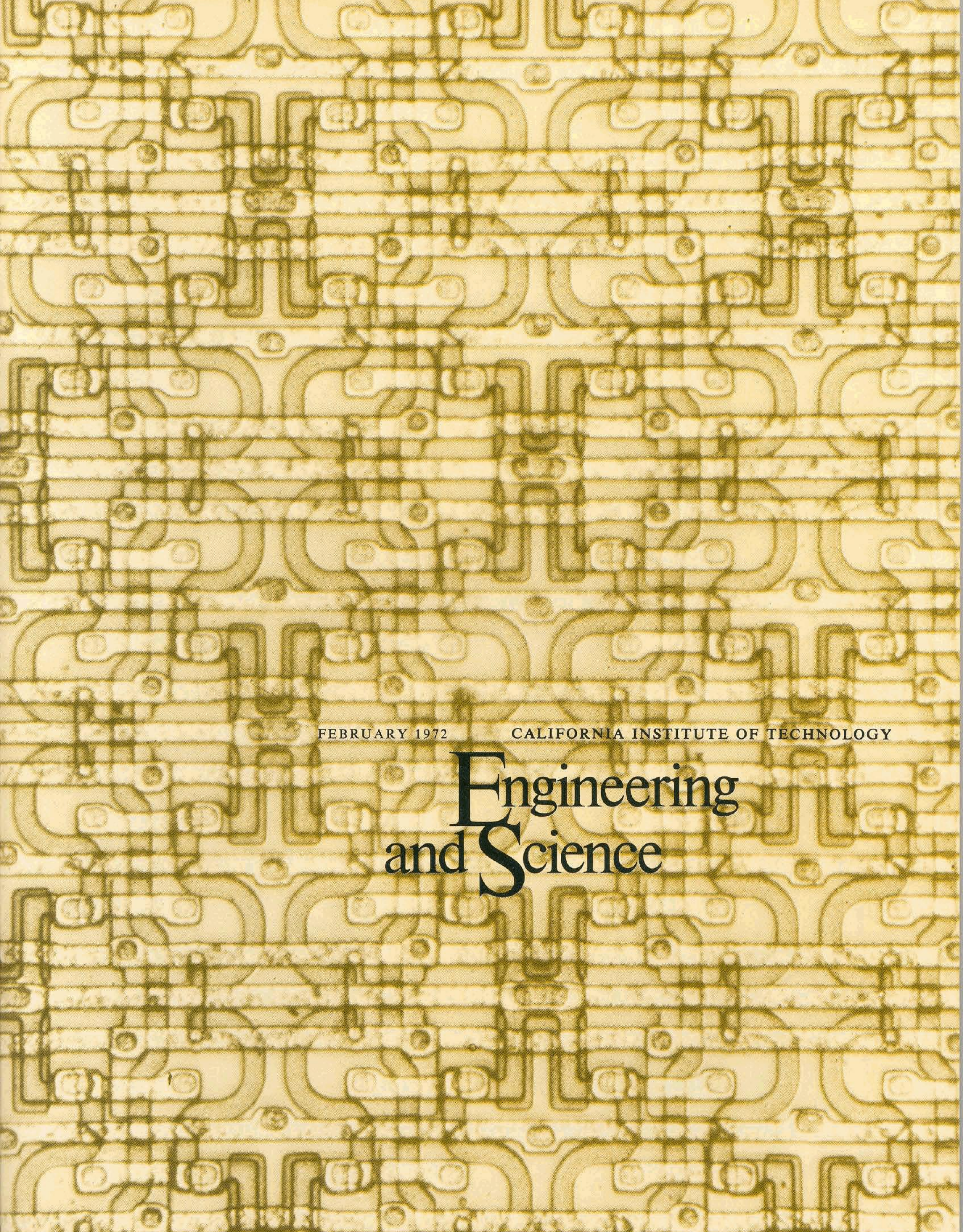

FEBRUARY 1972 CALIFORNIA INSTITUTE OF TECHNOLOGY

Engineering and Science

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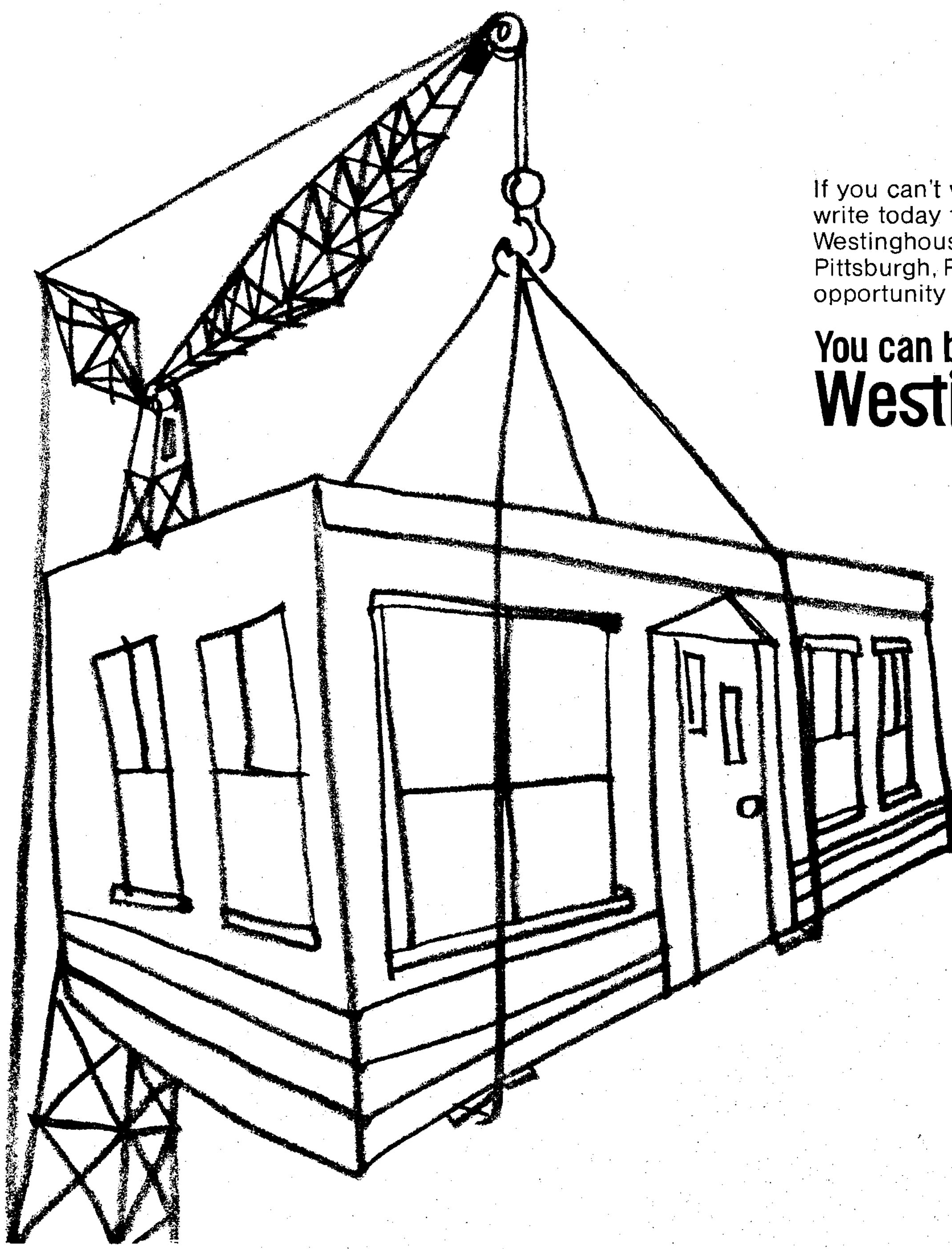

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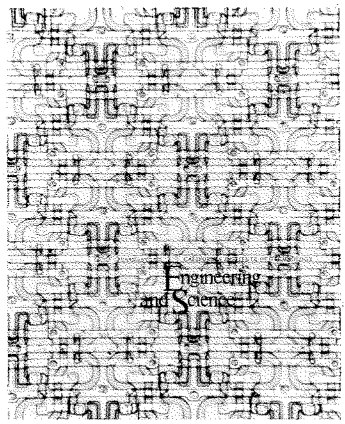
Engineering and Science



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Changing Technology

On the cover—one of the first transistorized semiconductor computer memory circuits of any commercial significance—the 1101, manufactured by Intel Corporation and photographed by Caltech's Carver Mead. This three-year-old memory circuit has 256 bits (a bit being the basic unit of information storage capacity) and already belongs to history. Today's more sophisticated versions have up to 4,000 bits—and the end is not in sight. In "Computers That Put the Power Where It Belongs" (page 4) Mead discusses the revolution in microelectronics technology that is not only reducing computer memory size but has the potential to reduce the size of a whole computer while at the same time significantly increasing its power. Mead's goal: computers for people instead of people for computers.

