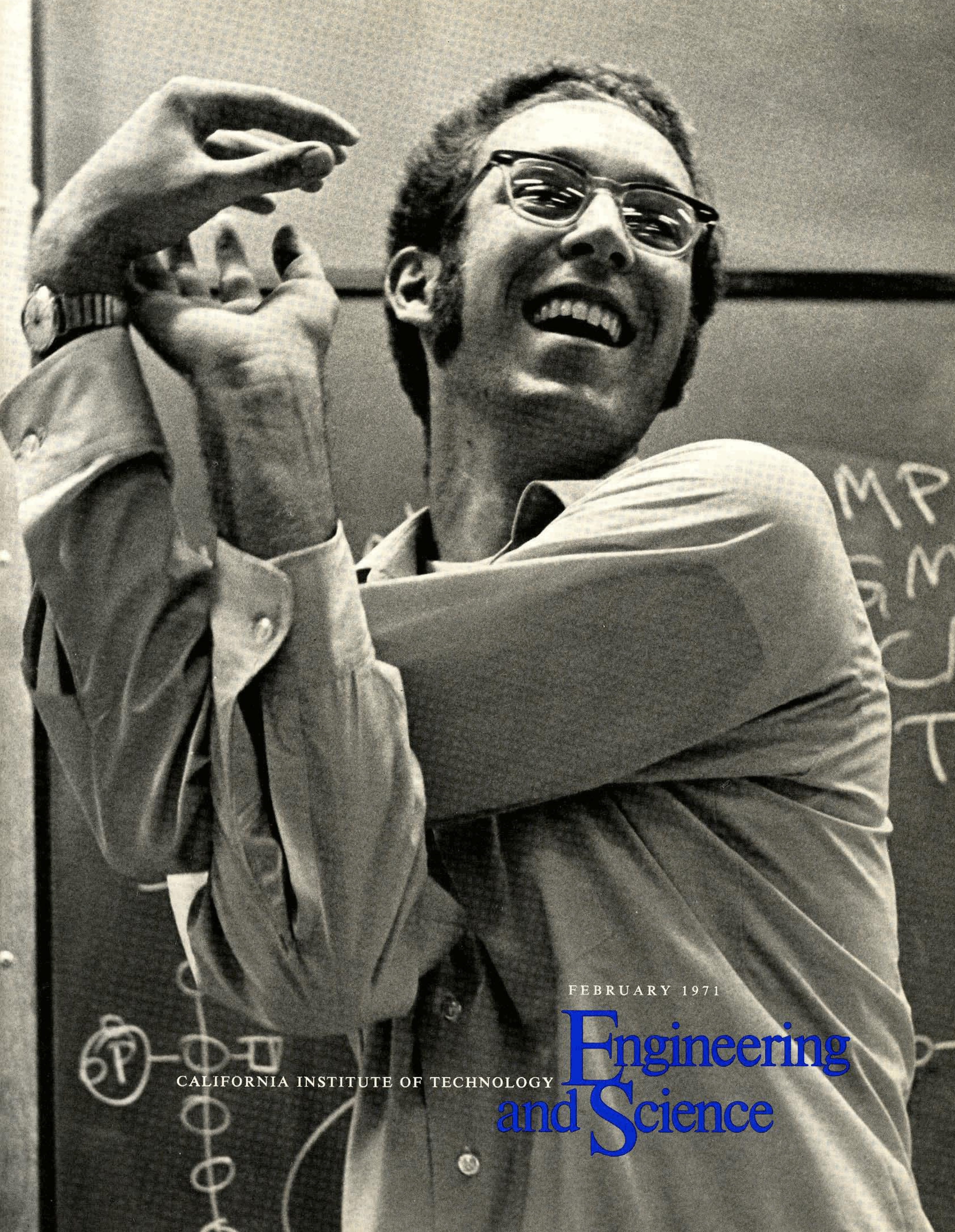
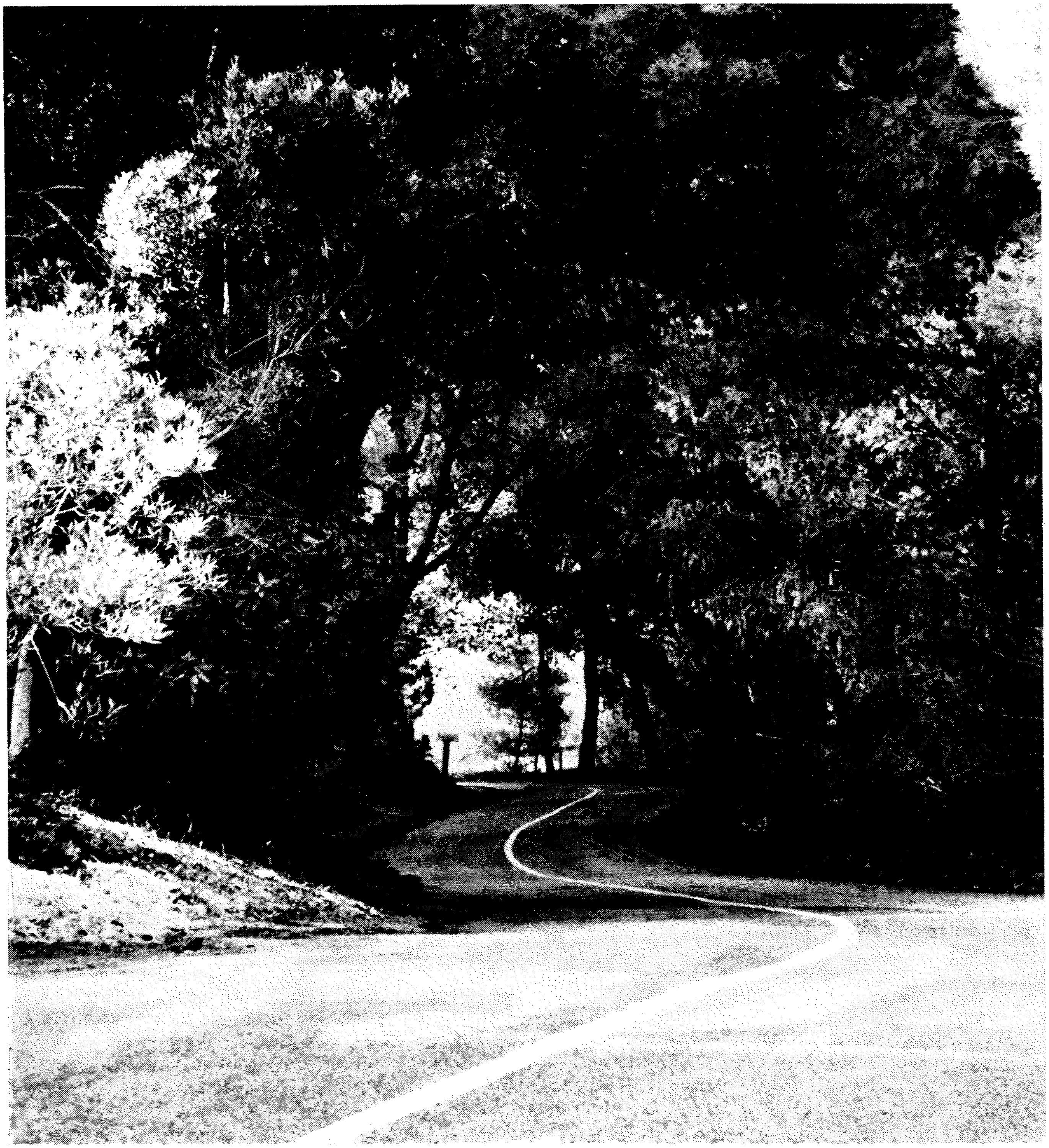


FEBRUARY 1971

Engineering and Science

CALIFORNIA INSTITUTE OF TECHNOLOGY



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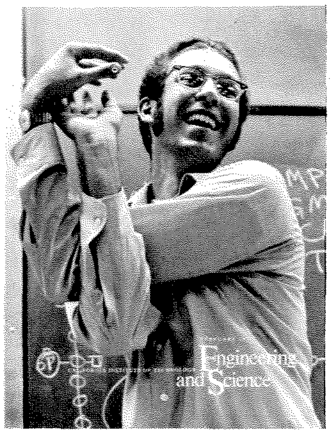
Engineering and Science



In this issue

Man on the Go

On the cover—by impersonating a double helix, graduate student Bill Beranek is doing his best (which is pretty good) to bring science alive for an audience of high school students. In fact, Bill spends a good deal of his time these days bringing science alive for all kinds of people—including scientists. "Caltech Is Not Just a Big Black Box" (page 27) tells about some of his current activities.

Life on Earth

"The Phenomenon of Life" (page 4) by Richard E. Dickerson, professor of physical chemistry, is adapted from the opening chapter of an introductory textbook in biology to be published by Sinauer Associates, Inc., of Stamford, Connecticut, next year. This material was written by Dickerson alone, though his co-authors for the rest of the book are Robert Metzenberg and Millard Susman of the University of Wisconsin, Thomas Eisner and Richard O'Brien of Cornell, and Winslow R. Briggs and Edward O. Wilson of Harvard.

Orbiting on the Ground

John Hall describes how—and where—he spent his vacation in "A Summer Trip to Nowhere" on page 14. John is a PhD candidate in geochemistry and the resident associate of Ricketts House at Caltech.

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EXT

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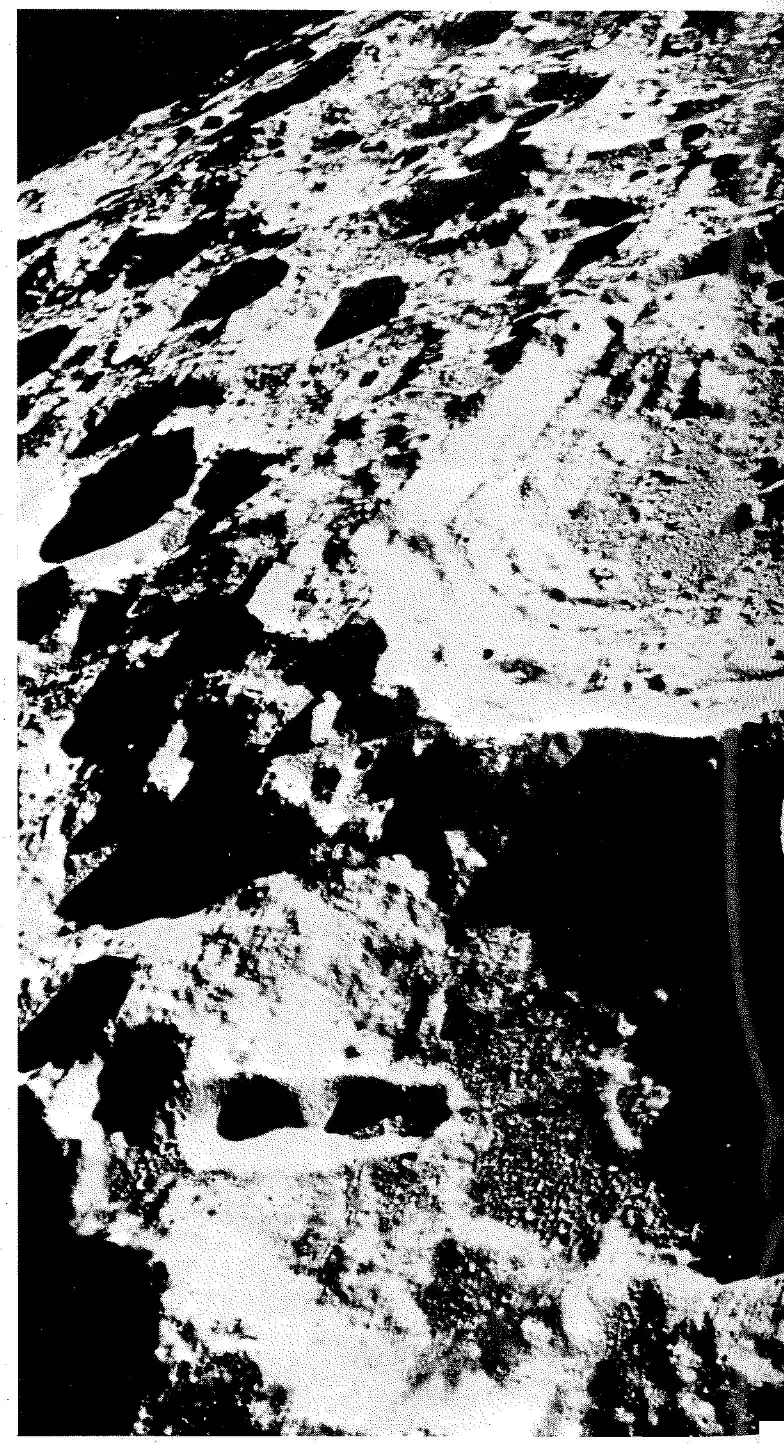
The Phenomenon of Life

What is unique to life wherever it may be found, and what features of life are accidents of its history on this particular planet?



This photograph of the far side of the Moon was taken from the Apollo 11 command module during lunar orbit. Our Moon has been shown by the Apollo expeditions to be an airless, waterless, lifeless gray sphere, the product of four eons of meteoric bombardment and vulcanism.

Very few men have ever left our planet Earth, and even fewer have seriously had to wonder whether they could get back safely. Most of us take the planet that carries us pretty much for granted. When the Catholic Church in the Middle Ages claimed dominion over "Urbis et Orbis"—City and World—it was claiming just about everything it knew of that mattered to mankind.

Kepler, Copernicus, and Galileo changed our point of view. By demonstrating that the Earth was no more the center of the universe than any of the other planets, they implied that these bodies might be worlds like ours. Fiction writers from Johannes Kepler to Jules Verne and beyond populated our neighbors around the Sun with life, humanoids, and civilizations. The astronomer Lowell built the Flagstaff Observatory in Arizona in 1894 specifically to study Mars, which he believed to be inhabited by intelligent canal-builders. H. G. Wells skirted the problem of the barren appearance of the lunar surface by postulating a subsurface civilization. Invaders from Mars and Venus became the science fiction writers' stock plot lines.

Today we are more knowledgeable and less optimistic about other life in our solar system. Mercury is a lonely cinder, keeping one face forever toward the Sun. Venus may have surface temperatures close to that of melting lead. Jupiter and the outer planets are apparently too cold. Our own Moon has been shown by the Apollo expeditions to be an airless, waterless, lifeless gray sphere, the product of four eons of meteoric bombardment and vulcanism. Only Mars offers hope, although slim, for life even of a primitive kind. More than at any time since the Middle Ages, we realize how special our own planet is.

A common theme of the Apollo astronauts has been the surprising lack of color anywhere in the visible universe save Earth. James Lovell on Apollo 8 remarked: "The Moon is essentially gray: no color. It looks like plaster of paris or sort of a grayish deep sand . . . The best way to describe this is really a vastness of black and white—absolutely no color." Charles Conrad, on Apollo 12, was even more blunt: "If I wanted to look at something that by Richard E. Dickerson

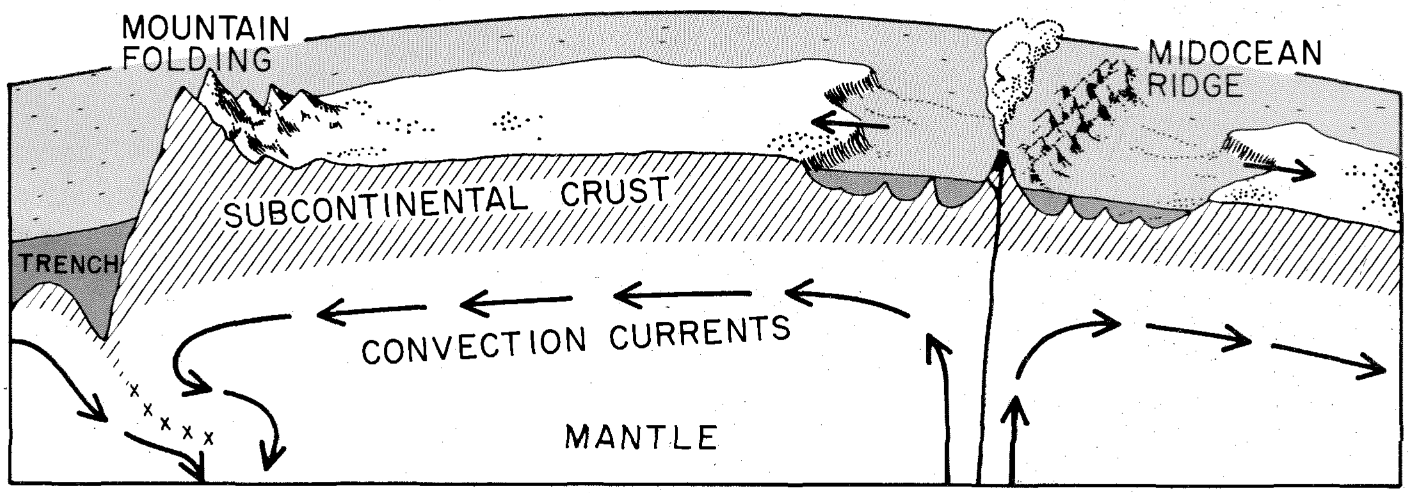
looked like the Moon, I'd go out and look at my driveway." The sky above the Moon, Conrad said, appeared to be very black, "like ebony."

The Earth presented a different picture to the first men ever to leave it completely. Lovell described it during the ascent of Apollo 8: "For colors, the waters are all a sort of a royal blue. Clouds, of course, are bright white . . . The land areas are generally brownish—sort of dark-brownish to light-brown in texture." Later, he speculated, "What I keep imagining is that, if I were some lonely traveler from another planet, whether I would think it was inhabited or not . . . I'm just curious whether I would land on the blue or the brown part of the Earth." He was moved to make what must be the most eloquent comment to come out of the space program: "The Earth from here is a grand oasis in the great vastness of space."

