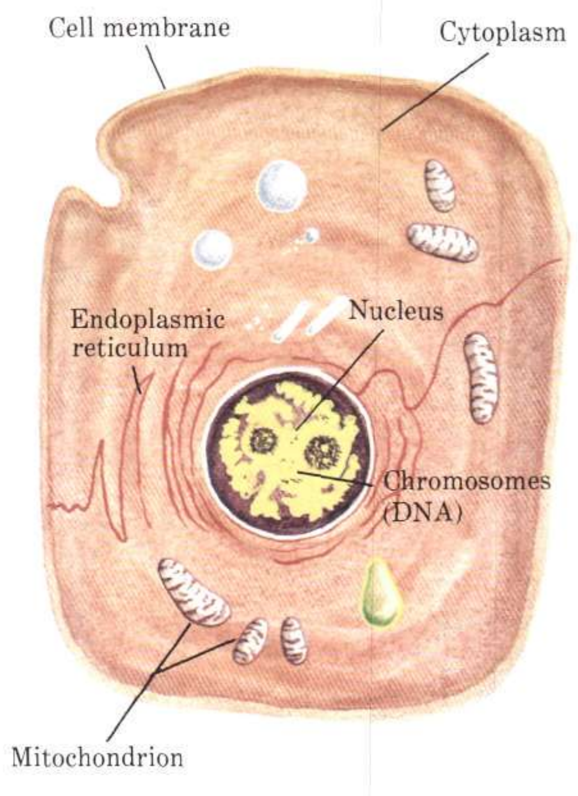
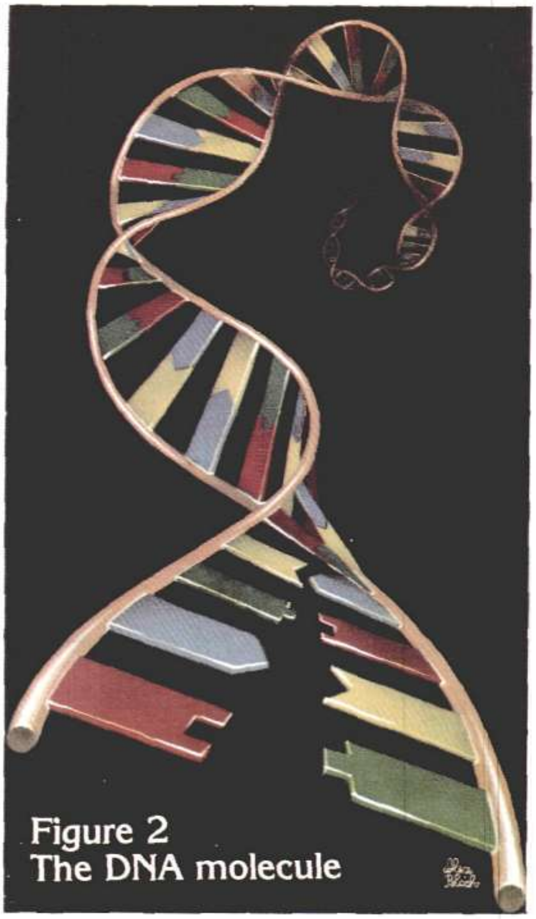


Figure 1
The cell: The basic unit of life

The **cell** *is the basic unit of life; all living things are made of cells. If you have a microscope, you can take a look at some cells. An onion skin is a good example, because its cells are in a thin layer and can be seen easily. Within the cell, you can see all sorts of small structures that carry on the work of the cell. But we are most interested in the genetic material, the DNA. The "brain" of the cell is the* **nucleus.** *You can see it as a darker ball within the cell. The DNA is in this nucleus, or control center. The DNA is a long, very thin molecule. If we made DNA the thickness of a pencil, each cell's nucleus would contain more than 100 miles of DNA. The DNA is packaged in structures called* **chromosomes.** *Every human cell has 46 chromosomes. The chromosomes are very important—many scientists now believe that changes in the chromosome's structure are associated with the evolution of new species.*



James Watson and Francis Crick won the Nobel Prize in 1953 for their model for the DNA molecule. Their DNA model is a very long double spiral, the **double helix.** *The backbone of DNA is two long ribbons of atoms twisted around each other in a spiral. Besides the backbone, the DNA molecule has millions of loosely connected links from one branch of the backbone to the other, in a long, spiral staircase. These links are called* **bases,** *and there are only four different ones used: adenine (blue in the drawing), cytosine (red), thymine (yellow), and guanine (green). Because of their chemical properties, adenine can fit together only with thymine, and cytosine can fit together only with guanine. So the DNA molecule has a staircase of pairs of (adenine + thymine) and (cytosine + guanine). Each gene is made of anywhere from 600 to several thousand of these bases in a row, and one DNA molecule can contain thousands of genes.*

and is used by the cell or organism it is part of to grow and develop.

Each gene or sentence is a message for the production of a particular, unique protein.

If we look at some small pieces of DNA from you and me, a rabbit, and a bacterium, the four different DNA pieces would look very similar. But the DNA-encoded messages are different for each organism or species. Your DNA and my DNA are very, very similar; if they were exactly alike we would be identical twins. But your DNA is not exactly like mine—that's why we walk, talk, and look different from each other. Our DNA is enough alike, however, that we are both members of the same species—*Homo sapiens*.

Every human's DNA is different from that of a rabbit. Because of these differences, no matter how much lettuce and carrots that you might eat and how much you hop around, you will never turn into a rabbit. I guarantee it!

The difference between the DNA in humans and the DNA in bacteria is even greater than the differences in animal and human DNA. But again, the important thing to remember is that humans, rabbits, and bacteria use their DNA in exactly the same way: the language is the same, but the messages are different.

The **DNA** is the genetic material passed on to us from our parents' genes that contains the directions for the development of our characteristics.

Genetically engineering insulin

As I mentioned earlier, Dr. Paul Berg won the Nobel Prize in 1980 for inserting the genetic material of one species into another species. One of the important uses of this kind of genetic engineering, or recombinant DNA, is to make the protein insulin. Making insulin is one of the first successful commercial uses of recombinant DNA in history.