Enigmatic Mars

Ideas about Mars (mistaken and otherwise) have existed as long as men have observed the night skies. But in the last six years, the Mariner spacecraft have contributed the first really precise data about the planet for scientists to examine and interpret—and the result is the clearing away of a few mental roadblocks and many conflicting theories. Many, but not all. Two planetary scientists, Bruce Murray (in "Mars:—Science Fiction to Science" on page 10) and Carl Sagan (in "Is There Life on Earth?" on page 16), agree that information from Mariner 9 will settle some of the dust of disagreement about Mars, but they still disagree about the likelihood of life on the planet.

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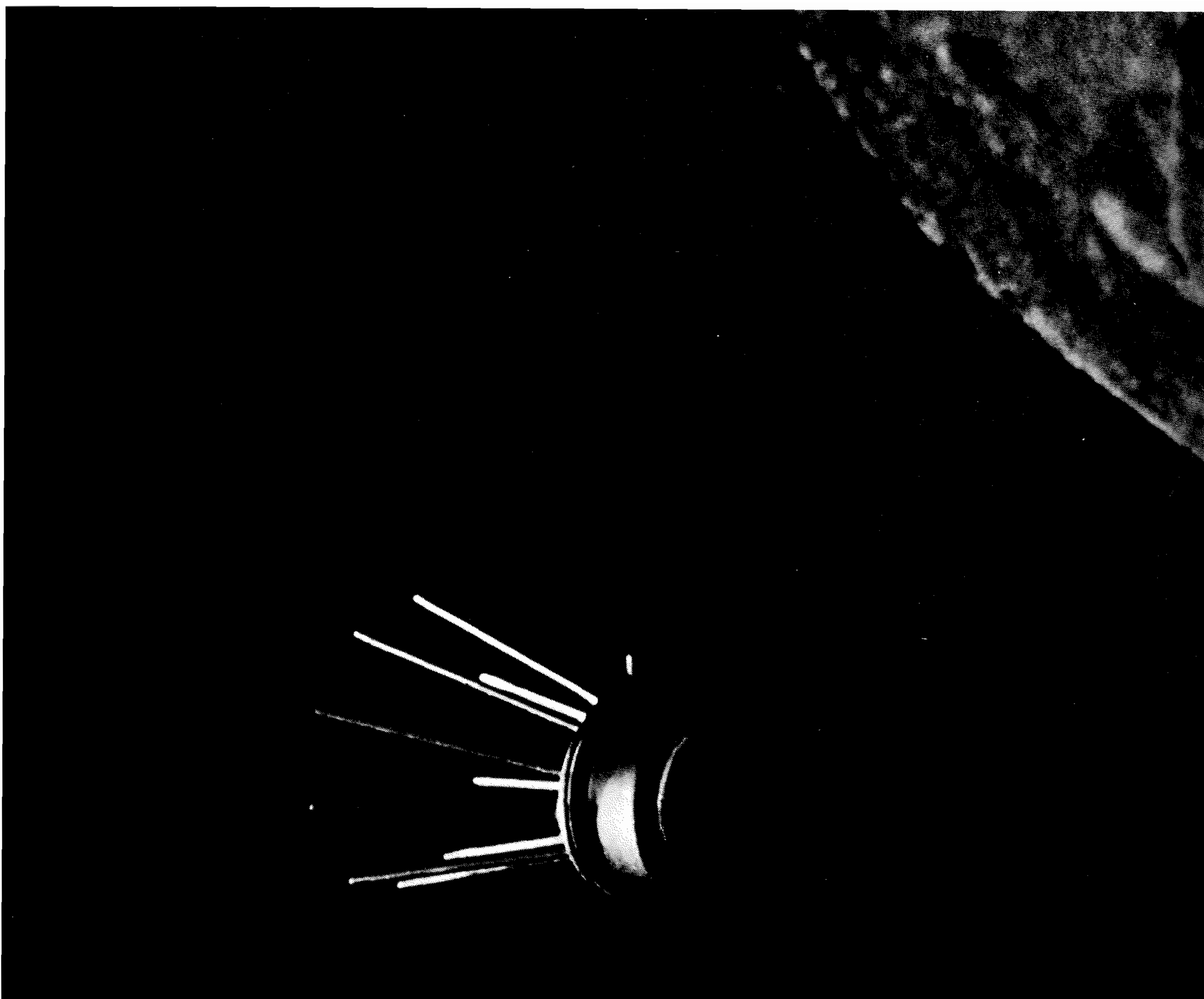

IF IT WORKS ON THE MOON, IT

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The U.S. Postal Service is busily streamlining itself with some of the most sophisticated electronic hardware in—or out of—this world.