What makes Earth such an oasis in an otherwise inhospitable solar system? Why does Earth have seas, and why have these seas been the cradle of life? Just what is this rare and peculiar phenomenon that has appeared on the third planet alone out of nine planets? Why has the family of living organisms developed and diversified as it has on Earth, and would we expect to find similar things happening, given comparable conditions, on planets around other stars? What is unique to life wherever it may be found, and what features of life are accidents of its history on this particular planet? Some of these questions have no answers yet, some may be answered in the next decade of study and exploration, and some may never be answered until we find another planet on which this phenomenon has appeared independently. Until then, the best we can do is look carefully at what has happened in the one case for which we have direct evidence, the planet Earth.

LIFE ON EARTH

Somewhat more than 5 billion years ago, our solar system evolved, including the planet Earth. Older theories about the formation of the Earth spoke of the cooling and condensation of hot gases. Since the early 1950's, it has been considered more likely that the planets were built up by the gravitational attraction and aggregation of cold dust and particles into clumps of solid matter. As the size of the Earth grew by this cold accretion process, the weight of the outer layers compressed the center. This pressure, and energy from radioactive decay, together heated the interior until it finally melted, and the settling of heavier elements led to the fluid iron and nickel core that we have today. Around this core of radius 2,200 miles lies an 1,800-



Adapted from "Continental Drift," by J. Tuzo Wilson.

Because of its liquid core and semifluid mantle, Earth is constantly in a state of geologic change. Where currents in the mantle rise beneath an ocean, they cause spreading of the ocean floor and separation of the continents bordering it. The crust may be piled up where it meets sinking currents to produce folded mountain ranges, oceanic trenches, and deep earthquake zones. All of this has had a profound effect on the evolution of life.

mile-thick mantle made of dense silicate minerals similar to basalt. Covering this is a lighter crust, as much as 25 miles thick under the continents but only 3 miles thick under the ocean floor. This crust is the only part of our planet about which we have any direct chemical knowledge.

From the scarcity of helium and other noble gases on Earth compared with their abundance on the Sun, it would seem that Earth lost its original atmosphere. There was a time when Earth was a sterile, rocky ball with neither atmosphere nor oceans. A new atmosphere arose in time from the outgassing of the mantle and crust. Water vapor from the interior condensed into seas, which ultimately became the cradle of life.

The pattern of sea and land in those distant times was totally different from what we now find. The crust of the Earth floats on a semifluid mantle, in which convection currents of basalt flow up from the heated core, expand laterally, and sink again into the interior. One such rising current in the mantle lies beneath the mid-Atlantic ridge, with a flow to the east and west of about a centimeter per year. The Americas and Europe and Africa are slowly drifting apart, and one of the side effects of this drift has been the folding and uplift of the Rockies and Andes mountain chains. Since the beginning of the planet, the Earth's crust has been in constant motion. Sea beds have been uplifted and folded into mountain ranges, and gradually eroded down into plains which have been flooded again. The history of Earth is one of constant and ceaseless change. External accidents such as meteor impact craters have been quickly erased, and today we see only the most recent ones.

The Moon and Mars present a far different aspect. They are essentially static worlds. They have few tectonic processes comparable with continental drift and crustal folding in Earth, and we think we know why. Moon, Mars, and Earth increase in mass in a regular progression: Mars is 8.7 times the mass of the Moon, and Earth is 9.4 times the mass of Mars. Both Moon and Mars were so small that the heat generated in their interiors by gravitational pressure and radioactive decay could escape from the surface as fast as it was produced. To use a nuclear analogy, the Moon and Mars were below the critical mass for the required buildup of temperature for a molten core. If their interiors melted at all, they probably solidified again as heat was radiated from the planetary surface. They became solid balls of rock, and the convection currents that shape the surface of the Earth either never developed or never lasted. The small size and weak gravitational fields also meant an early loss of what initial atmosphere they possessed, with far less outgassing from the interior on Mars and very little at all on the Moon. One effect of the lack of molten cores in these planets is their absence of magnetic fields, verified for Mars by the Mariner project.

The oldest rock and soil samples brought back from the Moon by the Apollo 11 and 12 expeditions have been dated by uranium/lead and rubidium/strontium radioisotope methods as 4.5 to 5 billion years old. Both expeditions found basaltic lava flows 3.4-3.6 billion years old, indicating that there was a widespread outpouring of lava over the Mare regions during a relatively narrow time interval. For the first billion years of its history, at least, the Moon was not a static ball of rock. It has been suggested that Mars, and perhaps even the Moon, might have been covered early in its history with shallow seas which were later lost as water molecules escaped the planet's weak gravitational pull and vanished into space. If so, these early moves toward an Earth-like planet were stillborn. The scars of over three billion years of history are visible on the Moon as a heavily cratered surface, and Mars also shows a surprisingly lunar-like appearance. Earth, by contrast, was large enough to develop differently.

This, then, is the stage on which life was to play out its drama—a water-covered planet, with shifting land masses in constant geological turmoil. Some time around three to three and a half billion years ago, the first actors appeared on stage. How and why chemical systems that we would describe as "living" appeared is another subject. But appear they did, and they spread throughout the seas. At one time in the history of the planet, the oceans teemed with life, including fish and well-developed aquatic plants, yet the exposed land remained as sterile as the Moon. The reason was that the land was bathed in ultraviolet radiation from the Sun—radiation so energetic as to be deadly to living organisms. Life was then confined to such depths in the seas (below 5-10 meters) as would shield out this radiation. Photosynthesis arose for another role, yet one effect of photosynthesis was the creation of an ozone layer in the upper atmosphere which blocked the ultraviolet. When this happened, the spread of life to shallow coastal waters and eventually to the land itself was only a matter of time.

Photosynthesis evolved in response to a shortage of natural high energy compounds for food. When this new method of tapping solar energy to synthesize sugars developed, life divided into two classes of organisms: those that made their own food and those that ate the food-makers—plants and animals. Both plants and animals moved onto the land in their own way: animals by migration of individuals, and plants by migration of generations, as spores and seeds were carried to new environments.

With the conquest of the land, the stage was set for the major steps in the history of life. In the animal kingdom this involved the rise of amphibia, reptiles, mammals, the special type of mammals known as primates, and finally that peculiar primate called Man. With the coming of Man, life crossed another threshold comparable to the evolution of the first life, photosynthesis, and the conquest of land. Man became the first thoroughly social animal, by virtue of his ability to communicate by speech and writing. A large part of his heritage became externalized in myths, traditions, custom, and law, rather than predominately internal and genetic. To use an only slightly exaggerated image, his genes were supplemented by libraries. The young fields of behavioral biology, anthropology, psychology, and cultural history are beyond the scope of this article. There is no clear and obvious break in the thread, however. All are stages in the history of life on this planet.

Life evolved at a time when the land and ocean distribution on the surface of the planet was quite different. The earliest traces of hominids, 5-20 million years old, come from the Olduvai Gorge in Kenya, south of the Nile delta. Man probably learned to plant grasses and domesticate animals 10,000 years ago in the Armenian and Iranian highlands north and east of Mesopotamia, and moved down into the river valleys of Mesopotamia, the Nile, and the Indus as he developed irrigation techniques. The effects of irrigation farming in Mesopotamia and the Nile valley are visible even from space as dark zones of vegetation. It puts things in their proper perspective to notice that the direct works of Man are invisible from space, and all that can be seen are his effects on the life of the planet.

CHANGE, EVOLUTION, AND INTELLIGENCE

The process of evolution is essentially conservative, and not innovative. The goal is not to bring about change, but as far as possible to counteract changes that have come about in the surroundings. To use an old example, fish did not first scrabble out of the water and across the mud flats because they wanted to open up new frontiers on land, but because they wanted to find new ponds where they could live in the old way when their former homes dried out. Reptiles did not develop hard shelled eggs to armor plate their embryonic offspring, but rather to give them an aquatic environment under conditions where the bodies of water used by amphibians were not available. To pick an earlier and more speculative example, little aggregates of chemical reactions in the primordial seas did not surround themselves with membranes in order to become more concentrated, but rather to avoid dilution. Or, recasting this in terms less offensive to the sensitive biologist, those local aggregates of chemical reactions that spontaneously synthesized membrane barriers that prevented them from being diluted and destroyed had an increased probability of remaining intact, growing, and developing.

Most evidence of external bombardment has been erased from the Earth's surface. Only the most recent impact craters are visible, such as the Barringer Meteor Crater in north central Arizona. The best calculations on impact conditions suggest that Barringer Crater was dug by an iron meteor of 63,000 tons, 81 feet in diameter, striking nearly vertically with a velocity of 9.5 miles per second. The crater is probably 40,000 to 75,000 years old.

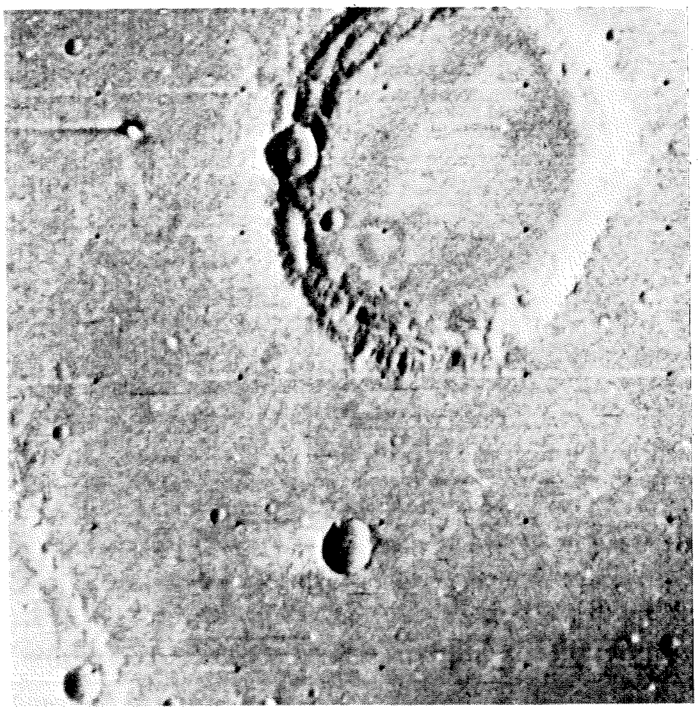
These are all examples of *homeostasis* (from the Greek *homeo-*, or "same," and *stasis*, or "state"). A well-regulated thermostat is a mechanical homeostat. It turns the furnace on, not to make the house hotter, but to keep it from cooling off when the outside temperature drops. Evolution is the history of one subterfuge after another adopted by living organisms to compensate for changes in their environment. A corollary of this is the idea that if there were no changes in the environment, there could be no evolution. This is one reason why the changeable Earth teems with countless varieties of living things, while the static Moon remains as dead as when it was formed.

Evolution is a mechanism for dealing with changes in the environment that are long in comparison with the lifetime of an individual. It can produce a strain of rabbits with unusually heavy fur as a new ice age commences over a period of many generations, but it cannot grow a heavy fur coat on an individual rabbit when unexpected cold weather comes. It can develop mammals such as whales that are adapted to the oceans that their amphibian forebears left 450 million years ago, but it cannot teach a mountain goat to swim. The great advantage of Man over the other animals is that his highly developed nervous system permits him to make rapid responses to rapid changes in his environment. Man *can* put on a fur coat or learn to swim, and can build heated houses and submarines. Intelligence is a trait which allows its possessor to adapt to changes within the lifetime of the individual. If the rabbit and whale are adapted to one set of conditions, Man is adapted to constantly changing conditions. Intelligence is a trait that one would not expect to find in a relatively static world. In a sense, we are the product of the instability of our planet.

LIFE ON OTHER WORLDS

We may find a primitive form of life on Mars, although the more we learn about Mars, especially its low water content, the less likely this appears. The reports from the Russian and American Venus probes are just confusing enough to offer continued hope. But there is a strong possibility that we are alone in our solar system.

Our Sun is a fifth magnitude star of no special character or distinction. What is the probability that another similar star would have one or more planets suitable for life? The difficulty in asking such questions is that we really do not know what to ask. How do we define the limits of conditions suitable for life, when all we have ever seen is one sample of the process? We are strongly tempted to fall into the trap of defining the conditions for *terrestrial* life, and making our boundaries too narrow. Even if we could define these limits properly, how can we estimate the probability of finding a planet with such conditions, when we have never seen a planet of another star, and only recently have been sure of detecting one indirectly by its



This Mariner 6 photograph of craters on Mars shows how closely its history may have paralleled the Moon's history. When the first shots of Mars were sent back by Mariner 4, the unexpectedly lunar appearance of the surface prompted one Caltech astronomer to exclaim, "My God, they shot the wrong planet!"

effect on the motion of the parent star? This is a fascinating guessing game, and one in which no one is likely to be able to prove you wrong.

We can draw a few boundaries, outside of which life is unlikely. To begin with, the planet almost surely must have or have had reasonable bodies of liquid present in which life could evolve. The chemistry of life is basically the chemistry of liquid solutions. Gases alone are too structureless to carry the intricate organization necessary for a system to have the properties of life, and chemical reactions in the solid state are too slow to be useful. A living organism must have solid elements for maintenance of its structural organization, and liquid in which its energy-extraction and other metabolic processes can take place. One can imagine that life, once evolved, could slowly adapt to harsher and harsher conditions as the planet lost much of its atmosphere and liquid phase, but it is difficult to imagine how or why living systems would evolve from the start in a dry and barren world. The conditions under which life could *survive* are surely harsher than those under which life would spontaneously appear.

The planet cannot be too hot or too cold. It must be above the melting point of the parent liquid, whether water or some other fluid. It must be below the boiling point of that liquid, and also below the temperature at which chemical bonds in the solid phase of living organisms are disarranged and broken. On Earth, temperatures high enough to denature proteins and destroy carbon-based organic compounds are deadly. This means that the planet must not be too near or too far from its star. Each type of star will have a "temperate belt" around it, within which planets (if present) will have suitable temperatures.
The orbit of the planet must not be so eccentric as to sweep out of this temperate belt, either dangerously near the star or out on a cometary orbit into the cold.

The planet must not rotate too rapidly. If Earth were turning 15 times as fast, gravity would be nearly counteracted at the equator, and the oceans and atmosphere would be lost. With much faster rotation the planet itself would break up. On the other hand, some rotation is needed to distribute the solar heat evenly over the surface, and to set up convection currents which are necessary for mixing and change in chemical evolution. If Earth kept one face always to the Sun, as Mercury does, then the oceans and atmosphere would distill away from the sunward side and freeze on the cold and dark back hemisphere.

If the temperature falls below the freezing point of the parent liquid for part of the planetary year, then this liquid should be one of the relatively few that expands when it freezes. We sometimes overlook how unusual water (H_2O) is, and how advantageous its properties are to us. Imagine what our oceans would be like if ice were more dense than water, and sank to the bottom. Then the cold ocean bottom, farthest removed from solar heat, would be perpetually frozen, with static layers of water of increasing temperatures above. The summer heat might thaw the oceans down to the hundred foot level, but in winter the ice would creep up again closer to the surface. The ocean temperature would fall steadily with depth. With the heavier cold layers at the bottom, there would be no thermal convection currents such as are so typical in our real world. The oceans would be stagnant and motionless. They would be far less efficient as temperature-moderating devices, warming the continents in winter and cooling them in summer. Finally, they would be less suitable homes for evolving life. The mixing and distribution of chemical substances, and the *change* that is so necessary for chemical evolution, would not occur.

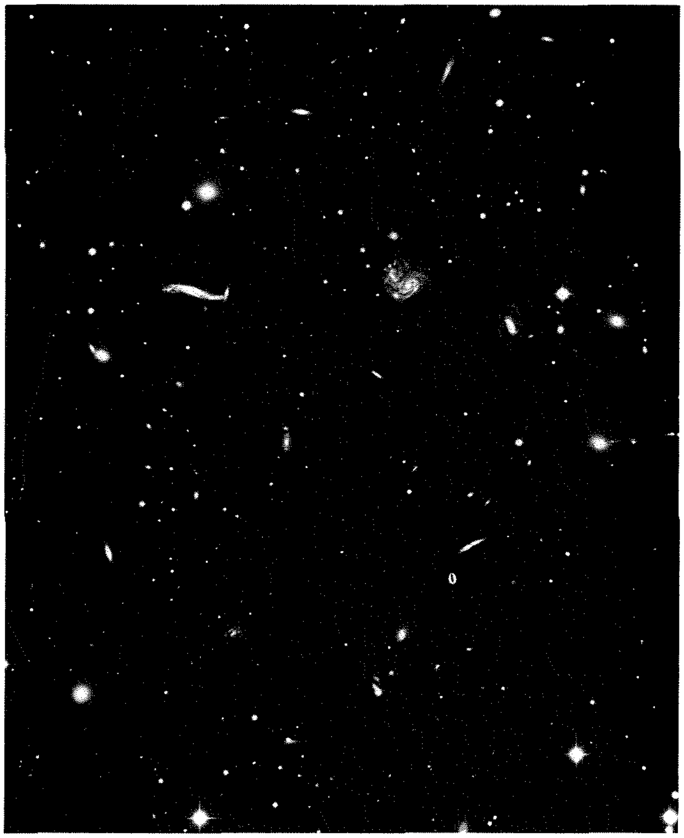
This limitation on buoyancy of the solid phase is a severe one. Other compounds similar to water, such as ammonia (NH_3), hydrogen fluoride (HF), and hydrogen sulfide (H_2S), have solids that are denser than the liquids at their freezing points. Only printers' type metal and a few other alloys of cadmium and bismuth expand upon freezing, and these are hardly likely candidates as media for life. We cannot say that water is the only liquid in which life could evolve, only that the problems created would have to be solved some other way in other liquids.