Until recombinant DNA technology was invented, no bacterium ever had a gene with the code for producing insulin. Using recombinant DNA to engineer a bacterium to produce insulin was a tremendous feat.

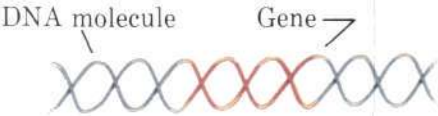
Just think, how could bacteria possibly make human insulin?

First, genetic engineers had to get the short stretch of human DNA, the gene, that codes for the production of insulin. They had to obtain this insulin gene from human cells or make it synthetically in the laboratory. (See Figure 3.)

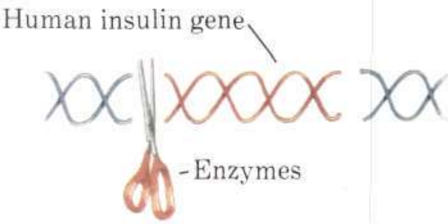
Then the scientists had to find a chemical "scissors" to cut this gene out of the DNA. Next they had to splice this insulin gene to a piece of

Figure 3
How recombinant DNA works

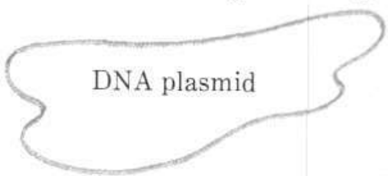
1 Find the gene for human insulin.



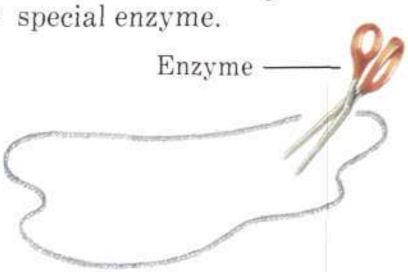
2 Cut the insulin gene out with enzyme.



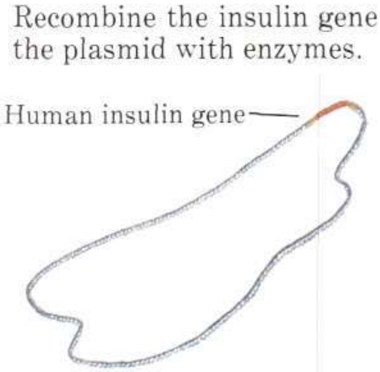
3 Find the piece of bacterial DNA where the insulin gene will go.

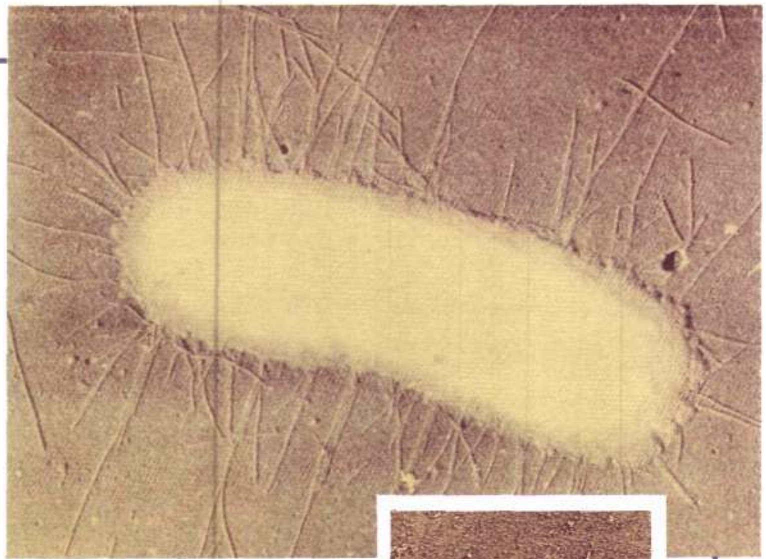


4 Cut a hole in the plasmid with special enzyme.



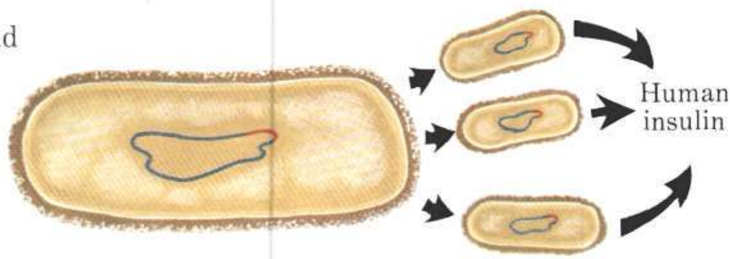
5 Recombine the insulin gene and the plasmid with enzymes.





Above, Escherichia coli, *a one-celled organism used as the host bacterium for making human insulin. At right, electron micrograph of DNA. Note the circular plasmid rings.*

Recombinant DNA *is* **recombining** *the DNA from one species with the DNA from another. To make human insulin, genetic engineers had to recombine the DNA gene for insulin from a human cell with the DNA of a bacterium, called* Escherichia coli, *or* E. coli *for short. The genetic engineer first must isolate the gene for human insulin and cut it from the DNA molecule using enzymes as scissors. At the same time, he must isolate a plasmid from the* E. coli. *A* **plasmid** *is a small loop of DNA with only a few genes. (Most of the bacterium's DNA is in very long chromosomes, not plasmids.) He cuts the plasmid with a different enzyme to make room for the human insulin gene. The insulin gene is then biochemically inserted into the plasmid and fastened with an enzyme that stitches the pieces of DNA together.*



6 Put the recombined DNA into a fresh bacterium. As this *E. coli* reproduces, its offspring start making human insulin in a test-tube factory.

DNA that belongs to the "host" bacterium, the bacterium they were trying to engineer to become an insulin-maker. This required finding the right kind of "glue." The scientists then had to get the host bacterium to read the message of the spliced gene telling it to produce human insulin.

You can see that there are many points along the way where things would not go very smoothly. For instance, it is very difficult to isolate the gene for insulin in a human DNA molecule. How do you know where the genetic sentence begins and ends? If you begin in the wrong place, you might get a meaningless sentence like RED PET THE, instead of our sentence for insulin: PET THE CAT.

Remember, the DNA molecule is very tiny and thin. It can't even be seen with a light microscope. Therefore, the genetic engineers must do all their work in test tubes, using solutions containing the DNA molecules and many other chemicals.