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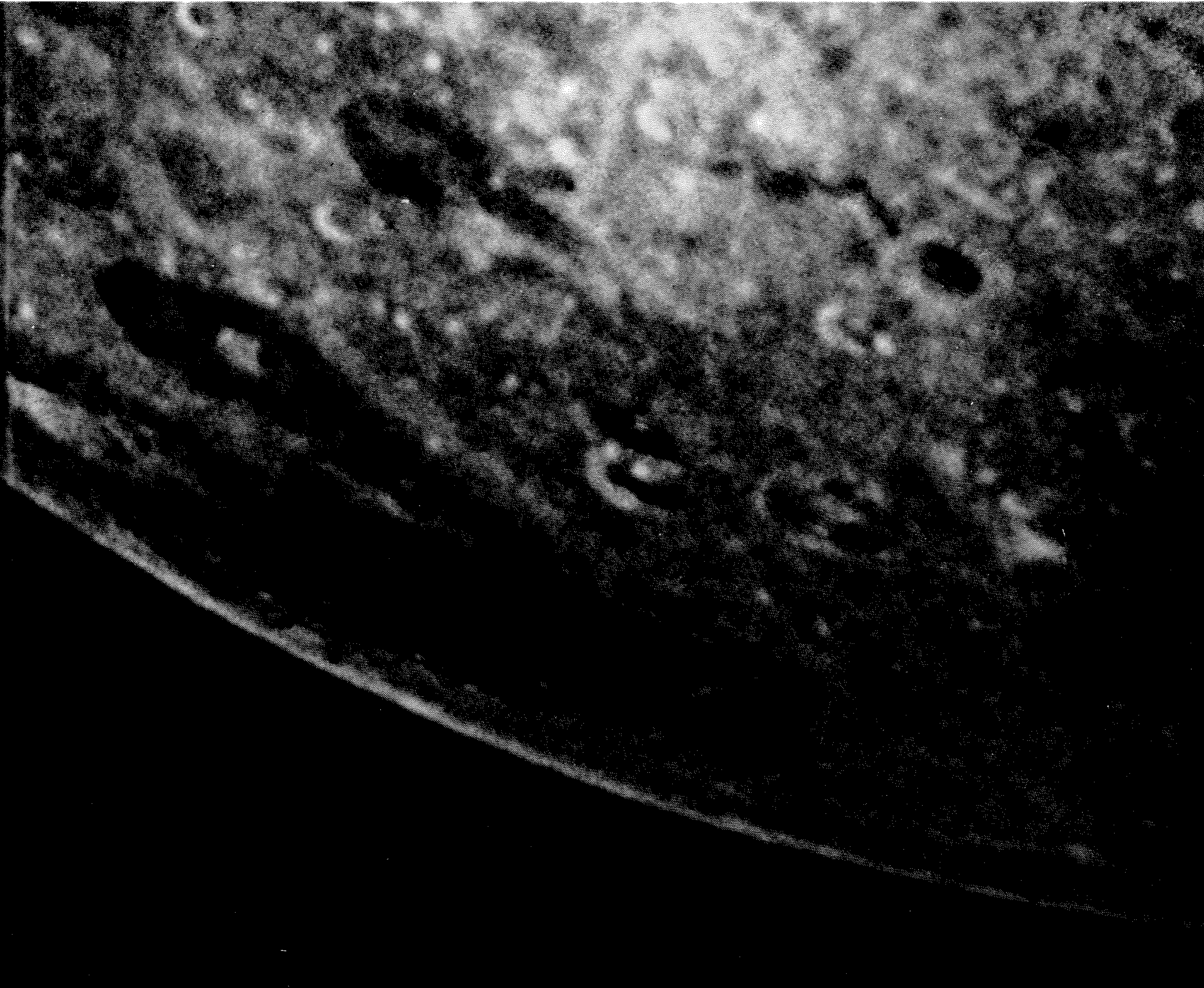
The nickel in the packages helps because it has



SHOULD WORK IN THE POST OFFICE.