The star of a life-bearing planet cannot be a variable star, flaring up periodically to wipe out what had evolved. Judging from Earth's example, it takes something like a billion years for living systems to evolve from a chemical environment, and even longer for higher organisms to appear. The star must be stable over such time spans. The level of cosmic radiation from outside, and natural radioactivity in the planet's crust cannot be too high. Yet here we risk drawing our boundaries too close by basing them on terrestrial life. We forget how reactive and corrosive a substance oxygen gas is, and how well-designed our skin structure and body anatomy are to keep this dangerous gas channeled where it will do good and not harm. One could imagine extraterrestrial biologists eliminating Earth as an abode of life because of its corrosive and hyperreactive oxygen atmosphere. Life might evolve in a high radiation environment to produce organisms that secrete shells of lead, like some terrestrial animals do calcium.

The chemistry of life must be based on elements that can combine to build long-chain polymers of varied chemical properties. A crystal is not alive; neither is an automobile or a digital computer. As we build more advanced computers and learn more about servomechanisms and the field of cybernetics, we realize that highly organized systems can possess properties which arise less from the nature of their component parts than

What is the probability that at least one planet around a given star has the right conditions for life? According to one calculation, one out of every 200 stars should have a habitable planet. Spiral Nebula M81 in the Big Bear Constellation contains approximately one million million stars (about the same as the Milky Way Galaxy) and may contain as many as 50 million stars that could have planets comparable with Earth.

how they are put together. The same behavior can be brought about in systems made of quite different physical parts, providing that they are organized in equivalent ways. Computers made of electronic hardware can reproduce many of the operations of brains, made of organic materials. The key is proper organization. The machinery necessary for a system to have the flexibility of action and response that we associate with life must be intricate and complex. The structural materials out of which the system is built must be correspondingly versatile. Terrestrial life is based on the chemistry of carbon compounds, which is accordingly called "organic" chemistry. It is difficult to see what element other than carbon could serve as the basis for life. No other element has anything like the varied spectrum of compounds that carbon has, and no other element can build polymers of indefinite length. Boron and nitrogen, its neighbors in the periodic table, cannot form stable polymers of appreciable size, and only silicon, below carbon in the next row of the table, is even a vaguely likely candidate. But the *silanes* are explosively unstable, the *silicones* are discouragingly inert, and the superficial resemblance between some compounds of carbon and silicon is



Galaxies occur in clusters, such as this one in the Constellation of Hercules about 340 million miles from our Galaxy. The spiral and lens-shaped objects are galaxies seen full-face and on edge. The brightest of them are comparable in size to our own Galaxy and the Spiral Nebula shown on the facing page. One estimate of the size of the universe predicts a total mass that would call for 10 billion such galaxies, which indicates that life may not be a unique or even a rare event.

probably misleading. Carbon dioxide gas (CO_2) in a carbonated beverage and silicon dioxide (SiO_2) in the glass that encloses it, or in pure form in rock quartz, have little in common. The chemistry of extraterrestrial life may well be radically different from that of terrestrial life, but it would probably be based on compounds of carbon with other elements.

THE PROBABILITY OF EXTRATERRESTRIAL LIFE

With all these restrictions, it may appear as if life is an unlikely occurrence. But we are really describing conditions that are likely to occur as solar systems evolve. When we believed in the older theory that the planets condensed from matter pulled from our Sun during a near-collision with another star, we had to admit that planets would be extremely rare and infrequent phenomena. But by current theories of the birth and development of stars, satellite systems are the norm and not the exception. It would be a rare Sol-type star that did not have planets. What is the probability, then, that at least one planet around a given star has the right conditions for life?

It is hard to put numbers to these ideas. Stephen Dole, in a study prepared for the RAND Corporation and published as "Habitable Planets for Man," has attempted the somewhat easier task of calculating the probability that a star has at least one planet sufficiently similar to Earth to be colonizable. He considers such factors as the prevalence of planets, inclination and eccentricity of orbit, temperature, mass, state of rotation, age, and presence of binary stars. He finds that one out of twenty Sol-type stars should have such a habitable planet, or one out of two hundred stars of all types. If his calculations have any validity, then there should be 50 habitable planets within a sphere of radius 100 light years from our Sun, and many more which, although unsuitable for Man, are perfectly capable of supporting an indigenous life.

Our Sun is one of approximately one million million stars in a spiral galaxy. Even if we assume that Dole is overoptimistic by a factor of 100, then 50 million stars in our Galaxy must have planets comparable with Earth. The galaxies occur in clusters, and one estimate of the size of the universe predicts a total mass that would call for 10 billion such galaxies. If all of these lines of thought are reasonably correct, then life is far from being a unique or even a rare event. Life is something that happens to matter when conditions are right, and they are right millions of times across a galaxy.

I have drawn a long curve through just one data point, the planet Earth. Most of this article has been speculation, but—I hope—not unintelligent speculation. It does no harm to ask questions for which there are no answers, for otherwise we would never find answers for new questions. We have a long way to go before we really understand living processes. A century ago the framework for understanding was developed in the theory of evolution, and in the following hundred years we have come gradually to realize that all life on Earth is one interrelated process.

At the present state of our knowledge, we have an incomplete picture of only one example of a general phenomenon. We shall know more eventually; and one of the readers of this article may be the first to detect extraterrestrial life in some future planetary probe, or make some breakthrough in understanding terrestrial life. The Romans named the first month of the year after Janus, a god with two faces who could look backward in time as well as forward. Man is the first animal to have the ability to look backward, in the sense that he can study and contemplate the process of evolution that produced him, as well as participate in it. We have the ability to decide, consciously, what will happen next in the history of life on this planet. It is a grave responsibility. As one biologist once remarked, it is not at all certain that superior intelligence confers a long-term survival advantage on the species that possesses it. But we may increase the probability of making the right decisions if we realize that we are not a lone and lonely addition to the world, but are in fact a natural outgrowth of the phenomenon of life.

JPL Looks at Inner Space

Image-processing equipment, developed at Caltech's Jet Propulsion Laboratory to enhance planetary photographs radioed back from spacecraft, has now been converted to an experimental system that can speed up by a factor of ten the analysis of pictures of human chromosomes.

Chromosomes are the tiny bodies that contain the basic patterns for life—the genes. Seen through a microscope, they appear to resemble a tangle of short spaghetti strands or stubby worms. Each chromosome contains strings of DNA molecules, which are believed to be the reproductive basis of all living organisms. DNA—deoxyribonucleic acid—holds the key to the genetic code of life on earth.

Chromosome analysis, or karyotyping, is a valuable medical tool, but it sees limited use at present because it is so time-consuming and expensive. (Karyo is the biological term for the nucleus of a cell.) As a result of JPL's experiments such analysis may become more widely used. When this happens, it will greatly aid the process of determining the genetic effects of atomic radiation, drugs (such as thalidomide and LSD), and environmental poisons such as smog.

Developed by a team headed by Kenneth Castleman, the Automated Light Microscope System (ALMS) is an outgrowth of JPL staff scientist Robert Nathan's work on computer-enhanced X-ray photos. This promising step toward speedy, low-cost chromosome analysis is being funded by the National Institutes of Health with additional support from NASA. Nathan has over-all responsibility as principal investigator for the NIH grant.

Chromosome analysis is currently used to spot hereditary disorders in patients—permitting positive diagnosis of such well-known chromosome disorders as Down's syndrome (mongolism), or the XYY syndrome in which the presence of an extra Y chromosome has been associated with criminal behavior. The clinical practice at present is to photograph chromosomes through a microscope. Each chromosome image is then laboriously cut out of the developed picture by hand, classified visually, and pasted up in groups to form the karyogram. The process takes about 30 minutes.

Under the JPL system, these functions are almost completely automated. An operator watches through closed-circuit TV as the automated microscope searches a slide prepared from a blood

Without manual or automatic karyotyping, human chromosomes would look like this under a microscope. These chromosomes show several abnormalities resulting from damage due to radiation or chemicals. The top arrow points to a chromosome with three centromeres (the narrow belt-like part that joins the longer strings); normal chromosomes have only one centromere. The other two arrows point to chromosomes without a centromere—an abnormality that occurs when the chromosomes are broken. This photograph was provided by Robert S. Sparkes, MD, a UCLA geneticist who acted as a consultant on the ALMS project.

The Automated Light Microscope System is a promising step toward speedy, low-cost chromosome analysis.

sample. He stops scanning when he spots a cell with a good chromosome "spread" —i.e., a group that is spread apart with no overlaps, so that each chromosome is separate and distinct. The system automatically sharpens the focus, enlarges the image 2,500 times, and converts the visual pattern into digital signals for evaluation and manipulation by the computer. The scanning and cell selection functions will eventually be completely automated.

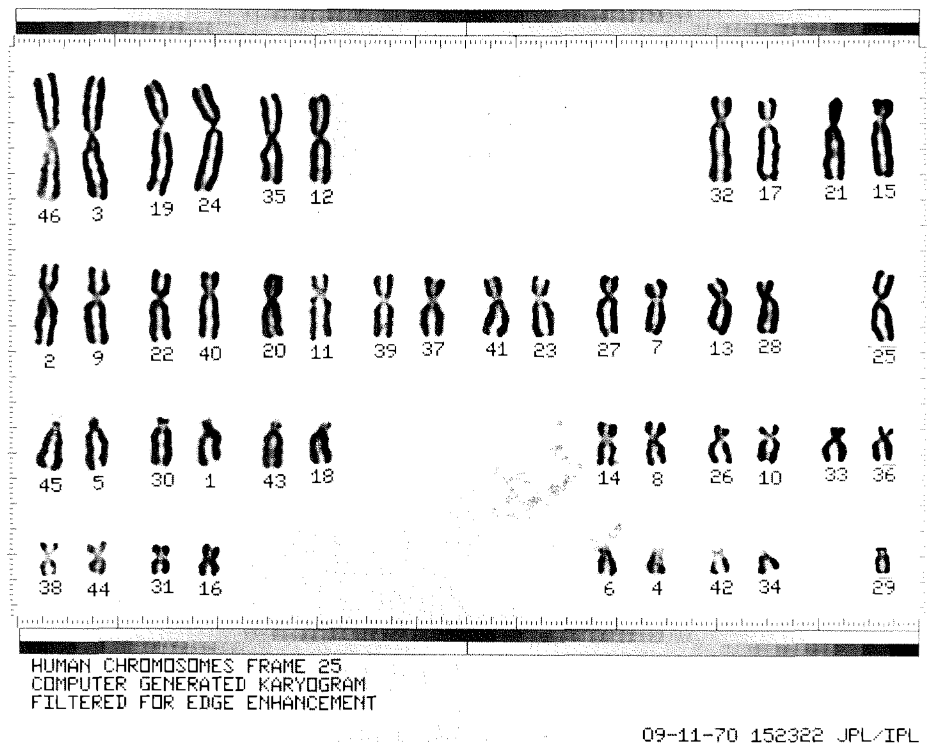
With the chromosome images still in digital code, the computer performs a series of routines that isolate and measure each set of digital values. The coded images are then numbered, classified, paired, and arranged into groups, so that when the digital "picture" inside the computer is translated by a special photographic printer into a visual picture on paper, chromosome images will appear in standard clinical karyotype format.

The entire process takes about three minutes.

ALMS is currently being refined on JPL's large-scale image-processing computer hookup, but it will eventually be structured for a small computer—with a desk-size console—in order to permit clinical applications. At present the system occupies a roomful of equipment, and includes an IBM 1130 utility computer as well as a time-shared IBM 360-44, plus peripheral devices. The 1130 controls the automatic scanning and operates the microscope, and the 360 measures and classifies the chromosomes and generates the output karyogram.

A prototype system utilizing a small computer could be developed in the next year or two. The results of the JPL effort, including design specifications and detail drawings, will become part of the public domain and could lead to commercial production of an economical karyotyping system. At a price of $50-90,000, such a system would be well within the means of many hospitals and clinical laboratories.

"Our long-range objective," says Castleman, "is a general-purpose automated microscope—one that can automatically analyze not only chromosomes but also blood cells, pap smears, viruses, and other important clinical subjects."



The sorting, numbering, and classifying of these chromosomes in a human blood cell, magnified 2,500 times, took just three minutes. The computer that produced this karyogram is the same one that is used to enhance photographs of the Moon and Mars.

A SUMMER TRIP TO NOWHERE

Ninety days in "an artificial environment"

by John Hall

A letter soliciting applications from "healthy male graduate students in the engineering, physical, biological, and social sciences to participate as scientist-astronaut crew members in a ground-based program" arrived in my mail one November morning in 1969. Answering it launched me—and some 50 other southern California graduate students—on a round of questionnaires, personal interviews, medical examinations, and psychological evaluations. Seven of us survived the selection process and became the prime and backup crews for a 90-day "holiday" confined in a Space Station Simulator (SSS) located in a large laboratory at McDonnell-Douglas Astronautics Corporation's plant in Huntington Beach.

Aside from the obvious criteria for selecting personnel able to sustain a relatively long period of confinement and remain in good physical and mental health, the selection process we went through is best summed up in the observation that the candidates who showed the most interest and perseverance in cooperating with the schedules of training emerged by mid-February as the team. The four "chambernauts" chosen as the prime crew included three graduate students from Caltech—Steve Dennis, from biology; Wilson Wong, from aeronautical engineering; and myself, from geology. Our fourth crewman was Terry Donlon, a UCLA graduate student in medical radiation physics.

The test, which took place from mid-June to mid-September, was set up to employ an advanced regenerative life support system (LSS) and to demonstrate that the system could be operated continuously for the 90 days, without resupply, to provide a habitable environment.

A previous 60-day simulation had tested a number of elements in the life-support loop, to which were now added a radioisotope-heated vacuum distillation system for the recovery of potable water from urine and humidity condensate, a solid amine resin carbon dioxide concentrator, a flight-weight alkaline electrolyte water electrolysis unit, a "shredder-type commode with vacuum dehydrated fecal storage," an improved reactor for reclamation of water from carbon dioxide and combustion of atmospheric toxins, and a microwave oven for food preparation.

If any of these new subsystems should fail, we were to repair them. Since no materials were to be passed into the chamber, the equipment repair we could perform was limited to procedures that might be done on a long space flight mission. Biological and medical samples could be passed out through an airlock in such a way that the chamber would not be contaminated from the outside.

As we began training, the SSS was a nearly empty double-walled horizontal cylinder, 12 feet in diameter and 40 feet long. An acoustic barrier and fireproof bulkhead separated the interior into two compartments. The first, adjacent to the airlock, would house the main living area, biological sampling area, and sleeping quarters; the second would eventually contain all of the LSS equipment. The space between the inner and outer chamber walls, as well as the airlock and pass-through ports, would be evacuated to several millimeters of mercury below the cabin pressure to ensure that all leakage would be outboard. Several inches of thermal insulation around the entire system would minimize thermal and acoustic transmission.

As the various subsystems of the LSS began to arrive and were installed in the chamber, we learned how to operate them, how they were most likely to fail, and how to repair them. We began to see the pieces of equipment in terms of their role in the over-all life support scheme and to appreciate their performance capabilities under various conditions of operation.

The general operation of the LSS consisted of cycling our urine through either an evaporative wick and condenser system or the plutonium 238 thermal vacuum distillation/vapor filtration boiler and condenser. The reclaimed water would be stored in zero-G design holding tanks and assayed for chemical and biological contamination prior to reuse.

To illustrate the economy of reclaiming body wastes, a crew of four men each consuming three quarts of water per day would require something over a ton of water for a 90-day mission, ignoring any provisions for washing. But through reclamation of processed urine and humidity condensate we in fact would operate with only several hundred pounds of water on board.

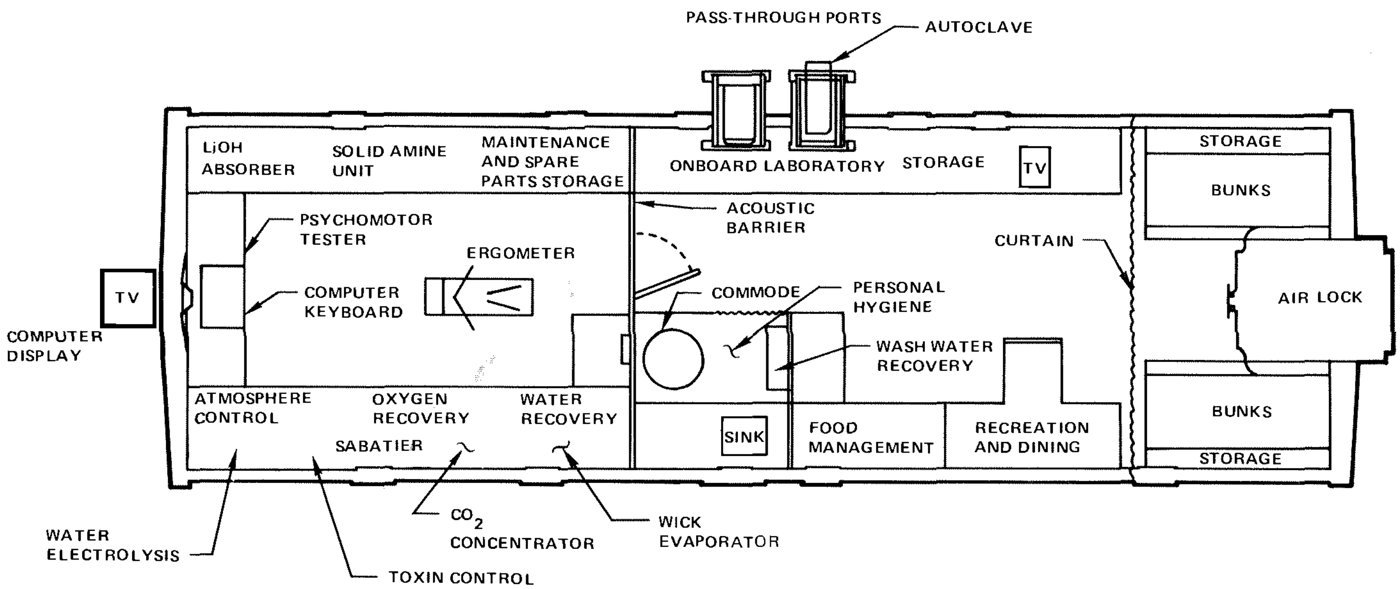
On even longer missions with larger crews, such as space trips to the planets, the economy of these regenerative systems becomes very important. Neither of our water reclamation systems was 100 percent efficient, but even allowing for the water losses incurred in processing and by

Terry Donlon and John Hall, on screen, confer with members of the ground crew outside the simulator. A battery of monitors followed the crew's activities throughout the run.

the requirements for passing samples outside the chamber for analysis, the metabolic production of water from the hydrogen in our food would result in a net water gain.