Isolating one particular gene is like finding a needle in a big haystack . . . blindfolded. To accomplish this step requires clever chemical techniques, electron microscopes that are much more powerful than light microscopes, and scientists who work hard, have wonderful imaginations, and who don't give up easily.

It took many years of hard work, but genetic engineers were finally able to tell just where the genetic sentence for insulin began and ended on a human DNA molecule.

The next step is also complex: taking the chemically isolated insulin gene and splicing it to the host DNA molecule. This is much more difficult than tying two very tiny strands of wet rope together under a microscope.

Once again, biochemical techniques are used. **Enzymes**, molecules discovered in living organisms in the last century, speed up chemical reactions, cut molecules apart, and stitch other molecules together. One kind of enzyme is used to cut the gene out of human DNA, and another kind of enzyme is used to stitch the gene to the bacterium's DNA.

But the problem is trickier than just stitching two molecules together. In the first place, the insulin gene can be attached only in certain places where it will be read by the machinery in the bacteria cell. Some regions of the host DNA are silent and have no code messages. When scientists attach the insulin gene at one of these silent regions, it also remains silent and doesn't do its job.

Or, scientists might attach the insulin gene in the middle of another genetic sentence by mistake. Then its message could be misread:

WET THE PET THE CAT DOG

But, as actually happened, suppose that everything has been done correctly up to this point and still the host bacterium produces no insulin. What else could be wrong?

The DNA puzzle

Many biologists look at genes as if they are "beads on a string." They believe that once we know all the genetic messages and just when the cells use each message, we'll know how all cells and organisms work. But other biologists believe there is more to the story, that the cell's characteristics are also influenced by large pieces of DNA or even all the DNA in a cell, and not just the DNA-encoded messages. They think the whole is greater than the sum of its parts. This means the DNA interacts with the cell and its environment in complex ways, which we don't yet fully understand. Observed changes in genetics and physiology could be explained by this approach but not by the "beads on a string" model. Compare this problem to a musical composition. In a symphony, the theme that is given at the beginning gets more complicated and exciting as the symphony progresses. You, the listener, are remembering the theme from the beginning as you listen to the process of development in the symphony as a whole. As a result of listening to the entire piece, the parts now mean something different from your first perception.

For years farmers have used genetic engineering techniques to breed crops resistant to diseases such as corn blight (inset). This genetic engineer at Genex Corporation is transferring engineered bacteria into a test tube of rich broth, where they will quickly multiply and produce large quantities of desirable proteins.

One possibility is that some types of bacteria might have an enzyme that digests insulin. So if the scientist used this type of bacteria as a host, the experiment would end up with just tiny pieces of insulin, because the insulin produced by the bacteria would be chewed up as soon as it's produced. The scientist would then have to go back to the drawing board to engineer a bacterium that would produce insulin but would not produce the insulin-digesting enzyme.

Other problems also arise that are even more interesting to the scientist. Even such small and simple organisms as bacteria have thousands of genes, making the thousands of molecules needed for bacterial life. If the engineered bacterium made only one or two insulin molecules with its new insulin gene and then "shut off" that gene, the few insulin molecules produced would be lost in a sea of thousands of other molecules made by the bacterium. It is extremely difficult to find such small amounts of insulin in this sea of molecules and purify it for medical purposes when it is so dilute.

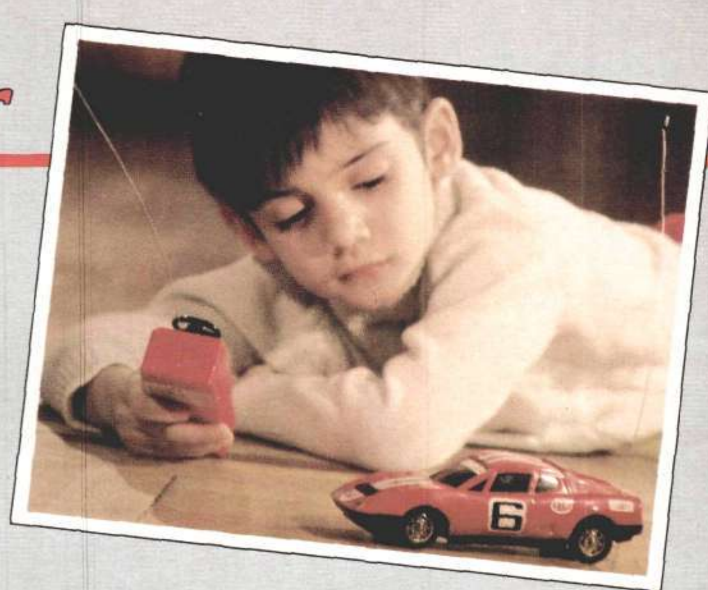
Obviously, you need to keep the insulin gene turned on permanently. This means the bacterium would make insulin continuously—something it does not do for many of its other molecules. Although it is possible to find bacteria that do this already, it would be better to learn how to control the on-off switch. If scientists can better understand how the genes are turned on and off, they will have a powerful tool to use in solving other genetic problems.

In the case of insulin-producing bacteria, genetic engineers overcame all the problems I have described here, with a lot of interesting discoveries along the way that are very important for understanding all biology, not just recombinant DNA work. That is why scientists who are working on practical tasks such as engineering bacteria to produce biochemicals like insulin must be willing and able to take on questions that are more far ranging than the immediate task at hand.