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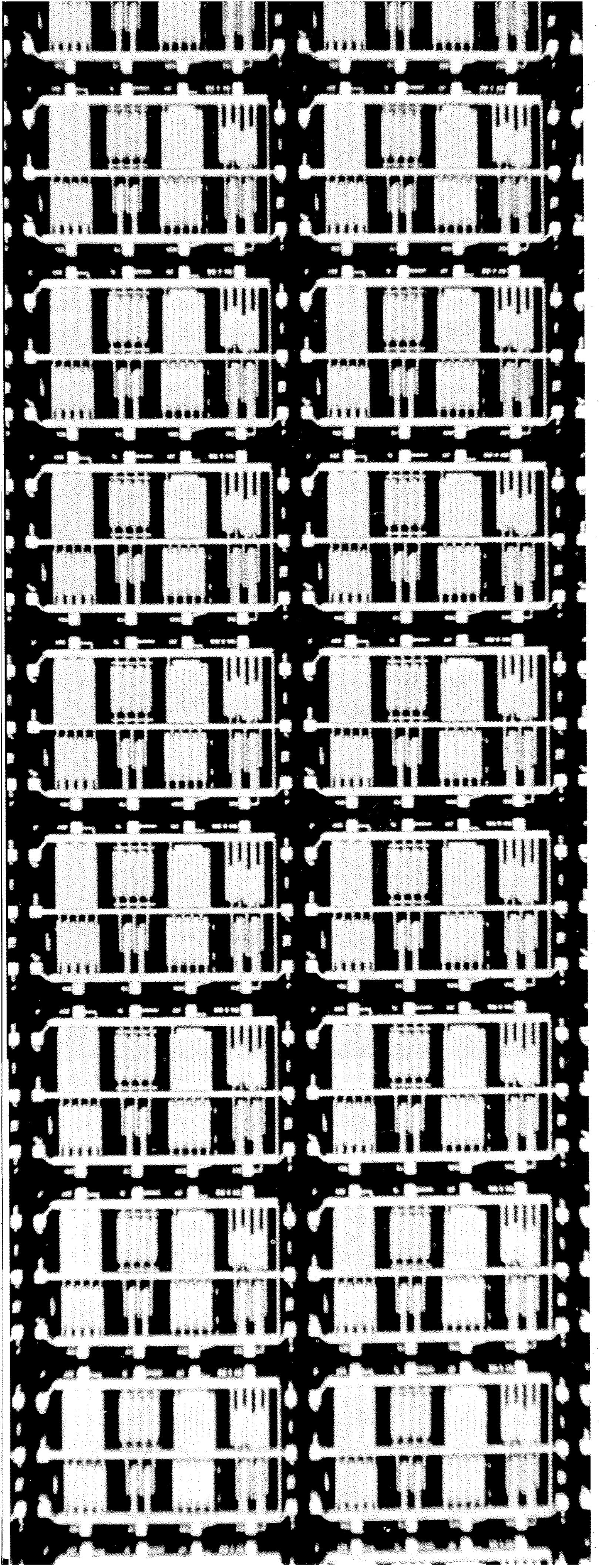


Computers That Put the Power Where It Belongs

In the next ten years almost every facet of our society will be automated to some degree. Whether this will be a change for the good or for the bad will depend on how it is done.

It will be good if it can be done in a humanizing way. If we can get machines to do things that people don't like to do, and if people can feed information into the machines in their own very human ways, this automation will be a constructive and humanizing process. The machines will do the grub work and liberate people to do more creative things.

It will be destructive if people have to learn the language of the machines and deal with them on *their* terms to exist at all—if the human beings have to learn to think like machines or else be discarded by society. The pressures in this direction are already apparent in those levels of society where the computer is heavily used—in business, in science, in engineering, and in manufacturing. Huge general-purpose computers are bent to specific tasks by elaborate programming and software systems (software being the term that describes all the written programs for computer use). But the human being must do most of the bending. He must learn the language of the computer. He must alter his logic to fit the logic of the computer. Even now he can't do certain things because they don't fit the "system." And it is going to get harder to do simpler and simpler jobs as these computers are applied to ordinary, everyday tasks.

This development is well on its way. But it needn't take over society wholly. There is another force in juxtaposition to it that may act to humanize this whole process: the development of powerful, special-purpose electronic machines that will make people more efficient in their everyday jobs, that will put more power at their fingertips.