The food consisted primarily of freeze-dried items, permitting savings both in weight and storage space. Still, the total food for 360 man-days weighed over 500 pounds and took up 60 cubic feet of storage.

Regeneration of expired carbon dioxide as oxygen completed the mass balance. The gas would first be concentrated by molecular sieve or solid amine resins from which it would be thermally desorbed. Our LSS then would consume the carbon dioxide by reaction with molecular hydrogen on a hot nickel catalyst to produce water and methane. This scheme, familiar to chemists as the Sabatier Reaction, is exothermic. With an appropriate reactor and reaction mixture the process is entirely self-sustaining, and water is removed from the other products by a condenser. The methane and some unreacted carbon dioxide are discharged overboard, and the water pumped into storage. Finally, an electrolysis unit provides the molecular hydrogen needed for the Sabatier Reaction and oxygen gas for rebreathing. Nitrogen and oxygen makeup to the atmosphere is controlled by a small mass-spectrometer sensing unit.



The floor plan of the 40-foot-long "home" for the four crewmen is a testimonial to careful planning and ingenuity in stowing a large amount of equipment into a compact area.

Another purpose of the 90-day run was to ascertain if any adverse effects on psychomotor response might occur. Toward this goal much of our training time was spent learning to perform on a variety of reaction-time devices which scored such things as neurophysiologic response delay in various modes, coordination, and short-term memory.

Weekly blood sampling sessions for several months prior to the run gave us all some expertise in the biomedical procedures we would later be using and allowed establishment of a baseline on our blood biochemistry.

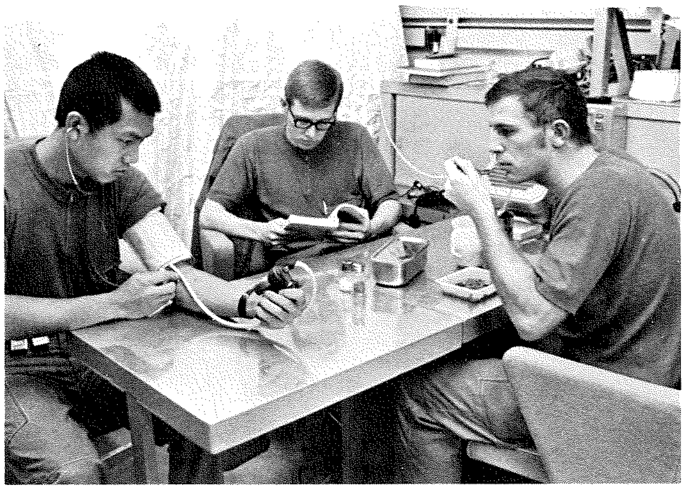
The original target date for commencing the run was April 29, but it was postponed several times. In late April Wilson and Terry, along with backup crew members Larry Hootman and Jim Shoemaker, participated in a five-day systems checkout "at altitude." This preliminary test revealed contamination in the potable water system which rendered the drinking supply completely unpalatable though chemically and bacteriologically safe. They also discovered during this period that adapting to the less-than-spacious seating of the zero-G commode presented some excretory difficulties. Dubbed "the slinger" by its manufacturer, this device left one with the sensation of being perched atop a garbage disposal unit. We who watched from the outside during the five days soberly made book as to how long it would take the inside crew to adjust.

All of these preliminaries out of the way, the day of ingress approached, and with it came mounting excitement and some second thoughts. Ten times I went through my choices of reading material. In the end I decided to limit professional materials to one anthology of recent articles, and to mollify my libido with *Fanny Hill.* Far more enticing during the actual run were a host of psychological and travel excursions: *Inside South America; Mood, States and Mind; Log from the Sea of Cortez; Amazon Headhunters; In Cold Blood; Cancer Ward;* and *Nansen in the Frozen World*—to name only a few.

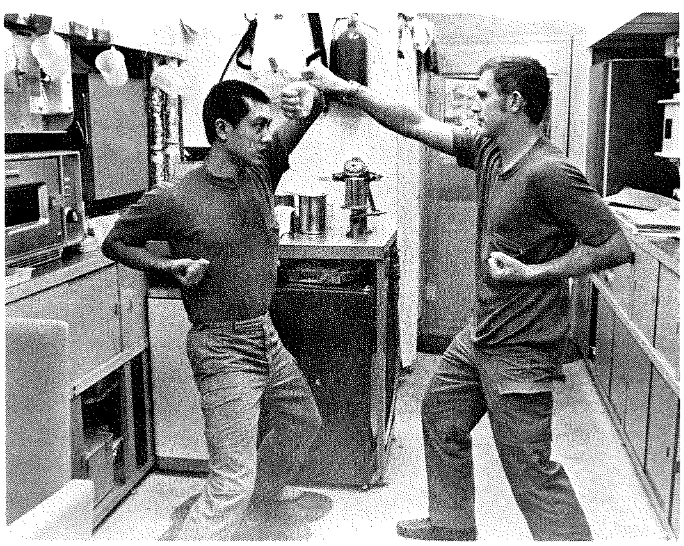
One by one the remaining items on the large chart which represented our "countdown" were crossed off. Finally on the fogged and drizzly morning of June 13, the rap of Wilson's fist at my apartment door alerted me to the fact that I had overslept.

Our last breakfast was hosted at the McDonnell-Douglas facility by chef Dave Myers, who had had the responsibility for training us in medical and microbiological sampling procedures. Depositing with him some last-minute samples of our body fluids, we concluded the handshaking formalities and filed into the air lock. The door slammed shut behind us, and the unperturbed face of our doctor Jim Wamsley smiled back through the outer porthole. A hiss signalled the pressure pumpdown as we approached the cabin pressure of 10 pounds per square inch, equivalent to about 10,000 feet altitude. The atmosphere was mildly oxygen-enriched (about 3.1 pounds per square

The days assumed the title of a particular task to be performed, or of some major food of the day. So we had blood day, eye day, and lobster day.



Crew members kept a photographic record of their activities inside the simulator. Here, Wilson Wong is taking his own blood pressure as part of the physiological data recording, while Stephen Dennis reads and John Hall tackles a meal of reconstituted freeze-dried food.



Wong and Hall take karate stances—for purposes of exercise only. In addition to such informal activity, each crew member put in 15 minutes a day pedaling on a stationary bicycle.

inch)—a condition which necessitated NASA's stringent regulations regarding elimination of combustibles from the cabin. Once during the run the potential for flammability in even this mildly oxygen-enriched atmosphere was dramatically brought home to me when a piece of cotton rag (normally stored in metal boxes) brushed the tip of a hot soldering iron I was using and immediately began to char without catching flame. In a matter of seconds before I could suffocate the ignition, the rag had turned to ashes and sent acrid smoke through the equipment room.

This accident points up another consideration in closed environment design. Any number of items which are basic construction materials—paints, woods, adhesives—outgas and release organic vapors, especially when taken to altitude. In a spacecraft the air cannot be used as a sewer, for simple dilution results in rapid buildup of potentially noxious substances which may adversely affect the health and well-being of the crew or even affect LSS equipment performance.

At the beginning of the run, we were called on to start and operate the systems, and the first several days passed quickly. Crew scheduling provided for two persons to be up at all times. Wilson and I operated on a swing shift, getting up at 9 p.m. With none of the normal clues to day or night, and living under essentially constant illumination, I was occasionally confused as to time of day, entering times off my normal wristwatch as 0900 (9 a.m.) for example, when it was really 2100 at night. The constant background noises of pumps cycling, blowers whining, and relays clicking were a further disturbance in making the adjustment to our new sleep cycle, and they remained a source of annoyance through the run.

With time and repetition we found that days assumed the title of some particular task which was to be performed on them, or of some major food of the day. For example, the audiometric testing was done each Saturday morning, and biomedical sampling every Tuesday—so that we would refer to "blood day," "eye day," or "lobster day," for example.

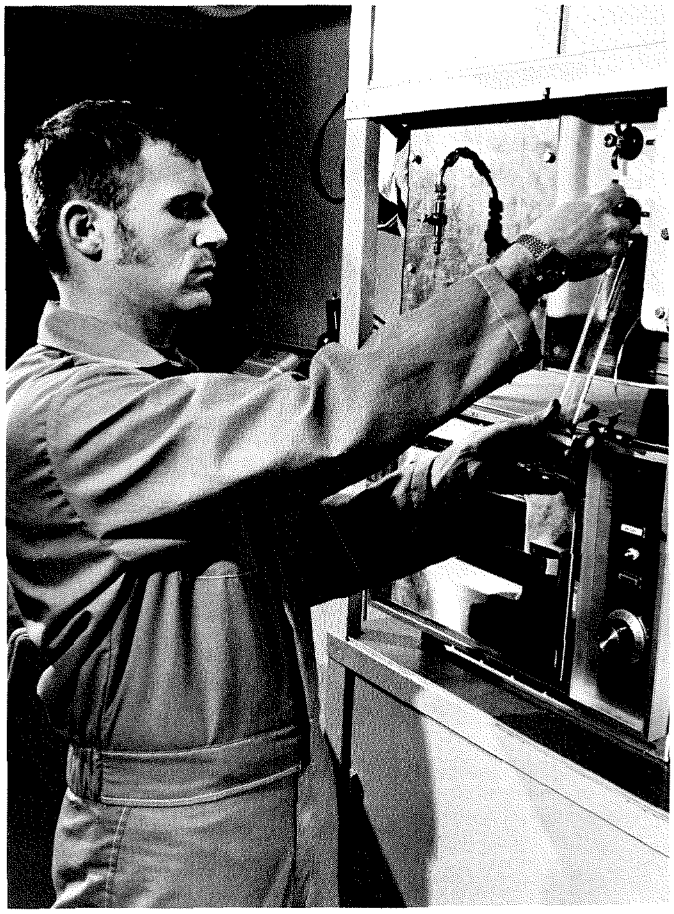
Our food menu rotated on a ten-day schedule with each four-man meal packaged separately. We all quickly developed food likes and dislikes, either of which served to characterize a particular day. Among our favorite items were beef tenderloin steak, the freeze-dried vegetables and fruit, and such desserts as fruitcake. The least appreciated included scrambled eggs (eventually boycotted by several of the crew), freeze-dried noodles, and a sweet canned gelatin dessert which only one person would eat. There was not much opportunity for modifying the prepackaged fare, and the consequences of any improvisation that was undertaken could be great, as I demonstrated one evening. Combining scrambled eggs with beef stew, broccoli, and beef with rice, I created a grand-appearing concoction which I then anointed with ketchup and devoured. Several hours thereafter my stomach was tied in knots, and my sleep became a stream of troubled nightmares involving decapitation, drowning, and death by fire as best I recollect.

For snacks we relied on chocolate bars, nuts, and the like. Our chocolate bars—800 of them in all—took up a good deal of storage space, and early in the run we would jest about anyone ever being able to consume such a volume of sweets. Yet on the day of our egress only several dozen bars remained. It was a continual source of surprise to our outside medical observers that the crew maintained such a high caloric intake (some of us consumed over 3,000 calories per day), in view of previous confinement experiences and the Apollo flights, where some weight loss has been the general rule and food intake has commonly been less than 2,000 calories per day. I attribute this to the generally high quality and acceptability of our food and the generally high degree of crew motivation.

A typical day's fare might consist of a breakfast including ham and eggs, toast with jelly, and chocolate or coffee. Lunch would be a carrot-raisin salad, tuna casserole, pudding, and cookies. Dinner was generally the high point in the culinary scheme, featuring on a typical day pork tenderloin, asparagus, squash, breadsticks, strawberries, and cookies.

The daily inventory of food items consumed was sent out via computer data link along with psychologic and physiologic questionnaire information and equipment performance data. Occasionally communications with the computer would break down, and on our television monitor unintelligible gibberish would be displayed. I recollect one day when some consternation and surprise was expressed outside the chamber that the computer printout indicated the consumption of a 6,000 calorie daily diet for one of us, mostly in the form of some 400 teaspoons of raw sugar! Upon interrogation, the crewman denied having developed any great new affinity for sweets, and our computer was duly instructed to replace the errant decimal point.

Steve Dennis early established himself as the poet of our mission, and spent much of his free time writing verse and composing music on his harmonica. Occasionally he would terminate his computer transmissions, which were monitored by the outside observers, with rhymes which



To keep track of water consumption, John Hall measures the amount he is withdrawing from the potable water dispenser. Water, recovered from the crew's urine, perspiration, and wash water, was purified for reuse.

expressed our immediate feelings on some aspect of cabin living. For example:

Watch what you say
Watch what you do
That man with the notebook is watching you.
Don't take off your clothes
Don't pick your nose
'Cept in the bunk room where anything goes.
I'll tell you something
If you ain't heard the news
I got the non-interference talkin' NIPA blues.

Studying hard at the foot of the hills
This cat with a beard sold me these little pills
Gave one to my bird and I took the rest
When I woke up I was stuck in an SSS
If I ever get out
I'm gonna stick with the booze
I got the non-interference talkin' NIPA blues.

NIPA—Non-Interference Performance Assessment—was an Orwellian innovation of our project psychologists that the crew occasionally found annoying. The purpose of NIPA was to develop techniques for ground support personnel to use in detecting significant changes in an astronaut's emotional or performance characteristics during space missions.

In practice, closed circuit televsion cameras and microphones were arranged to allow outside personnel to monitor the cabin continuously and completely—except for the sleep and hygiene areas. The crew did not have any visual contact with the outside, and relied entirely on microphone headset communications.

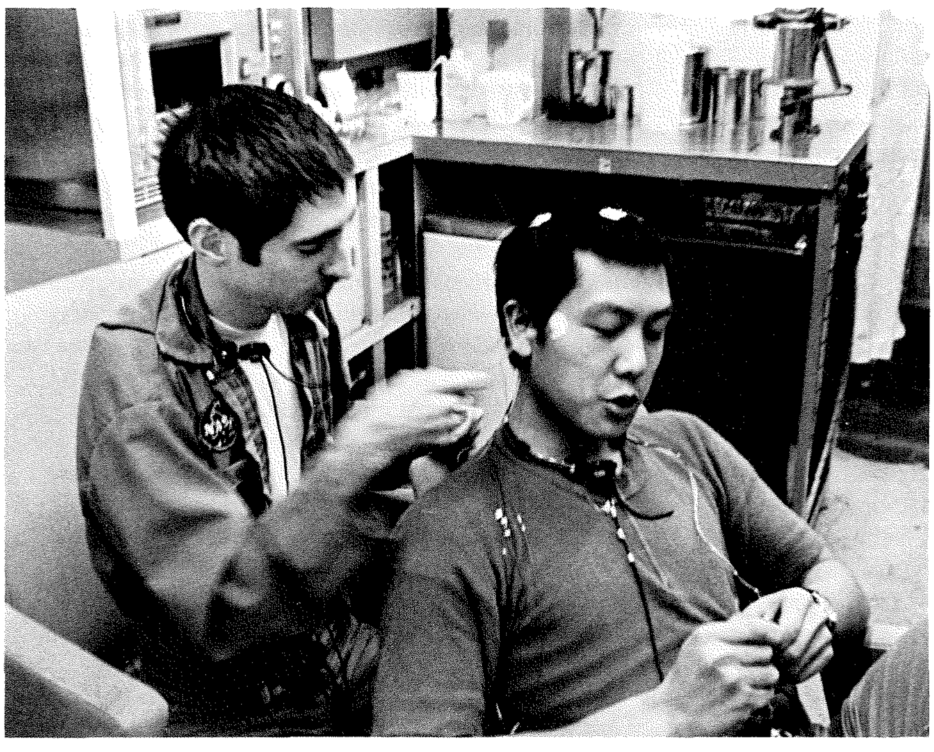
The NIPA observers, who were trained personnel with some background in psychology, were provided with a bank of television screen displays as well as acess to our bank of television screen displays as well as access to our told only that the NIPA observers were going to study crew behavior in relation to task performance. In consequence we often had the feeling of being watched with little appreciation toward what end. Thus, while NIPA was indeed "non-interfering," it was seldom unobtrusive.

In fact, what the NIPA personnel did was to code into the computer a number of fairly objective features of crew behavior, such as position in the cabin, frequency of conversations, persons involved in conversation, and the affect content of speech, toward the objective of discerning some behavioral parameters which might correlate with the caliber of crew performance. Since the crew accomplished all of the jobs requested of them during the run, this sort of straightforward correlation was not possible. However, NIPA did chart the changes in crew morale, and that information may be of some benefit in predicting performance changes during longer tests or actual space missions.