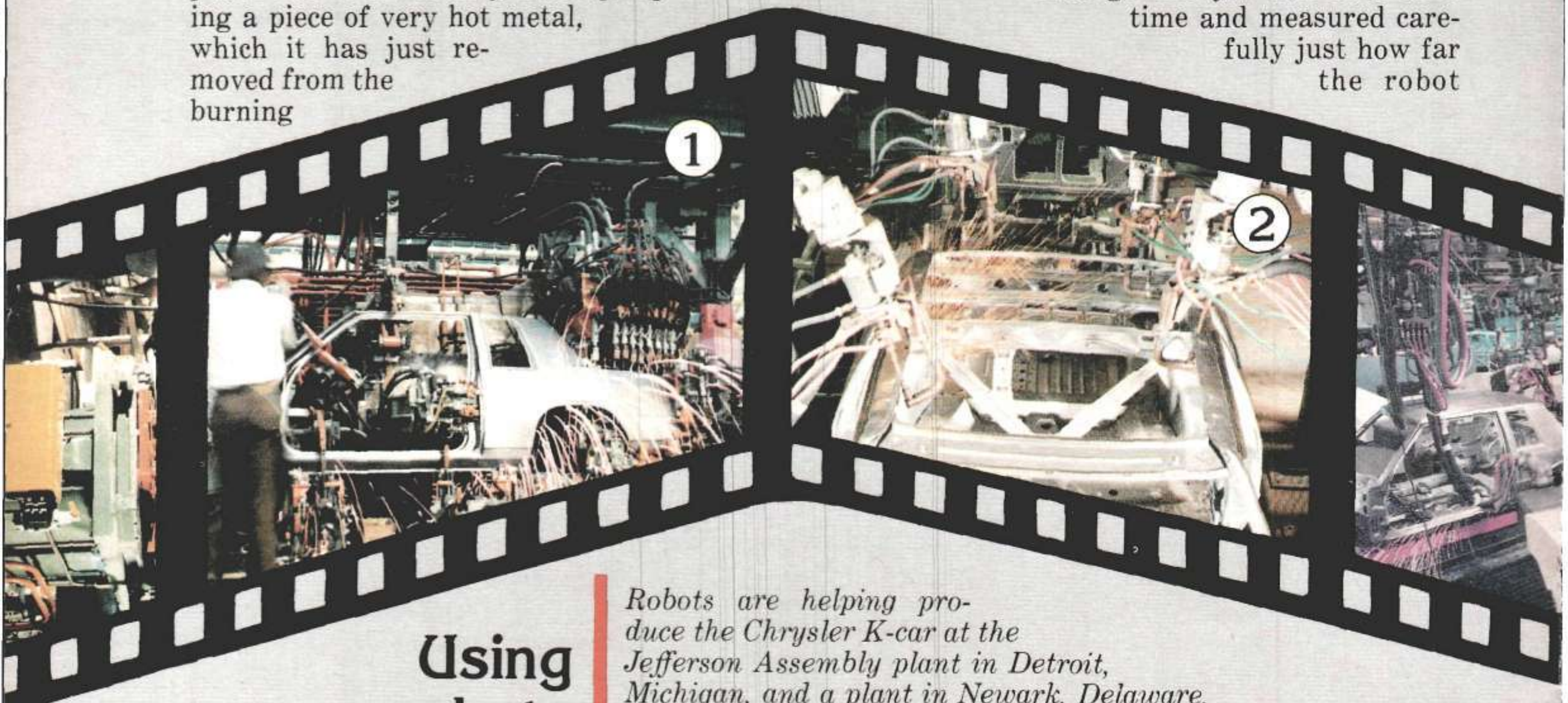
You can see that this makes genetic engineering exciting and thoughtful work. In the scientific struggle to produce the insulin that diabetics need, genetic engineers come face to face with the fundamental questions of biological functioning. There are many questions still unanswered, and as genetic engineering makes progress, there will be even more questions raised. A real cure for diabetes will mean engineering human cells taken from the diabetic's own body to produce insulin, and then replacing the engineered cells in the diabetic's body to cure the disease permanently. But what questions must be answered before this can be done? Scientists will have to get more detailed knowledge about the basic processes involved as the gene functions in the human cell.

Will you be one of the scientists venturing into the frontiers of biology as a genetic engineer? Perhaps you will be a member of that space crew that will tackle the biology questions that come up on the frontiers of space travel in colonizing other planets.

Robotics: The new tool



The Robots are coming! The Robots are coming! But wait—don't run away. These are real robots, not the fake robots shown in movies and TV. Real robots are not dangerous and do many things to make our lives better. That's because only people can make robots and "teach" them how to work. Without people, robots are merely chunks of metal, gears, motors, and wires. A scientist figures out how to put the parts together to make a robot that can do a particular job. There are many kinds of robots. The toy robot car in the photograph is moving according to the radio signals the boy sends from his hand-held transmitter. The next photo shows a working robot grasping a piece of very hot metal, which it has just removed from the burning furnace. Handling molten metals to shape them into tools and parts is a very dangerous job for people. To design a robot to do the job, a scientist first watched how human workers grab the hot metal with tongs to remove it from the furnace to a work area where it can be shaped. Then he built a robot that could grab, lift, and move the molten metal. To "teach" the robot exactly the right distance to move its arm, the scientist put the robot through the job one task at a time and measured carefully just how far the robot



Using robots to make cars

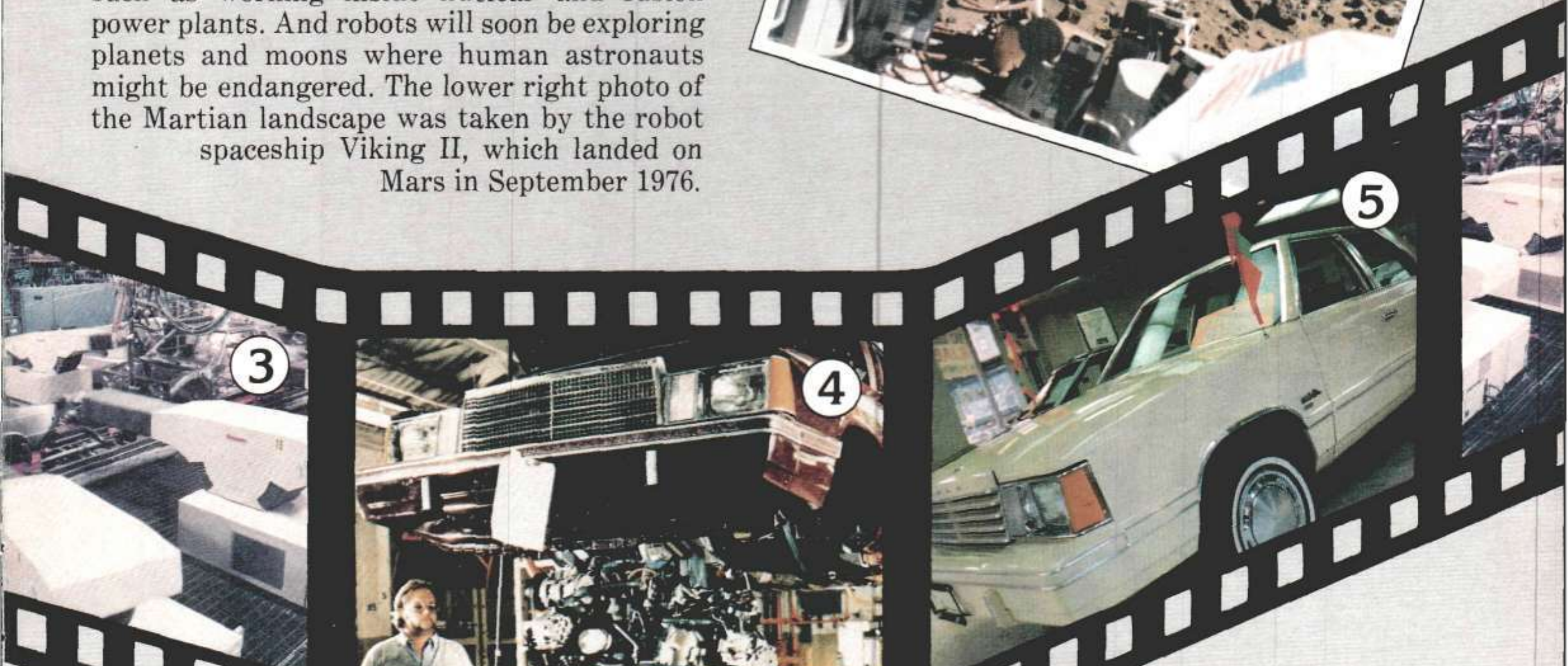
Robots are helping produce the Chrysler K-car at the Jefferson Assembly plant in Detroit, Michigan, and a plant in Newark, Delaware.

(1) "Monotractor," an overhead transfer system, carries the sides of the cars to precise locations where robots weld the parts together.

(2) Farther down the assembly line, the two sides of each car enter the Robogate assembly area where robots weld the sides to the underbody frame.

(3) Imagine how many cars can be welded at once by this army of robots!

must move and how hard it must grasp the metal. A computer programmer then turned all these measurements into a "machine code" of precisely counted electrical impulses that move the robot's motors as required. You can see how fast the robot is moving in the next photograph. We are really just at the beginning of the robot age. Scientists are designing robots to recognize shape, size, odors, and sounds, and to handle fragile objects with "fingers" of soft plastic. Future robots will take on more difficult tasks such as working inside nuclear and fusion power plants. And robots will soon be exploring planets and moons where human astronauts might be endangered. The lower right photo of the Martian landscape was taken by the robot spaceship Viking II, which landed on Mars in September 1976.



(5) The finished product.

(4) The assembled K-car, held together by 3,000 robot weldings, is slowly dropped onto its engine. The man is only supervising this step, making sure the robots do their work correctly.

TALES OF SCIENCE

Samuel Morse

Part II

It may seem hard to believe, but the Voyager 1 spacecraft traces back to my invention of the telegraph in 1838 and my code for transmitting messages using electricity. Although others had the idea, I was able to carry it forward and fight the political battles to get the money for a full test. In fact, when I first went to Congress to get money, they all laughed at me and thought I was talking about **mesmerism** (hypnotism) instead of magnetism!

In 1865, just as the Great Eastern neared Newfoundland, the Atlantic Cable broke. All attempts to recapture it failed.

After I first got my idea for a telegraph while sailing back to America on the ship Sully from Europe in 1832, I spent six years working out the bugs in my telegraph system. But in 1838 I successfully demonstrated my electromagnetic telegraph in a New Jersey factory.

In 1844, after another six years spent convincing Congress to finance my new technology, I set up a wire from Baltimore, Maryland, to Washington, D.C., a distance of 40 miles. By 1850, there were telegraph wires connecting the entire nation.

My main interest all along had been to develop the science and industry that would make the young American republic strong and secure. This proved to be critical with the outbreak of the Civil War in 1861. Then my telegraph really got full use as a means of military communications.

A special Signal Corps in President Lincoln's Grand Army of the Republic strung 15,389 miles of wire to carry more than 6 million messages all across the war front. It was the first time an army had been coordinated like that, a historic event!

A	.—	J	.———	S	...
B	—...	K	—.—	T	—
C	—.—.	L	.—..	U	..—
D	—..	M	——	V	...—
E	.	N	—.	W	.——
F	..—.	O	———	X	—..—
G	——.	P	.——.	Y	—.——
H	....	Q	——.—	Z	——..
I	..	R	.—.		

Morse's simple dot-dash code for each letter.

The 1,200 telegraph operators of the Signal Corps were mostly boys in their teens, some only 12 years old. They worked in danger, right behind the war front. Lincoln loved to spend time in the White House telegraph office, calling the boys "Sonny" if he didn't know their names.

Perhaps my greatest achievement was my part in laying the first Atlantic Cable, a telegraph wire thousands of miles long, stretching from Heart's Content, Newfoundland, to Valentia Harbor in Ireland. Cyrus W. Field, a young business partner of mine, carried out my dream when I was 75 years old. The cable was laid four times, but each time it broke. The most heartbreaking attempt was in 1865, when the cable broke just 660 miles from Newfoundland. But we refused to give up. In 1866, the Great Eastern steamboat left Ireland with 2,500 miles of cable and reached Heart's Content Friday morning, July 27. Then Field returned to the spot where we lost the 1865 cable and brought it up, giving us **two** Atlantic Cables!

Field deserves credit for his indomitable perseverance, but the original idea was mine, in 1838. No one was happier than I to see Europe and America united across the sea on which I first got my idea of the telegraph.

Interview

with Dr. Leslie Anne Leinwand

Dr. Leinwand is a genetic engineer working with recombinant DNA. She is an assistant professor in the Department of Microbiology and Immunology at Albert Einstein College of Medicine in New York City.

Question: How did you become interested in biology?
Leinwand: I was always interested in science, but it was taught in a dull way, as if it weren't exciting. I think children should be taught about genetics and the exciting frontiers of biology from an early age.