The onboard equipment included a number of cameras for documenting our activities, and after we had filmed representative samples of most of the daily activities and yet found much film remaining, Wilson Wong decided to produce a movie. As he zoomed in and out following our movements, we put together a gripping melodrama which begins with me emerging from one of the food storage cabinets with a tin hat and proceeding to climb the walls, while Steve torpidly responds to buzzes from the outside and keeps sleepily falling from his chair. Inane, yes, but the occasional variety offered by such outlets aided the passage of time.

Concerned that we might not be providing our psychologists with enough data on men under confinement stress, Wilson began sending his own narrative prose out among the weekly vials of blood. One week the appearance of several winged adult fruit flies inside the chamber was traced to larvae in some of the raisin stores. After a boycott of the raisins by several crewmen and the suggestion that we ought to get rid of all the raisins lest the rest of the larvae hatch out and invade our accommodations, I resolved the dilemma by a combination of microwave cremation and deep freezing. Pity for the deceased larvae brought forth a moving document from Wilson detailing the events of their annihilation.

Besides clowning, we enjoyed movies, television, and games; Scrabble rapidly became the most popular group recreational pastime. However, equipment shortcomings emerged early in the run, and at one point the urine reclamation boiler had to be fully disassembled and 80 pounds of urine stored in plastic containers, the



As one way of obtaining physiological and psychological data on the effects of long-duration confinement, electrodes were attached to the crewmen's heads for periodic electroencephalographic (EEG) readings while resting. Here, Terry Donlon puts the contacts on Wilson Wong.

Sabatier Reactor was disassembled for catalyst replacement, and a gas concentrator valve stuck, requiring wrenching every half hour; so no one could complain of being bored.

As we celebrated the passage of the 60th day—the previous U.S.A. record for a manned test of this sort—there was a general attitude of "it's all downhill now," and in retrospect I don't think we were ready for yet another 30 days of confinement. In these later days of the simulation the psychological aspects of the confinement experience became wearing. During the early days of the run the novelty of the situation and press of learning new skills had occupied everyone, and in mid-run the flurry of equipment repairs had kept us busy. Now, however, the elation of day-60 slowly fizzled out as we realized that there was indeed still a considerable time to go. The small maintenance tasks that were not absolutely necessary or included in the time-line schedule were shirked entirely. Cohesion of the crew as a group had stemmed more from the common experiences we had shared than from emotional affinities, and now with a diminished activity schedule small tensions escalated themselves until, around day-70, they began to seem intolerable.

However, during our cohesion training sessions prior to the test, we had learned that the buildup of hostilities is always a risk in such small-group confined situations, and we had all expressed some resolve not to suppress the small annoyances, but rather to vent them as they occurred. Accordingly, we conducted an open discussion to iron out these sources of friction. This proved effective in restoring our proficiency, and the remainder of the run passed smoothly.

In long-term space ventures it is of course important that an astronaut crew be kept physically fit. Since we were not living under zero-G, we could not hope to duplicate the physiological stresses or exercise requirements of men in space. Yet we could establish the degree of exercise necessary to preserve cardiorespiratory conditioning under prolonged confinement conditions on earth. Furthermore, since task performance is undoubtedly correlated with a sense of physical well-being, I feel that the exercise program was important to the maintenance of crew morale and performance.

Our exercise consisted of 15 minutes each weekday pedaling on a variable-resistance bicycle ergometer against a load individually determined to result in a plateau heartbeat rate of 150 to 160 beats per minute. An improvement in conditioning would be indicated by a declining plateau heart rate against a set load over a number of exercise periods.

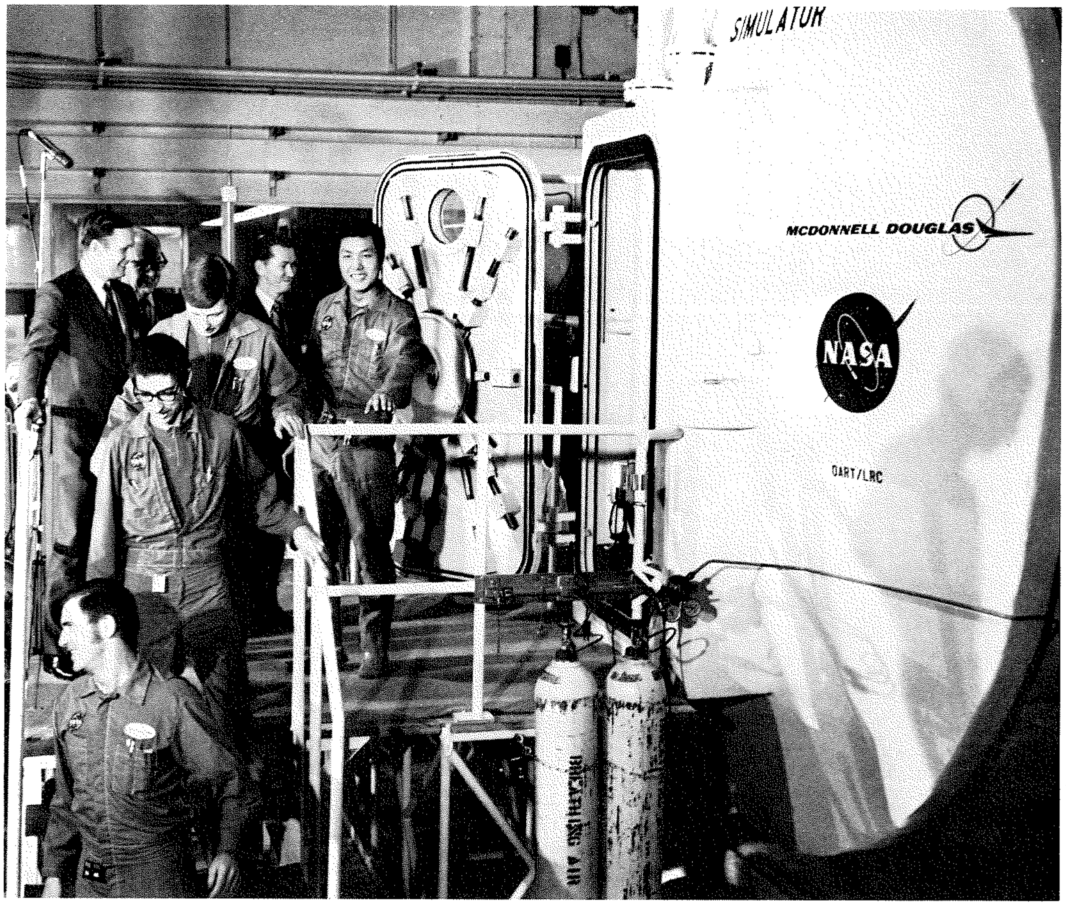
Because astronauts in space are not limited in their exercise, we also could undertake any ad lib exercise programs we desired. My own choice was to adopt a set of calisthenics and isometric exercises done each day for about 45 minutes. Though I felt myself to be in good physical condition before the test, my physical conditioning in fact improved inside the chamber. Treadmill tests before and after the simulation substantiate the observation that those of us who undertook some exercise program in addition to the bicycle all retained or improved cardiorespiratory conditioning, while limitation of exercise almost solely to the ergometer seemed to result in a slight decrease in physical conditioning.

The pollution control problem in the SSS was in many ways a microcosm of the same problems in our normal environment. Earth's resources are not infinite, and we cannot continue to rely on simple dilution in the air, soil, or waters for disposal of waste materials. In the SSS, reclamation of our limited resources meant not only that water and gases had to be regenerated, but also that garbage and trace contaminants had to be disposed of. Dry food wrappings and papers were baled and sealed in aluminum wrappings to prevent fire, while wet food wastes were disinfected and canned.

Because of the precautions exercised in cabin material selection, there was little danger of having to cope with problems of heavy metal pollution. The accumulation of hydrocarbons from outgassing of foods and metabolic activity was kept to low levels by the use of adsorbents in the atmospheric purifying systems and a catalytic burner which slowly processed the cabin air, combusting hydrocarbons to water and carbon dioxide. The human body is of course a source of small amounts of hydrocarbons, mostly methane, as a result of microbial activity in the gut. It also generates some carbon monoxide as a result of other physiological activities. Recent medical studies indicate that even very low carbon monoxide levels, which may deactivate only 2 percent of the body hemoglobin, cause certain impairments in mental functions such as arithmetic and judgment of time intervals. In one test our catalytic burner was shut down for several days, and levels of several parts per million of carbon monoxide were allowed to accumulate. While the crew suffered no specific chronic effects from the elevated CO levels, there is a suggestion in some of the psychomotor data that performance was adversely affected.

What did we accomplish? First, the wealth of design and equipment operational data alone justifies the exercise. No amount of bench testing could provide the same information.

Was this simulation successful? My answer is yes: The test objectives were met, and the equipment was



Astronaut Neil Armstrong was on hand to greet the SSS crewmen as they emerged from the simulator at the end of their 90-day run.

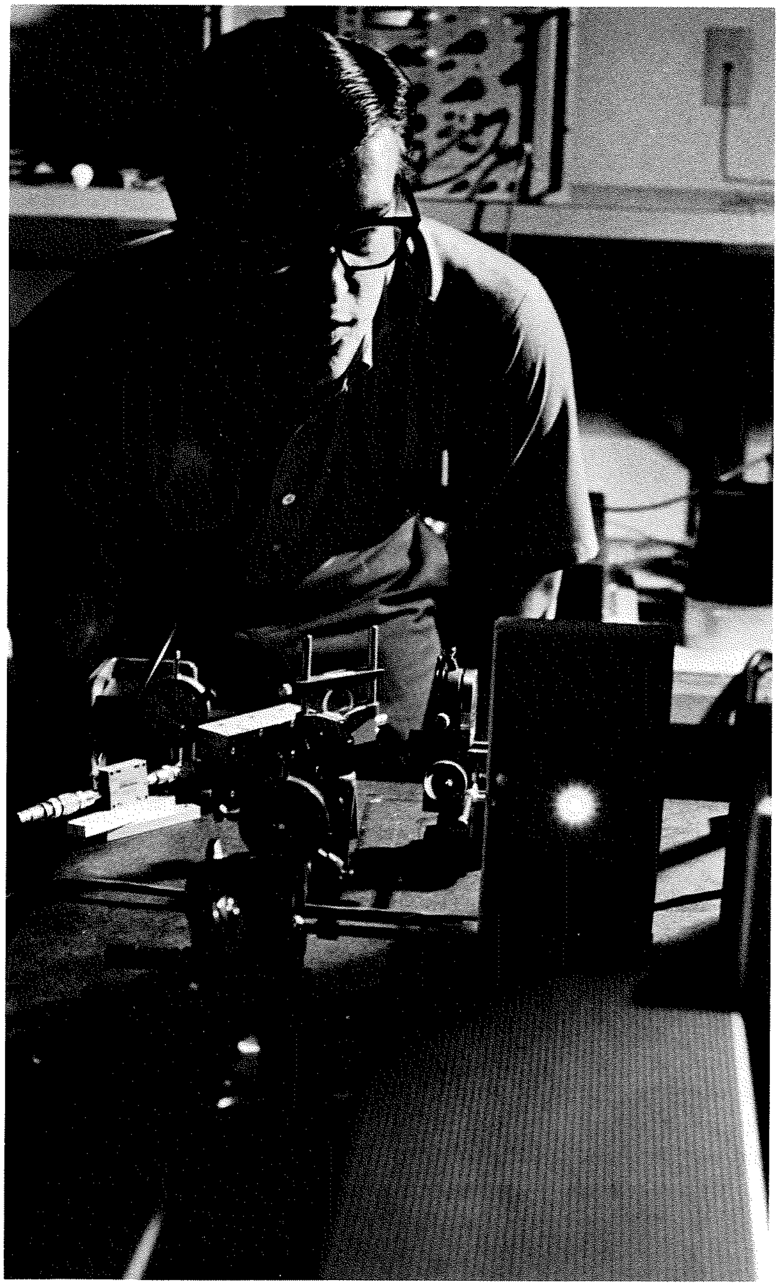
operated under conditions of limited weight, space, and energy consumption, as well as limited maintenance and repair. Moreover, from a medical and physiological viewpoint, the data will serve as an effective control in future experiments on the long-term effects of confinement and exposure to an atmosphere of elevated carbon dioxide partial pressure, such as will be encountered in at least the next generation of spacecraft.

Of course, there were many important differences between our experience and an actual space mission. Our environment was not particularly hazardous, and the safety of an abort was never more than a few seconds away. Hence the stress we experienced could not have duplicated that of a real astronaut's for whom equipment failure or meteorite puncture could have catastrophic results. Further, there was no opportunity for extravehicular activity, such as "space walks." Such opportunity might have a mixed effect, acting on the one hand to moderate tensions resulting from confinement, but on the other hand producing a more immediate realization of the confrontation between man and environment. Finally, there was not the sense of a "mission." However high the motivation of a simulation crew, no man can experience on earth the sensations felt by the first astronauts to arrive at a distant planet after a year or more of travelling to get there. I cannot doubt that astronaut crews on such long-term flights will possess an extra amount of drive and be willing to tolerate annoyances otherwise unacceptable.

The purpose of the 90-day Space Station Simulation and similar tests is not to stress men to their limits; rather, it is to provide an artificial environment in which men can work and live with the minimal stress and compromise of a "normal" type of existence. The 90-day run demonstrated the response of an astronaut-like crew to a long-term confinement experience.

In the immediate future many of the habitability responses encountered during the 90-day run are being incorporated into planning for the Skylab I, the Apollo Applications Laboratory being built by McDonnell-Douglas for launch by 1973. Eventually regenerative life support modules will be installed in the larger orbital space stations of the late 1970's, and in the interplanetary craft of the next decade. Toward these future endeavors re-engineered and improved life support equipment with increased automation will first have to pass longer tests of operation and performance. The next step may well be a 180-day Space Station Simulation. *I* still think *90* days is a long time.

Research Notes



Research fellow Robert Menzies activates a high-powered carbon dioxide laser resembling the ones that will one day be used to detect pollution violators. The laser mechanism itself is contained in the long rectangular box at the lower right. The bright spot is the fire brick safety shield glowing white hot from the laser beam, which is invisible because it's in the infrared portion of the spectrum.

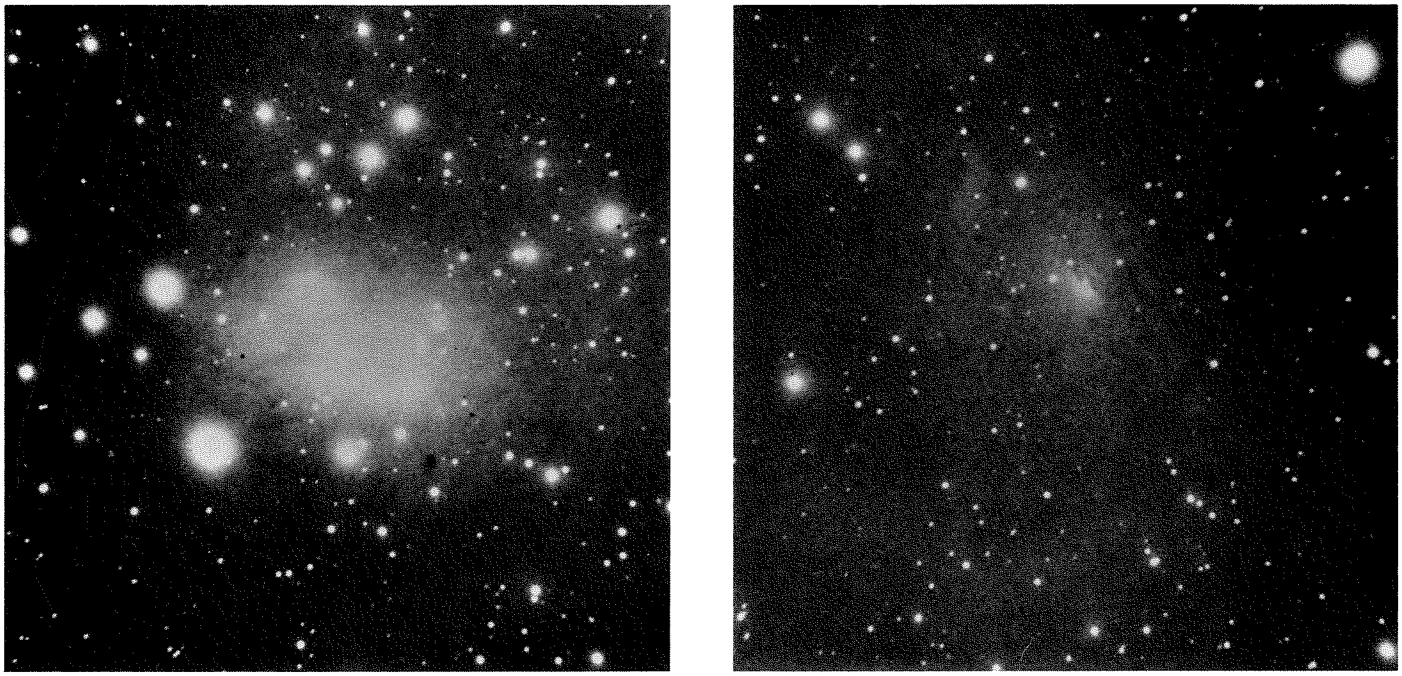
Laser Smog Detector

Robert Menzies, research fellow in electrical engineering, and Nicholas George, associate professor of electrical engineering, are currently developing infrared laser devices that can not only measure the presence of smog but can pinpoint the sources of it as well. The systems can detect pollutants over distances up to several kilometers, and may someday be used to spot air pollution violators in the way that traffic patrolmen use radar today.

The development of these devices has been concentrated on two general types of infrared laser systems for pollution detection and monitoring—a passive system and an active one. Both systems depend on the fact that molecules of the most important pollutants radiate in the infrared portion of the spectrum, and also that the emissions fall into identifiable spectral regions. Consequently, oxides of nitrogen—one of the major constituents of smog—as well as methane, ozone, carbon monoxide, and sulfur dioxide, all have spectral signatures that can readily be identified and measured.