I didn't connect science with experimentation until the 10th grade, when we had to do a science project. I decided to see how drugs would affect the behavior of insects using caffeine and a few other things. I noticed that the drugs changed the behavior of the insects, and it fascinated me! I felt that I had discovered experimentation all by myself. It was so much fun. I wanted to know what would happen if you did this or that to the insects. That was probably when I first thought that I really wanted to be a scientist. I wasn't sure up to that point.

Question: How did you become a genetic engineer?
Leinwand: I became fascinated with this area when I took a genetics course in college. I started thinking about the relationship of genetics to physical things like diseases. I wanted to study disease at a deeper level than, "the patient has a high temperature." At that point, I was still thinking of becoming a doctor, of treating the symptoms of disease. But gradually I began to wonder about genetics and the activity of certain genes and how what happens in the cell could cause the outward signs of disease. I thought there must be specific biochemical processes that produce certain disease states. Now I am more oriented to basic science—away from cures and symptoms and more toward understanding what causes these things in the first place.

Question: What positive things do you think will come out of recombinant DNA research?
Leinwand: I think there will be many practical applications. Most important to me, personally, is my work on dissecting individual genes and being able to understand what the structure of genes has to do with their function. I'm interested in what it is about the conditions in the cell that makes a gene active or inactive. For example, why do embryos—organisms developing from fertilized eggs—turn on some genes and turn off others? What affects this?

Finding the answers to questions like this could not be done without recombinant DNA. Recombinant DNA has completely revolutionized science. Things have changed so rapidly, especially in the past five years. Experiments you thought were impossible are now possible. On the medical side, there are several genetic diseases like *thalassemia* that we can now understand from recombinant DNA research. I am thinking of getting into this work, which is very exciting and holds great promise for helping people.

Hydrodynamics

The motion of a liquid drop

Why are soap bubbles shaped like spheres? Why are some galaxies spiral? Why do planets bulge at their equators? These experiments with a drop of oil will give you some answers to questions about shapes in nature. You will see that the shape of an object reflects how its energy is distributed.

Here is the equipment you will need:

- large water glass with clear sides
- measuring cup
- rubbing alcohol
- vegetable oil (cooking oil)
- tablespoon
- butter knife
- toothpick, sewing needle, or sharp pencil

In the measuring cup, mix three parts rubbing alcohol with one part water in an amount large enough to nearly fill the water glass.

For example, if your water glass holds one cup (8 ounces), use 2 ounces of water mixed with 6 ounces of alcohol.

Pour the mixture of alcohol and water into the glass.

Now, with a tablespoon, carefully pour some oil into the mixture. Use about 2 tablespoons of oil.

The oil should form into a ball, or sphere, that floats in the alcohol and water mixture. (The sphere in the photograph is distorted by the curvature of the glass.) If the sphere sinks to the bottom of the glass, add small amounts of water until it floats. If it stays on the surface, add small amounts of alcohol to sink it a bit. See what happens as you change the mixture by adding more water or more alcohol.

Since the oil floats in water and sinks in alcohol, we know that its density is between that of alcohol and that of water. (**Density** is the weight per unit volume—a fluid ounce of water is heavier than a fluid ounce of alcohol.) The oil is denser than alcohol but less dense than water. So the mixture we're making should match the density of oil in order to suspend the sphere of oil.

Another thing you should notice is the shape that the oil drop takes—a sphere. The sphere is the smallest surface that will enclose the volume of oil when it is at rest. No matter how big your drop, it should form into a sphere. Any other surface, a cube or a cylinder or even a shapeless blob, would have a larger surface area for the same volume of oil. This is an example of the **principle of least action,** which says that a body will have the shape that most efficiently distributes the energy within the body.

Now you are ready to perform some demonstrations.

Gently tap the oil sphere with your spoon.

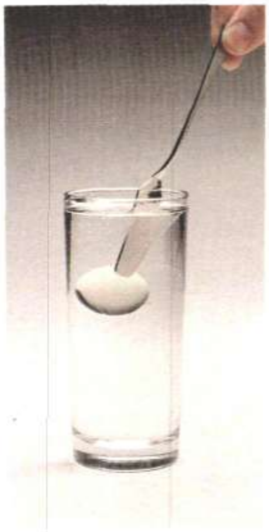
This will set up some oscillations (vibrations) in the sphere, changing its shape. But what happens after a while?

The reason that the oil drop returns to its spherical shape is because it is viscous. All liquids are viscous to varying degrees. This means that they're "sticky"—the molecules tend to stick together.

Syrup is very viscous; catsup is less viscous; and water is hardly viscous at all. The viscosity of your oil drop acts like friction to stop the motion in a liquid. That is why your oscillating blob returns to its spherical shape.

Now take a butter knife and slice the sphere.

The pieces form into smaller spheres. Some scientists think that atomic nuclei like uranium act as liquid drops when they undergo fission in a nuclear reactor. The neutrons are like your knife. They hit the nucleus, causing it to jiggle, and sometimes it splits, reforming into smaller nuclei. This idea is called the *nuclear liquid-drop model*.



To put your sphere back together again, bring the pieces into contact and prick the surfaces where they touch with a needle, toothpick, or sharp pencil point.

Pricking them allows the two separate surfaces of the small spheres to reform a single deformed surface that then rearranges itself into a single large sphere.

For your third demonstration, gently stir the liquid so that the sphere begins to rotate on its axis.

The sphere will flatten out as if someone sat on it. Does this remind you of how planets bulge at their equators?

Stir faster.

What happens? Now it forms a pattern that looks like the spiral arms of a galaxy. Do you think this may be a clue to how galaxies form?

Allow your apparatus to sit for a few minutes.

You will notice that the sphere rises to the surface. Why does this happen?

Hydrodynamics

You have just been performing experiments in the area of science called **hydrodynamics** (from *hydro-*, water, and *dynamics*, motion). **Hydrodynamics** is the study of moving fluids and the forces acting on solid bodies placed in fluids. Scientists find hydrodynamics helpful in all sorts of scientific problems.

For example, oceanographers (scientists who study the oceans) use hydrodynamics to understand the currents of the water. Plasma physicists (scientists who are working to understand fusion energy) also use hydrodynamics. Meteorologists (scientists who study weather and climate) use hydrodynamics to help them understand weather patterns. In fact, the motion of a liquid drop is a valuable study for all areas of science.