The passive system employs a type of infrared radiometer known as a heterodyne receiver, which operates in roughly the same way as an ordinary radio. It uses a small laser as a local oscillator, together with a photosensitive device such as a crystal, to pick up pollutant infrared emissions from the atmosphere. Such emissions occur naturally, and since their amplitude increases with temperature, passive devices need to be calibrated with temperature measurements of the pollutants. These devices are directional: They can be pointed, like a radio telescope, to receive signals from a certain direction.

The active system—sometimes called a lidar (Light Detection And Ranging) system because of its similarity to radar—is also directional. It utilizes a telescope and a heterodyne receiver linked to a high-power pulsed laser. The laser emits radiation that is in turn absorbed by a particular type of pollutant molecule. For example, in experiments with locating and measuring sources of oxides of nitrogen, a beam from a carbon monoxide gas laser can be used, since part of its radiation coincides with the absorption frequencies of nitric oxide. When the laser beam encounters a pollutant molecule, the molecule absorbs



Maffei 1, left, photographed with the 200-inch telescope in infrared light, appears to have no structure except for some narrow dust lanes that probably belong to our Galaxy. Maffei 2 has a faint but visible spiral pattern that suggests it is structurally much like our own Galaxy.

infrared energy, becomes excited, and fluoresces, emitting radiation at its own characteristic wavelengths. The heterodyne receiver, which is sensitive to radiation at these wavelengths, is connected to the telescope, which scans along the direction of the laser beam and picks up the induced radiation from the pollutant molecules in the path of the beam.

Both the passive and the active systems have been used successfully in the laboratory in detecting three major components of smog—nitric oxide, nitrogen dioxide, and methane. In fact, George and Menzies, together with a group of Caltech doctoral students and faculty, are extending the technique to include other pollutants by matching their radiation absorption and emission characteristics with the radiation patterns of other laser beams. So far, matchups have been found—using carbon dioxide and carbon monoxide—with nitrogen oxides, carbon monoxide, and sulfur dioxide. Both of these gas lasers are capable of very high-power emissions and are suitable for active, or lidar, systems.

Although none of these devices have yet been tested in the field, preliminary laboratory measurements indicate that the passive system should be able to monitor atmospheric pollutant concentrations at distances up to a few kilometers. Since this type of system detects ambient radiation—the radiation that is already present— as opposed to induced radiation, it cannot be used to focus on a specific point in space. It measures the *average* concentrations over its total path length in whatever direction it happens to be pointing. However, by directing the receiver at a localized emission point such as a smoke stack, then shifting the view slightly to one side or the other and measuring the *difference* between the two radiation levels, it is possible to calculate pollutant concentrations at a specific point.

The more complex lidar system, using a high-power pulsed laser to induce radiation, is capable of "resolutions" of about 300 yards. By operating with a timer, it can focus on 300-yard increments along its path and measure the concentrations in each increment. The lidar system, then, should be suitable for monitoring atmospheric concentrations in short increments at distances up to about a kilometer. Because of the greater sensitivity of this type of system, one possible application might be to measure pollutants in auto exhausts. The use of high-powered lasers will require strict safety precautions, though: A 10-watt unit like the one Menzies is currently working with can inflict severe burns at distances up to about 20 meters.

Menzies first began thinking about using infrared lasers to detect air pollutants while he was a graduate student working with Nicholas George. After he received his PhD in physics in June 1970, Menzies went to work at JPL on a NASA project to develop a portable laser receiver for eventual use in tracking satellites. Today, in addition to the JPL project, he is continuing his work on pollutant detection as a part-time research fellow at Caltech.

New Neighbors

About two years ago a young Italian astronomer named Paolo Maffei reported finding two strange "objects" on infrared photos he made in the Laboratory of Astrophysics at Frascati, Italy. Maffei's brief research note, appearing in 1968 in the *Publications of the Astronomical Society of the Pacific*, sparked an investigation that culminated last month in the announcement by Caltech and U.C. Berkeley astronomers of two massive but previously unknown galaxies—right in our own stellar backyard.

The report on the galaxies, which appeared in the January 1971 issue of *The Astrophysical Journal,* was written by Wallace Sargent, J. B. Oke, and James Gunn, who are astronomers at Caltech and staff members of the Hale Observatories; Gerry Neugebauer, a physicist at Caltech and also a staff member of the Hale Observatories; Gordon Garmire, associate professor of physics at Caltech; Hyron Spinrad, Ivan King, and graduate student Robert Landau, of the astronomy department at U.C. Berkeley; and Nannielou Dieter of the Radio Astronomy Laboratory at Berkeley. Their statement, "Maffei 1: a New Massive Member of the Local Group?" enlarges the probable membership of what astronomers call the Local Group of galaxies—our Galaxy's nearest neighbors. Until now, astronomers have thought that the Local Group included only the Milky Way and the Andromeda Galaxy plus several smaller or satellite galaxies.

The new galaxies—named Maffei 1 and Maffei 2—appear to be about three million light years from earth (or about twice as far away as the Andromeda Galaxy). Maffei 1, the brighter of the two, may be larger than either the Andromeda or Milky Way galaxies, which would make it the largest member of the Local Group.

Overlooking objects of this size until now may seem incredible, but it really is not. The galaxies are located in a region that, for earthbound observers, is heavily obscured by interstellar dust. Discovery and confirmation of their existence was partly the result of intensive study by astronomers at Berkeley, Caltech, and the Hale Observatories, and partly the result of a lucky guess by a Berkeley graduate student.

Robert Landau, who is working toward his PhD in astronomy at Berkeley, read Maffei's research note in 1968 and was struck by the fact that the objects could be seen in a region so congested with dust that it is known as one of the "dirtiest" places in the sky. (Interstellar dust, believed to be mainly tiny grains of carbon and sand, is concentrated in many regions in the plane of the Milky Way Galaxy.) The dust is so dense in this particular vicinity—a spot in the northern sky between the constellations of Perseus and Cassiopeia—that it blocks all but about one percent of visible light and six percent of infrared light. Landau suspected that if the objects were actually shining through this heavy cloud, they might be much larger and brighter than they appeared to be.

Following his hunch, Landau and others at Berkeley made infrared photos with a 30-inch reflector telescope at the Leuschner Observatory at Lafayette, California. Spinrad and Gunn then photographed the objects with the 48-inch Schmidt telescope at Palomar. Both objects appeared fuzzy in the new photos but nevertheless showed unmistakable traces of the characteristics of large galaxies.

Infrared plates were obtained with the 48-inch Schmidt, and further infrared measurements were taken by Neugebauer and Garmire using the 200-inch Hale telescope at Palomar and the 100-inch, 60-inch, and 24-inch telescopes at Mount Wilson. Gunn, Oke, Sargent, and Spinrad used the 120-inch Lick telescope at Mount Hamilton, California, and the 200-inch Hale to study the light from the new objects; and Spinrad and Dieter used the facilities of the Hat Creek radio observatory in northern California to search for radio emission.

So far, the research findings strongly indicate that Maffei 1 is a "large, normal elliptical galaxy." Maffei 2, which is also large, appears to be a spiral rather than an elliptical galaxy, which means that it has pinwheel-like arms extending from a central nucleus to the periphery.

Light from Maffei 1 was found to be reddened by the effect of the dust in the Milky Way Galaxy—an indication that the light source is beyond the Milky Way. In addition, the spectrum properties of the Maffei 1 light clearly fit the pattern expected to match the chemical abundances of many large galaxies. The light energy characteristics measured across the core of Maffei 1 were shown to be similar to the energy distribution across the Andromeda Galaxy and other large, elliptical galaxies.

The distance calculations were hampered by the obscuring dust, but the astronomers applied several tests to arrive at their "reasonable estimate" of three million light years for Maffei 1. They were also guided by some basic assumptions—for one, most elliptical galaxies are not much larger than the Andromeda Galaxy. This leads, by means of brightness comparisons, to an estimated upper distance limit for Maffei 1 of 10 million light years. If the distance were smaller than about one million light years, individual stars could be distinguished in photographs of the galaxies, but this cannot be done. The estimated distance of three million light years was arrived at after careful study of gravitation and inferred motions in Maffei 1.

A weak radio signal can be detected from Maffei 2, but as yet there has been no radio detection of Maffei 1. More radio observations as well as a variety of other studies are being planned for the future.

The position of Maffei 1 and 2 in the sky is really a piece of bad luck for the astronomers. Moved only a few degrees to one side or the other, the new galaxies would miss the obscuring dust and be clearly visible to earthbound observers. Eventually, of course, Maffei 1 and 2 will swing into view as our solar system rotates with the Milky Way—in about 10 million years.

Young Galaxies?

For years astronomers have searched the universe in vain for a "young" galaxy. And now astronomers at the Hale Observatories have found two that appear to be a mere 10 million years old—one-thousandth the age that all galaxies are supposed to be, according to the "big bang" theory. This rather generally accepted theory says that 10 billion years ago all the material in the universe was in one location—and then exploded. The universe has been flying apart ever since in great chunks called galaxies, which are aggregates of stars, gas, and dust.

Astronomers are especially interested in finding a young galaxy because such an object would provide the first evidence that these, the largest collections of matter in the universe, evolve from infancy to old age. The discovery of a young galaxy would also prove that galaxies can be created subsequently to that original big bang.

The two astronomers searching for youth in the universe are Wallace L. W.

Sargent, associate professor of astronomy, and Leonard Searle, who with Sargent is a staff member of the Hale Observatories. In an article in the December issue of the *Astrophysical Journal* they point out that the two young galaxies are unusually rich in the star-making material hydrogen, and contain only one kind of star—short-lived, large blue ones. Older stars, which are reddish, small, and can live for billions of years, do not show up in these galaxies.

The newly discovered galaxies are very small—about 100 light years in diameter compared with 10 billion light years for our Milky Way Galaxy—and are irregular blobs instead of spirals, or sphericals, as are most galaxies. They are similar to the ionized hydrogen regions in the arms of dust and gas in spiral galaxies where new stars are being born, but this is the first time such regions have been found outside of galaxies in deep space. These particular little galaxies do not even reside in galactic clusters, as most galaxies do, but are "loners" in space.

Are these astronomical oddballs actually as young as their stars (10 million years), or are they the same age as other galaxies (10 billion years) and unable, for some reason, to harbor old stars? Sargent and Searle admit that they don't really know, but—paradoxically—they are inclined to believe the two oddballs are really old galaxies that are cosmic perpetual motion machines capable of manufacturing only short-lived young stars.

"One must assume that the hydrogen clouds from which these galaxies originated were formed 10 billion years ago," Searle says. "If the galaxies are only 10 million years old, the clouds must have existed only as clouds for some 9.99 billion years and then suddenly, only 10 million years ago, started manufacturing stars.

"That is more difficult to imagine than that the original clouds immediately started condensing into stars, as is believed to be true of conventional galaxies. In these two cases, however, the only stars that were manufactured were large blue ones that are short-lived. Such big stars matured quickly, then exploded, ejecting their material back into the galaxies to be recondensed into new young stars. This process could be repeated over and over, and the galaxies always would appear to be very young because all their stars always were young."

It is not known why a galaxy would limit its manufacture only to big blue stars. Some simple reason such as the density of hydrogen in the galaxy might account for it; some 50 percent of the material in these galaxies is hydrogen, compared with only 5 percent in our own galaxy.

Astronomers Leonard Searle and Wallace Sargent scan a sky map similar to the one on which they recently found two small galaxies that just might represent youth in the universe—or may be cosmic perpetual motion machines.

Appropriately, the two unusual galaxies have unusual names—I Zw 0930 plus 55 and II Zw 0553 plus 03. The Roman numerals refer to two catalogs in which they are listed. The Zw refers to Fritz Zwicky, professor emeritus of astrophysics at Caltech, who catalogued them along with some 2,000 other objects that he calls compact galaxies. The Arabic numbers refer to positions in the sky.

I Zw consists of two blobs very close together with a pair of faint, luminous patches nearby. II Zw consists of a bright core with very faint plumes extending from it. Both objects are a little more than 15th magnitude, which means they are invisible to all but powerful telescopes.

The tentative conclusion from the available evidence is that the two objects are dense intergalactic clouds of neutral hydrogen in which the formation of massive stars is proceeding vigorously while the formation of low mass stars is suppressed.

Taking the Pulse of the Gulf of California

Geologists are monitoring the Gulf of California's earthquake-prone floor to learn how its motions affect California's great San Andreas fault and how the continents appear to be drifting over the earth's surface.

The National Science Foundation has awarded a total of $132,600 to Caltech, U.C. San Diego, and the University of Mexico to establish a network of eight seismological stations around the gulf. Chief investigators in the international study are Clarence Allen, Caltech professor of geology and geophysics; James Brune, formerly of Caltech and now professor of geophysics at U.C. San Diego; Cinna Lomnitz, professor of geophysics at the University of Mexico, who received his PhD from Caltech in 1955; and Federico Mooser, chief geologist of the Mexican Federal Power Commission.

Understanding how the earth's crust is being deformed in the gulf is vital to understanding and predicting the future behavior of the San Andreas fault system —the source of most of California's large earthquakes. In fact, the San Andreas fault is an extension of the fault system within the gulf that is responsible for the northwest coast of Mexico splitting off and forming the gulf and the peninsula of Baja California. The split began about four million years ago and is still widening—by about one or two inches per year.

The system of faults involved in this separation intersects the North American continent near the Colorado River delta and continues northwest through California as the San Andreas fault, which goes out into the sea north of San Francisco in Mendocino County.

Crustal activity in the gulf results in many earthquakes there. Swarms of them shook the north end of the gulf beginning on March 20, 1969. During the ensuing week 196 earthquakes of magnitude 4 to 6 were recorded. In one six-hour period, there were 75 tremors of more than magnitude 4—the largest being magnitude 5¾.

Through the network of seismic stations, the researchers hope to pinpoint the origins of these earthquakes and eventually develop an accurate map of the fault lines in the gulf floor. They also want to find out whether the deep trenches in the gulf are the sites of earthquakes.

The other major objective of the project is to increase our understanding of the now generally accepted continental drift theory, which in essence holds that the earth's great land masses have been drifting apart since the time when they were all in one piece. Great plates that include entire continents, and the ocean floor as well, are moving over a plastic layer of rock. Some plates have drifted thousands of miles over the past millions of years.

This massive drifting is related to the upwelling of molten rock beneath the great mid-ocean ridges. The material moves up vertically, solidifies, and then spreads out to form the ocean floor, moving laterally away from the ridges as huge plates.

Where two plates meet head-on, one usually is driven under the other, forming mountains and deep oceanic trenches, and causing earthquakes and volcanoes. In some instances the edges of two plates slide horizontally against each other, which is what happens along the San Andreas fault. The fault and the Gulf of California separate two major plates—one extending eastward from the San Andreas to the middle of the Atlantic Ocean, the other extending westward from the San Andreas to the Asiatic shoreline.

The floor of the Gulf of California is a young "mid-ocean ridge," but one with a very complicated and little-understood pattern. The upwelling of molten rock along this ridge is believed to be associated with the widening of the gulf. This oblique widening movement is consistent with the movement of the Pacific plate to the northwest at a rate of about two inches a year in relation to the adjoining North American plate.

By studying the sea-floor spreading in the gulf, the scientists hope to be able to understand something about how the big plates are moving: They may be pushed, carried by convection cells in the mantle, or driven by gravity or by the forces related to the earth's rotation.

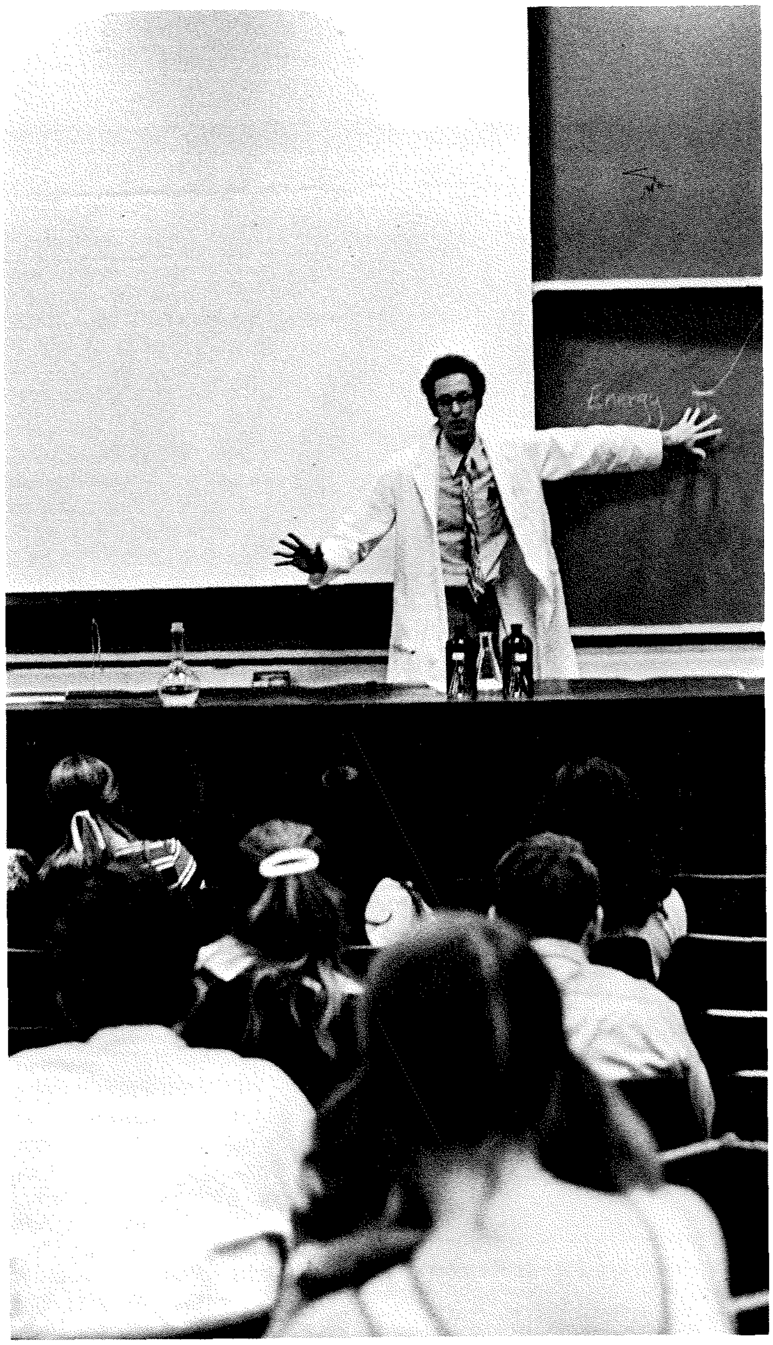
The international seismological team already is monitoring the gulf's pulse. After the first swarm of earthquakes there in 1969, Caltech rushed portable seismographs to the area. Back-pack instruments were set up, and subsequently more permanent stations were established at Rio Hardy, San Felipe, and El Golfo in Mexico's Colorado River delta.

Scientists now are looking for sites for the five other permanent stations. The sites must be located near the gulf, a minimum distance apart, built on bedrock, and near some community so they can be serviced. Probable locations for the five new stations are Caborca and Guayman, both in Sonora State; Los Mochis in Sinaloa; and Bahia de Los Angeles and La Paz, both in Baja California. The Mexican Federal Power Commission will service them all.

Initial installations will include a short-period seismograph, a photographic recorder, radio, clock, solar panels for power, and portable housing. The instruments are under construction at the Caltech Seismological Laboratory and eventually will become the property of the University of Mexico.

CALTECH IS NOT JUST A BIG BLACK BOX—

and graduate students like Bill Beranek are one of the reasons why



A Saturday morning science seminar at Caltech brings Bill Beranek front and center to speak to Huntington High School students. These seminars are part of the secondary schools science program that Bill helped start two years ago.

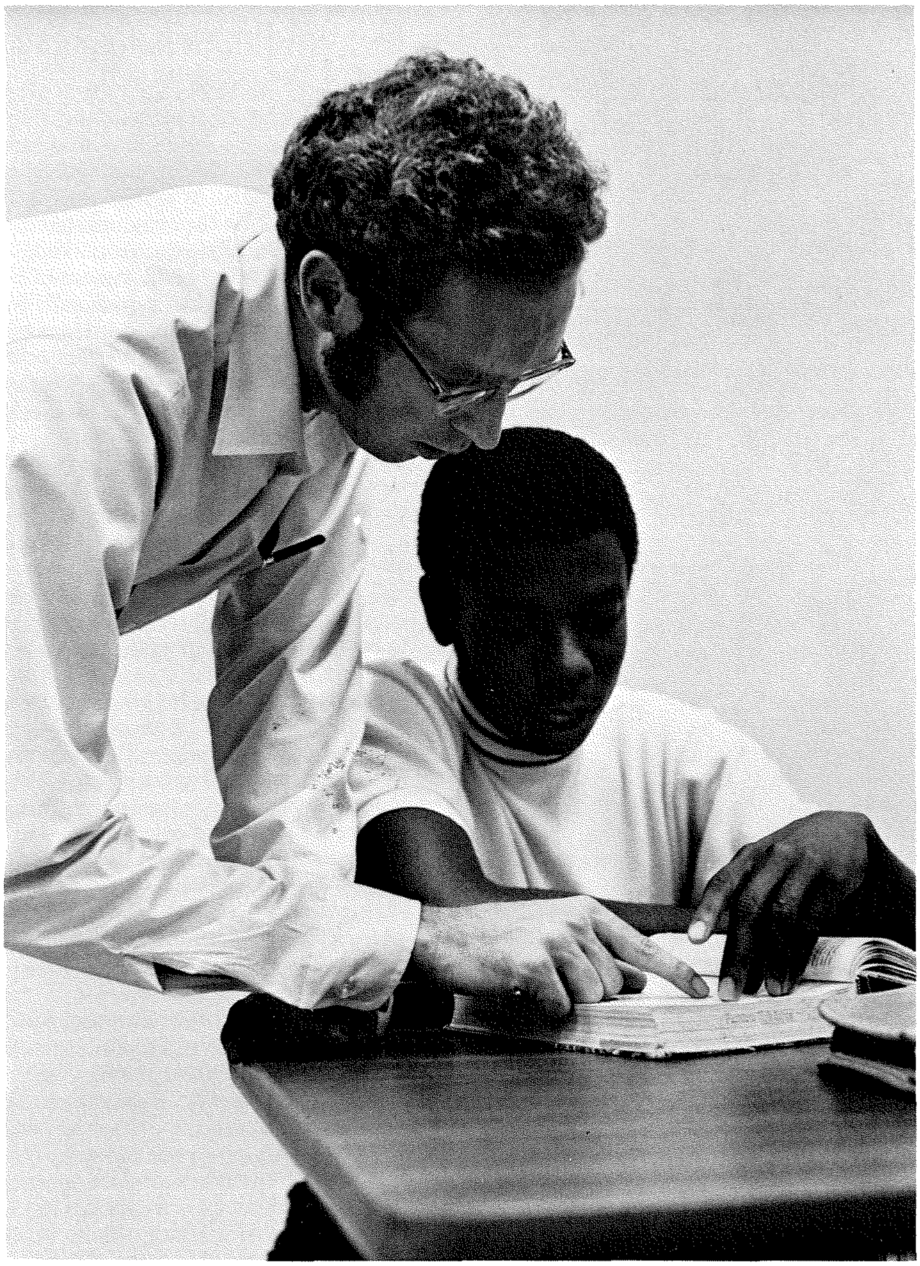
Bill Beranek is one of a new breed of graduate students. As a PhD candidate doing research on the enzymes that catalyze chemical reactions in living systems, he is a dedicated student of science. As the resident associate of one of Caltech's undergraduate student houses, organizer of a stimulating new series of seminars in Caltech's chemistry division, tutor and lecturer at local high schools, a member of the Caltech Environmental Action Council (to mention just a few of his activities), he is a concerned member of society—which is a fancy way of saying he cares a lot about other people.

These days, Bill spends a lot of time combining these enterprises by trying to bring science and people closer together.

"Society is paying for scientists to do their thing," he says. "It must get something in return—whether it's knowledge for its own sake or knowledge for economic benefit. Since non-scientists are not coming to *us*, we have to try to communicate with *them*."

One way Beranek has put this conviction into action has been to generate a series of weekly seminars at Caltech on "Chemistry and Society" which offer four broad and challenging areas for discussion: the effect of chemistry on society, the structure of chemistry, the responsibility of the chemist, and the future of chemistry as a discipline.

The seminars started in January. So far they have featured James Morgan, professor of environmental engineering science, speaking on trace metals in the environment; A. J. Haagen-Smit, professor of bio-organic chemistry, on air pollution; Norman Brooks, professor of environmental science, on strategies for solving environmental problems; Daniel Kevles, associate professor of history, on the moral dilemmas of the American chemist; and George Hammond, chairman of the division of chemistry and chemical engineering, on his philosophy of chemistry. Most recently, M. R. Barusch of the Chevron Research Company spoke on the history of the



Bill started tutoring Charlie Armstrong back in the summer of 1969 when Charlie was enrolled in Caltech's first junior high school science program. Now, Charlie is helping Bill. He designs the color slides and posters that Bill uses to illustrate his high school science lectures.

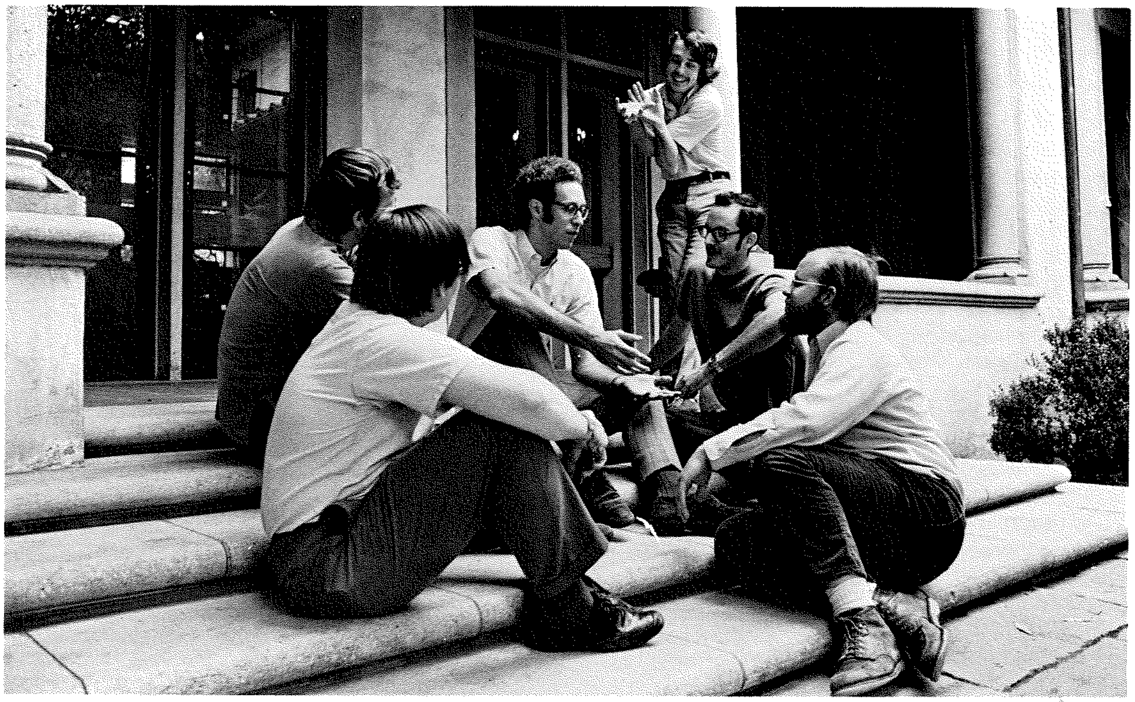
development of F-310; and Morton Z. Fainman, petroleum consultant, on the problem of lead in gasoline.

In organizing the seminars, Bill's primary aim was "to stimulate introspection among graduate students and the faculty in chemistry," but he has also arranged to have the talks videotaped for distribution to local schools, and he is now editing manuscripts for publication of the talks in a book. If the seminars are run again next year, he thinks that quiz sections and research assignments may be added so that undergraduates can "take" the seminars as a course for credit.

In addition to the chemistry seminars, Bill is arranging a series of panel discussions between faculty and students of Caltech and Occidental College. These discussions will take a philosophical look at the questions of how science has affected man's concept of himself. A preliminary session—a discussion of medical ethics, led by Dr. Joseph Fletcher of the University of Virginia Medical School—was held on February 14.

Along with these heady projects, Bill continues to work on the high school science program he started two summers ago in collaboration with Jerry Pine, professor of physics, to get junior high school students interested in science. The project is now headed by Lee Browne, Caltech's director of secondary school relations. The program runs throughout the academic year and offers lab work, tutorial assistance, monthly science lectures by Caltech faculty members, and science lectures at high schools in the Los Angeles area. As one of the lecturers this term, Bill is visiting high schools in Glendale, Gardena, San Fernando, and Watts. His topics range from enzymes to metal pollution ("High school students are especially interested in subjects like drugs, pesticides, DNA, and contraception—and they ought to be explained in layman's language"), but his main objectives are to excite students about learning in general and to show them—by means of dramatic and creative demonstrations—that "Caltech is not just a big black box where the mysteries of science are performed."

But Bill Beranek is more than a graduate student, chemist, and tutor. To many Caltech undergraduates he is also "Uncle Bill"—the resident associate



Uncle Bill is surrounded by a (mostly) respectful group of nephews on the steps of Fleming House. Not all his activities as resident associate are so sedentary.

of Fleming House. In this role, he is particularly enthusiastic about getting the students interested in activities outside their classes. With sports, of course, it's easy. He plays basketball and softball with them, and Fleming managed to win most of its intramural games this year. But with plays, opera, or concerts it's a little tougher. "Some of the guys are embarrassed to sign up at dinner for tickets. So I've learned to buy the tickets in advance, and I tell them to see me *after* dinner. I may lose a couple of bucks, but this year a number of students have gone with me to see things like *Faust, Abelard and Héloise,* and *Hamlet.*"

For his doctoral research at Caltech, Bill is studying lysozyme, an enzyme found in human tears and in the whites of birds' eggs. By catalyzing the hydrolysis of the polysaccharide chain—the backbone of bacterial cell walls—lysozyme kills bacteria and thus protects the egg yolk and the eye.

"Lysozyme is interesting medically," Bill explains, "because it is found in large quantities in certain leukemia patients. We study it because it's easily obtainable —there are plenty of chicken eggs around, and we also cry a lot—and because it's one of the few enzymes whose three-dimensional structure is well known. A lot of the principles of enzyme catalysis that we learn from lysozyme will probably apply to other enzyme systems that are much more difficult to isolate."

A 1967 graduate in theoretical chemistry from the University of Wisconsin, Bill became interested in biochemistry while he was doing summer research at a hospital in Madison. "I took the job because I'd been working in physical chemistry and I wanted to know what the 'other half'—biochemistry—was about," he says.

At the same time, he was working as a youth counselor for the Lutheran Church. His work for the church—both as a counselor and as a member of the choir—added to his liking for people and taught him a lot about working with them. When he came to Pasadena in the fall of 1967, he worked as a science tutor in Watts, then as a volunteer for the Headstart Program, and, later, he taught English to 40 Cuban refugees.

"When I came to Caltech, I wanted to be a top scientist," he says, "and I've always wanted to be a professor— because my dad's a professor, I guess. I enjoy the academic environment and doing research for its own sake, but I have a real problem because whatever I do I always want to be the best. I used to play chess and bridge until I got so competitive that I found myself reading a lot of books on how to play. So I gave up chess and bridge, but I can't give up people. Inevitably I'll have to choose between orienting my life around science or around people—if I can't synthesize the two. I guess I have so many goals that I don't really know where I'm going. Actually, right now I enjoy just being a plain graduate student."

The Month at Caltech

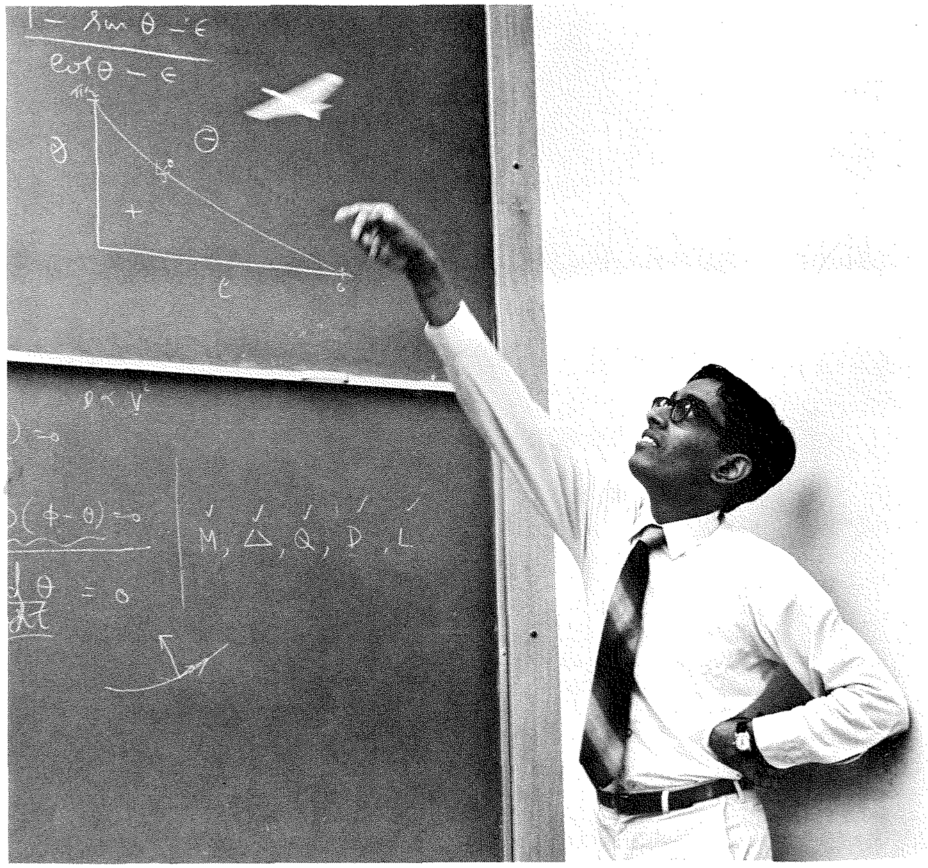
The National Medal of Science

Allan R. Sandage, staff member of the Hale Observatories, has been awarded the National Medal of Science by President Nixon. Sandage, whose research has concentrated on stellar evolution and the birth and death of stars, helped discover quasars—the mysterious power sources believed by some astronomers to be the most distant objects in the universe. He is currently making studies to determine the accuracy of the Hubble Constant, a formula that describes the rate at which the universe is expanding.

According to a White House announcement, the award was given to Sandage "for bringing the very limits of the universe within the reach of man's awareness and unraveling the evolution of stars and galaxies—their origins and ages, distances and destinies." The National Medal of Science is the highest award of the federal government for outstanding contributions to scientific and engineering development. Since 1963 it has been given by the President to 78 men and women in the physical, biological, mathematical, or engineering sciences.