The great Renaissance scientist and artist Leonardo da Vinci was an early investigator in hydrodynamics. His interest was both practical and theoretical. Among his many inventions and designs are pumps and other devices for moving liquids from one place to another. He also planned canals in many parts of Italy.

From studying the motion of your liquid oil drop, you have learned a lot about hydrodynamics. The shapes your drop took depended on the amount of energy you gave it when you stirred the mixture or touched it with the butter knife or needle. Each shape you observed corresponded to the particular way in which you disturbed the drop and the drop then reorganized itself.

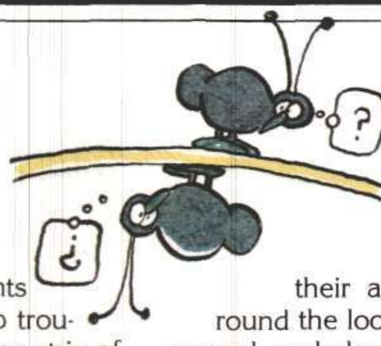
Whirlpool Galaxy in Canes Venatici (M-51). Could the formation of spiral galaxies be related to the hydrodynamics you observed with the whirling oil drop? Can you think of an oil-drop model for the Saturnian system described in the News article on page 2?

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, 888 Seventh Ave., New York, N.Y. 10019.

The ant race



A famous mathematician and his younger brother, also a mathematician, each kept a pet ant. To let their ants exercise without getting themselves into trouble, each mathematician would cut a long strip of paper and tape it together at the ends.

Their ants seemed to enjoy circling round and round the loops of paper, which the brothers would hang by a string from the branch of a tree when they were outside.

One day the younger brother proposed an ant race. He bet his older brother that his ant could go round the loop and return to the starting line twice as fast as the older brother's.

The older brother knew that the two ants were the same size and moved at almost exactly the same speed. So he accepted the challenge. "All right, then," said the younger brother, "we will race. But you must let me build the two loops."

The younger brother cut two strips of paper to exactly the same length, fastened the ends of each with tape, and hung the two loops from a tree branch. He took the pet ants out of their jars and placed them both on their starting lines at exactly the same moment.

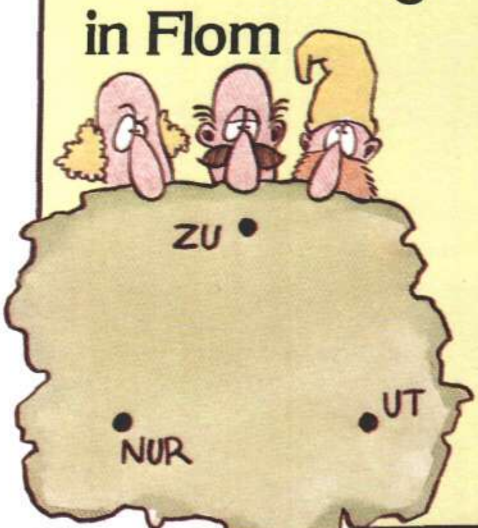
The ants immediately began their accustomed exercise of walking round the loops. Soon they were both halfway around, and almost exactly even with each other.

But soon a strange thing started to happen. As the younger brother's ant neared the starting line, the other ant seemed to be going the wrong way. He hadn't turned around, and he never left the surface of the loop. But somehow, just as the first ant crossed the finish line, the older brother's ant was walking right underneath his finish line, on the wrong side of the paper!

The younger brother looked at his stopwatch: 12 seconds had elapsed. And when just over 24 seconds had elapsed, the two ants were at the finish line, the younger brother's ant for the second time while the other was just crossing it for the first time.

Can you figure out how the younger mathematician designed the loops for the ant race?

Roadbuilding in Flom



The people on the plain of Flom lived in three cities named Nur, Zu, and Ut. Although very industrious, they did not like to waste their time on unnecessary tasks. So when it came time to build a road system, they offered a prize to the wise man who could tell them how to build the shortest road system that would connect the three cities.

Three men offered solutions.

One man said the road system should be a triangle connecting the three cities as if they were the three points of a triangle.

The second man said that was wrong. He said the shortest road system, using the least amount of materials, would be made up of curved lines that were parts of circles.

The third man said that both the first two were wrong. He said that the solution could be found with circles, but that the roads should be built in straight lines.

Can you decide who was right, and why?

Answers

Here are the answers for my puzzles in the December 1980 issue of the magazine.

PUZZLE ONE

As long as you kept the toothpicks flat on the tabletop, you couldn't arrange the 6 toothpicks to make 4 equilateral triangles without breaking the toothpicks.

For this, as in so many other scientific and mathematical problems, the secret is to go to the next **higher dimension.** In this case, the solution is to go beyond the two dimensions—length and width—of the tabletop into three dimensions—length, width, and **height.** Build up off the tabletop and make a four-sided pyramid called a tetrahedron! You now have 4 triangles with 6 toothpicks—3 in the air and 1 on the tabletop.

Tetrahedron

PUZZLE TWO

There are 22 white socks and 16 black socks in a drawer and you can't see the socks as you pull them out. How many socks must *you pull out to end up with a matching pair of white or black socks?*

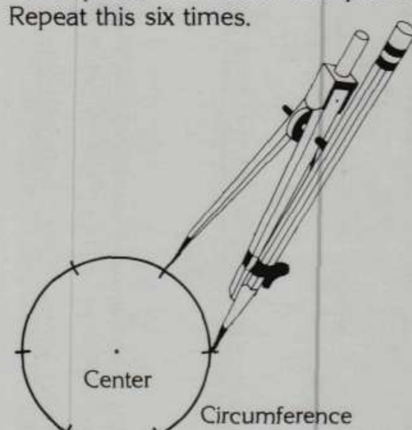
This problem is actually part of a branch of mathematics called **probability theory.** The first thing *to do is to forget about* the total number of socks in the drawer and think about the ones you are pulling out. When you have two socks in your hands, there are only three possibilities: you have (1) a pair of black socks, or (2) a pair of white socks, or (3) the worst case, one black and one white sock.