Sandage is one of five Caltech faculty or alumni who have been so honored. The very first recipient was Theodore von Karman, professor of aeronautics and director of the Guggenheim Aeronautical Laboratory at the Institute from 1930 until his retirement in 1949. He was awarded the medal by President Kennedy in February 1963. A. H. Sturtevant, Thomas Hunt Morgan Professor of Biology and a member of the Caltech faculty for 42 years, was given the award in 1967. Other Caltech recipients are Wolfgang K. H. Panofsky, PhD '42, who is now at Stanford University as professor of physics and director of the Stanford Linear Accelerator Center; and John R. Pierce, '33, MS '34, PhD '36, executive director of the Research-Communications Division of Bell Telephone Laboratories

Sandage received his AB in physics from the University of Illinois in 1948, and his PhD in astronomy and physics from Caltech in 1953. He also holds ScD's from both Yale University and the University of Chicago.



S. P. Govindaraju launches a paper glider on a successful flight—and demonstrates principles of airplane dynamics at the same time.

The Dynamics of Paper Gliders

Teaching airplane dynamics is often hampered by the absence of anything concrete to experiment with. S. P. Govindaraju (PhD '70), graduate research assistant in aeronautics, has found a way around this problem.

Far from being a put-on, Govindaraju's technique demonstrates that the dynamics of paper gliders involve the same mathematical equations that the dynamics of real airplanes do. Of course, the nature of the construction material (a sheet of paper and a couple of strips of Scotch tape) imposes some pretty severe design constraints, namely that the experimental craft have to be kept fairly small—say, nine inches or less in wingspan. But there are some offsetting advantages, too; for example, the cost is significantly lower than that of most experimental tests in aerospace technology.

There are other advantages: Since everything happens so slowly with paper gliders, it's easy to observe what they do in flight. And while few of us would be willing to entrust our lives to an aircraft constructed of paper, the material is nevertheless rigid enough (if the proper wing curvature is achieved) to return to its original shape in case it crashes into a chair or something. This makes it easy to ensure experimental validity by repeating experiments using the same construction and shape, and to observe the effects of any changes.

Govindaraju's squadron exhibits a variety of construction designs—straight wings, swept-back wings, and even a weird-looking affair with swept-forward wings that looks as though it had been overtaken by a very strong tailwind. But they all fly, and each one demonstrates something different in the discipline of airplane dynamics. In a recent lecture on "The Dynamics of Paper Gliders," one of Govindaraju's aircraft flew in a series of increasingly suicidal oscillations until it finally plopped, belly down, on the floor. The oscillations were induced by marginal static stability (the nose wasn't heavy enough). Another flew in a series of stalls —straight down to the floor. Yet another required a higher launching altitude, so Govindaraju had to stand on tiptoe for that one. (It flew in a long, straight glide path, brave and true—and drew a rousing cheer from the audience.)

Govindaraju doesn't know when he'll use the demonstration technique again, but he is already thinking about refinements. For example, photographing the flight of his craft using a strobe light against a black background would make it easy to plot the flight path in precise measurements. It would, he says, be a good undergraduate project.

It would also be a lot cheaper than most any other kind of experimental aircraft.

Give-it-a-second-thought Department

Caltech's Environmental Action Council (CEAC) is one year old and still going strong. Last spring's Ecoweek, featuring speakers, displays, and an Ecology Faire, was the first big event sponsored by this student group—*E&S,* May 1970. It was well publicized, well attended, educational, and a lot of fun as well. CEAC's subsequent activities have been less spectacular, though one of them—the recycling center—is making a special kind of contribution to reducing environmental problems.

The center consists of an open-air area located behind the Campbell Plant Laboratory on the campus, north of San Pasqual Street and on the west side of Michigan Avenue. Anyone who wants to leave materials there for recycling can do so at almost any hour. There is a sign and lots of accumulated material to indicate where to put things: An old platform area is for deposition of glass containers and aluminum cans, foil, and baking dishes; and there is a roofed shelter for newspapers so that a rainstorm won't turn them to pulp prematurely.

What doesn't show in a casual inspection of the site is the applied thought, social concern, long hours, and muscle-building labor of the students who have manned the recycling center for the eight months it has been in operation. Many students and other anonymous volunteers have contributed time to keeping the center going, but continuing leadership has been provided by Dwight Carey, a junior in geology; graduate students Karl Bell in chemical engineering, Bob Rohwer in biology, and Bill Beranek in chemistry; Russell McDuff, a sophomore in engineering; and freshmen Chris Goldstein and Rob Olshan. One female volunteer, Patty Horne, a graduate art student from Cal State Los Angeles, spends several hours a week at the recycling center—a good part of it in the office in the Dolk Plant Physiology Laboratory reading and answering the increasing volume of mail. She is also helping to prepare a brochure describing the services of the center. When it is printed, it will be available in some local supermarkets, at other recycling and collection centers, and upon request by mail. Right now the center has no mailing address or telephone of its own, but uses the services of the campus YMCA.

The manual labor at the center during the week consists of tying newspapers in bundles and stacking them, loading glass into 55-gallon metal drums and then using steel rods as plungers to smash it, and pounding cans with a 12-foot-long four-by-four to flatten them. The purpose of all the crushing and smashing is simply to reduce the bulk of the material, which is considerable in the round.

Glass must be freed of any metal rings or lids or plastic parts; then it must be sorted by color—clear, green, or brown. Sometimes a very nice discrimination is needed to make a color choice—particularly, Carey notes ruefully, if you're color blind. If the glass is properly

Caltech's Environmental Action Council has collected, smashed, and sold approximately 50 tons of glass for recycling in the last eight months. Dwight Carey wields an effective tool—a metal rod.

separated, manufacturers can use 20 percent old glass to 80 percent new glass. If it has been mixed, impurities—by glassmakers' standards—mean that the percentage of old glass must be reduced in the new mix, and so the old glass is less salable. Incidentally, paper labels on a glass jar make no difference; the heating and washing processes at the manufacturing plants take care of that kind of adulteration.

Newspapers are tied in bundles because most dealers will not accept them in any other condition, and *no* magazines are accepted. Getting rid of magazines is everyone's problem, though magazines left at the center—like other unsalvageable material—are picked up and hauled away by the Institute's trash collection service at CEAC expense.

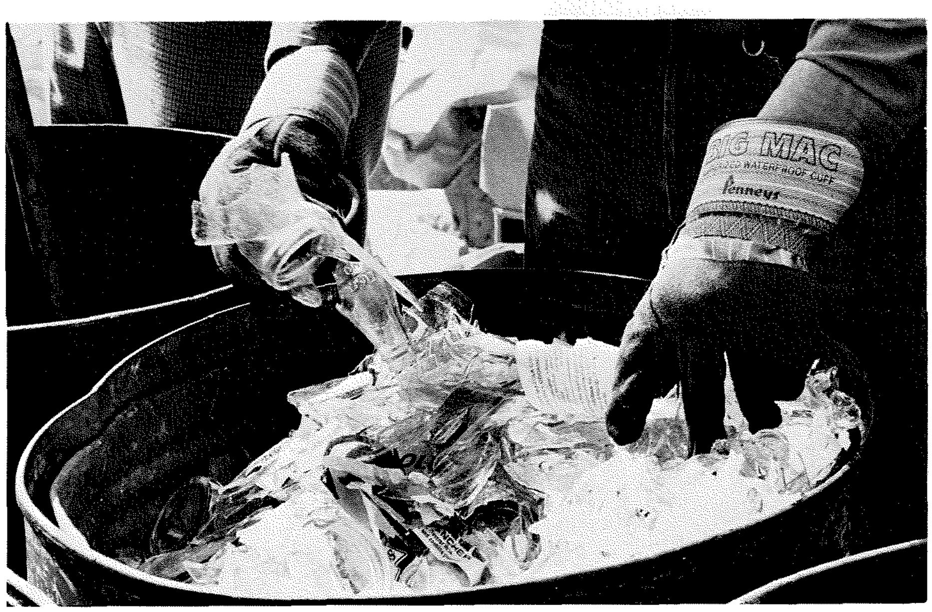
Getting materials for recycling has never been a major problem, and the volume of material handled has increased steadily since the center opened last May. About three tons of discards are now processed each week.

Once a week—usually on Saturday—the students load the bundles of newspapers, and metal drums of crushed glass and aluminum, onto rented trucks (the kind with elevator-style tailgates) and take them to manufacturers in the Los Angeles area who have agreed to buy them for recycling. The Caltech group cooperates with other collection centers in the Pasadena area by pooling what they collect for the weekly sales trips, and Caltech students drive the trucks. When the center first started, very few truckloads of used materials were turning up at the various unloading docks. Now, Saturdays at least are days of land-office business for cooperating manufacturers, and the trucks have to line up to unload.

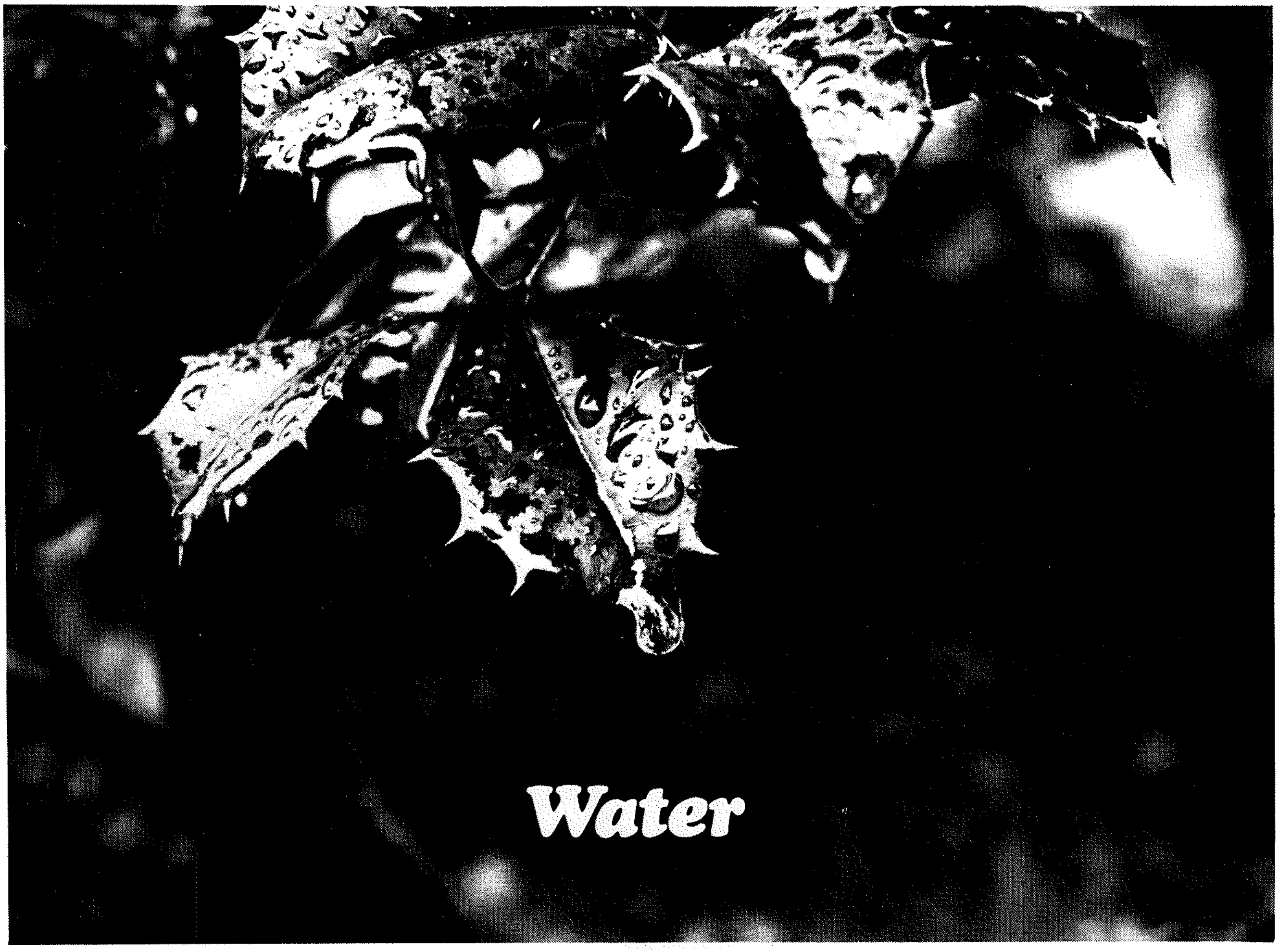
The uncertainties of dependable manpower have been one of the big problems in keeping the recycling center a going concern. In fact, because of lack of adequate help, final exams for the regulars, and some understandable concern on the part of Institute authorities regarding the sanitation and esthetics of the operation, the center was closed for most of December and early January. Now it's open again and is soliciting continuing contributions of material for recycling and increased regular volunteer help.

The money the center receives from the sales of discards is used for maintenance, to buy such equipment as heavy gloves, to rent trucks, and—in time, maybe—to acquire machinery for automating the operation. Smashing glass by hand can relieve a lot of tensions (volunteers are invited to come over and lend a hand and get a little simultaneous therapy), but machines would be a lot more efficient. A glass crusher and a can smasher are high-priority items.

Meanwhile, realizing that we live on a small planet with increasing environmental problems, the staff of the center is putting a lot of dedicated muscle and valuable time into the job. "We have no illusions," Carey says, "that the center—here or in combination with all the other recycling centers in the area—is really doing anything substantial toward solving pollution. We would like to think that maybe we're helping to educate people about the magnitude of the problem. Maybe they'll even begin to give a second thought to what they buy and how it can be disposed of and where more is coming from."



A three-day accumulation of glass adds up to a mountainous mass. Kim Mitchell, Patty Horne, and Bill Beranek apply themselves to sorting and reducing the volume. Eventually, in 55-gallon drums, it will be sold for recycling. A small part of the proceeds goes to buy the protective—and essential—heavy gloves.



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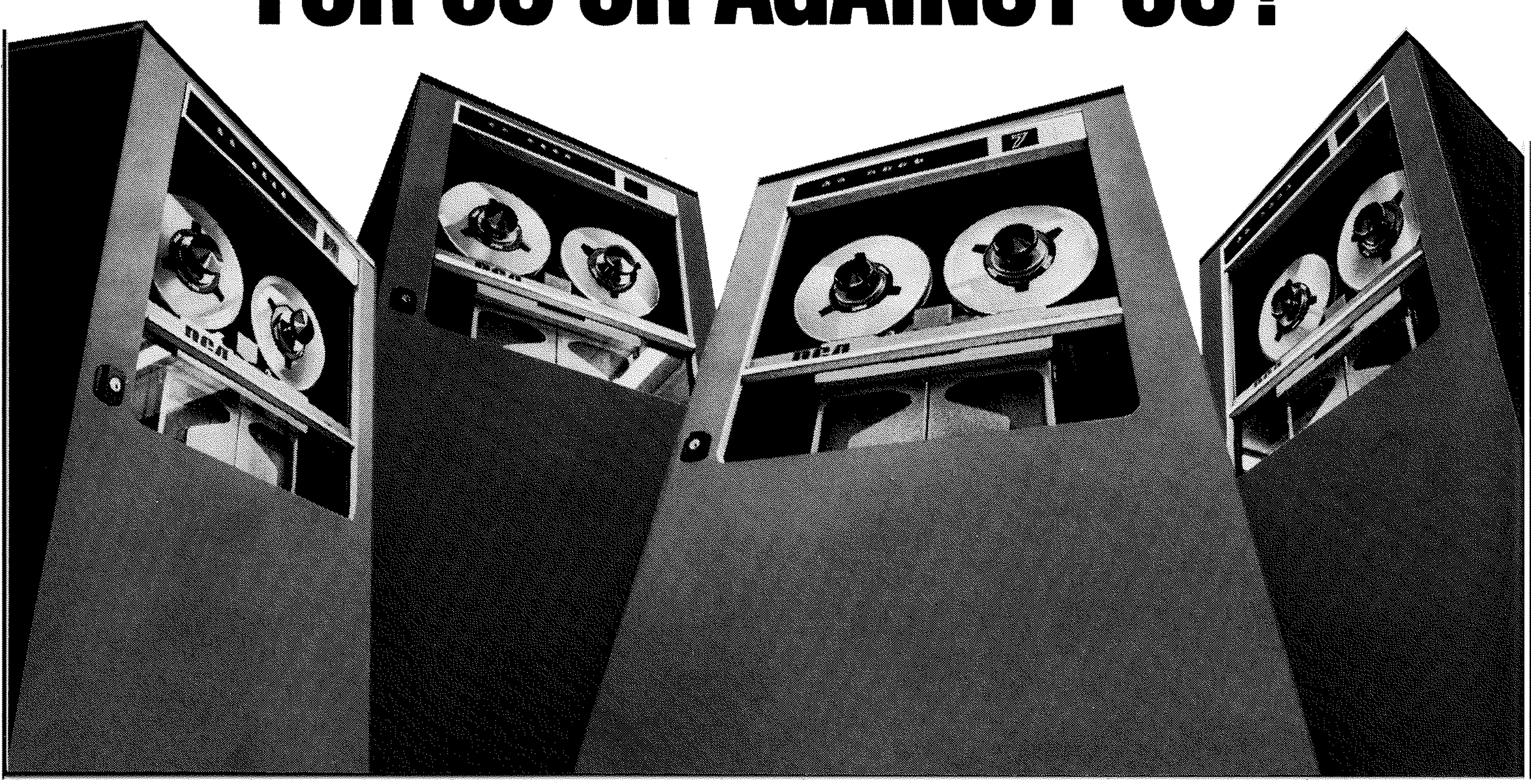

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