In the first two cases, you have a pair, but since you can't see, you must pull out another one to make sure. If you now pull out a third sock, it must match either the black or the white sock already in your hand, guaranteeing that you now have a matching pair. So the answer is **three socks!** Now, how *many would you have to pull out* to get two pairs?

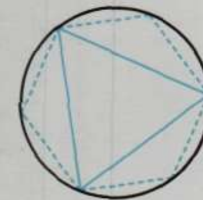
PUZZLE THREE

The problem was to draw an equilateral triangle that fits just inside a circle, using only a compass and a ruler.

Draw a circle with your compass and mark a point somewhere on the circumference. Then, without opening or closing the compass (that is, keeping the distance between the pencil point and the compass point equal to the radius of the circle), place the compass point at the point you marked on the circumference. Swing the pencil end of the compass until it crosses the circumference at another point, and mark this point. Repeat this six times.



Now, connect the first, third, and fifth points with straight lines, using your ruler. You have now inscribed an equilateral triangle in a circle. If you had connected every point, you would have drawn a six-sided figure called a **hexagon.**



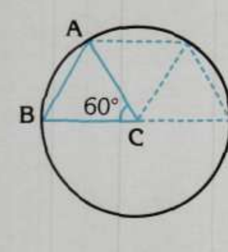
(Dotted line shows hexagon)

No matter how big the circle, the radius—the distance from the center of the circle to the circumference—can always be marked off exactly six times around the circumference. This is quite a remarkable result, since the length of the total distance *around* the circle—called the circumference—is **not** six times the radius, but involves the totally different kind of number called pi.

But we took the straight-line shortcut from one point on the curve to another, called a **chord** of the circle. The sides of the inscribed hexagon are six chords of the circle.

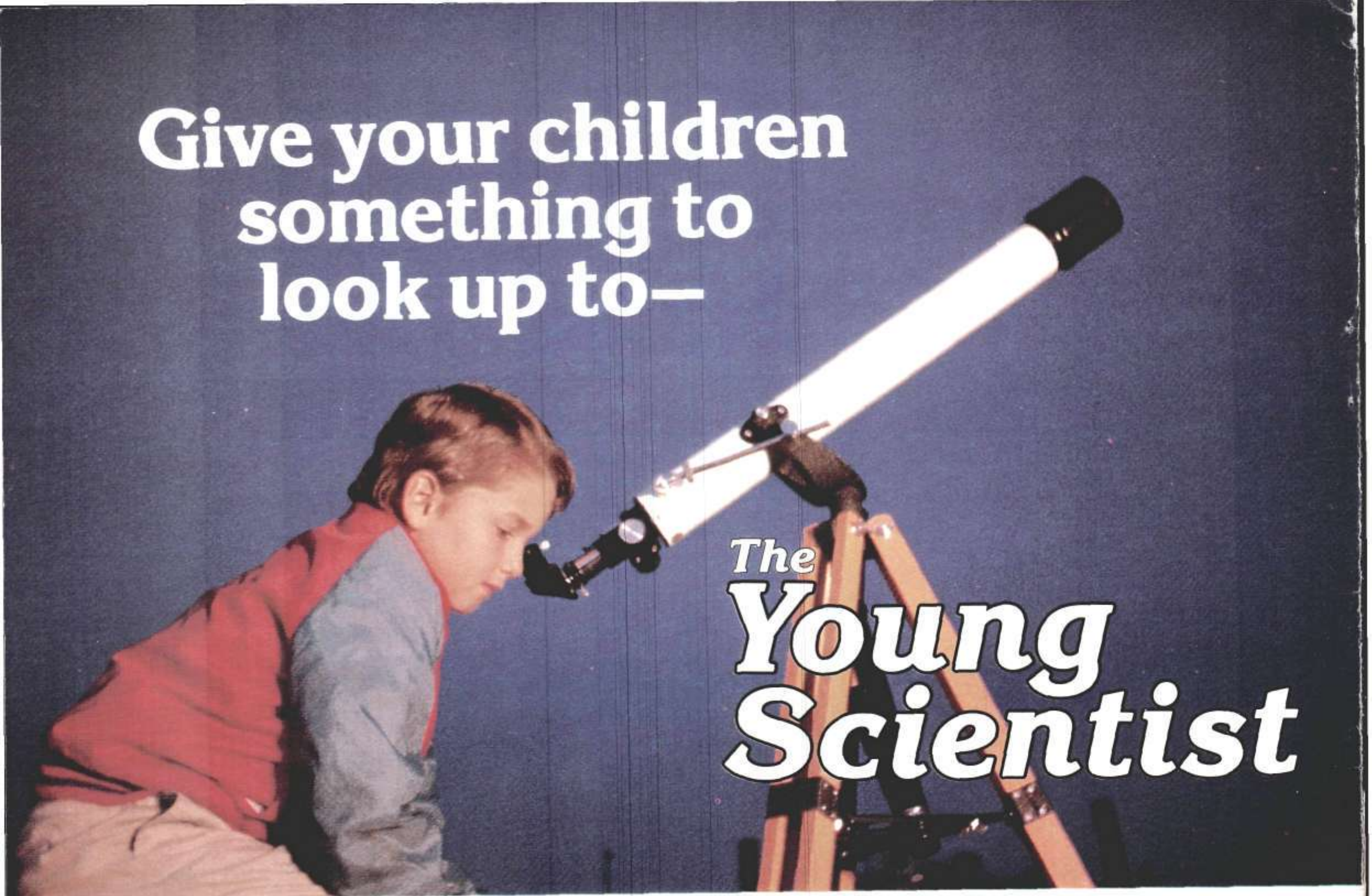
You may wonder why this is true—why does the radius make exactly six chords? Why not five, or six and one-half, or seven? If you already know some geometry, it's *not hard to show why.*

Draw a circle and its diameter. From one end of the diameter, mark off the length of one radius along the circumference. Now connect this point A on the circumference to the center of the circle C and to the near end of the diameter B, making a triangle ABC.



The triangle is *equilateral* by construction (all three sides are the length of the radius). Therefore, its angles are all *60 degrees.*

Now can you complete this proof, using what you know about the angles and sides of equilateral triangles? (**Hint:** You will have to construct six triangles in the circle.)



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