This is an intermediate step in the miniaturizing of an integrated circuit. The designs in each of the squares represent specific electronic functions that are first plotted on large sheets of film and then reduced photographically to about a tenth of an inch. Designs are etched on silicon wafers by ultraviolet light through this plastic mask. The wafers are then superimposed one on another to produce a complete transistor "chip."

by Carver Mead

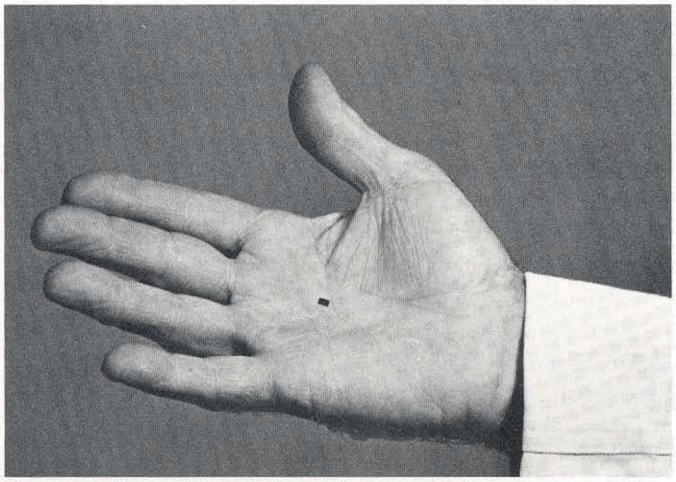
A person doesn't feel dehumanized by such a machine—one that frees him from routine tasks and is under his control. Quite the opposite. This is why people like to drive automobiles, and why they don't feel dehumanized by them. An automobile is a machine that can give you a lot of power, yet it leaves you as much in control as if you were walking. There is no reason why automation of information cannot proceed in the same way.

The next ten years will see a clash between these two forces—two philosophies, really—and society's fate will hang in the balance. The catalyst is the microelectronics technology and its ability to put more and more components into less and less space.

In the past 200 years we have improved our ability to manufacture goods and move people by a factor of 100. But in the last 20 years there has been an increase of 1,000,000 to 10,000,000 in the rate at which we process and retrieve information.

This change was brought about by development of integrated circuit technology, a development that has made individual transistors obsolete—just as transistors made electronic tubes obsolete. The number of transistors that can be placed on a silicon chip has doubled every year since 1960 until it is now possible—using advanced techniques in photolithography—to put 10,000 transistors on a chip that would have held only 1 ten years ago.

There are basically two types of microcircuits: One uses metal oxide semiconductor (MOS) transistors, and the other bipolar (NPN) transistors. (The NPN transistors were developed by William Shockley, '38, and won him the Nobel Prize in 1956.) Both of these transistors are produced in patterns on a silicon chip by a photographic process that reduces the size of each transistor to one ten-thousandth of an inch.



A transistorized "chip" of silicon that would be lost in the palm of your hand can hold as many as 10,000 of a computer's memory circuits. Soon a million circuits may fit on this size chip.

In the near future, using an electron beam for generating the very small patterns required, it will probably be possible to put a million transistors on the same chip that now holds 10,000. This would mean that an entire computer, consisting of a single chip, could be built for about $25. And with this decrease in size comes an increased ability to build more talent into smaller machines.

Up to the present time, what electronic processing machines have been best at is arithmetic. But in the future they will be doing things that aren't arithmetical. They'll be handling all kinds of information, and they will be especially useful in searching out and sorting data. The great strength of the integrated circuit isn't that we can make larger memories, which is what the computer industry has pretty well confined itself to so far. The real advantage is that we can have a tiny computer deep down inside our telephone, or our washing machine, or our car.

This technological revolution has been held up so far by the limited view of what can be done with micro-electronics by the computer industry. The fundamental architecture of computers has not changed since 1946, when John von Neumann reinvented the stored-program

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new microelectronics technology.

Carver Mead works out integrated circuit design with students in his microelectronics class. His students emerge from the class with the ability to design small, powerful user-oriented computers and automated machinery.

computer as conceived by Charles Babbage and others 100 years before, and put the necessary new technology of electronics into it. If you read Von Neumann's instruction set for his machine, you will find that it is basically the same set we have in many machines we use today.

The use being made of microcircuits today can be compared to that of the early days of the electric motor, which was invented at a time when most industries had a big steam engine out in back driving a big shaft the length of the factory. Belts running down from the shaft powered individual machines. The industry had already invested in the pulleys, shafts, belts, and machines; so, from an economic point of view, they could not change the way things were done. Even though it was perfectly clear that the way this innovation should have been used was to put electric motors on each machine, it couldn't be done rapidly. The most that could be done economically was to replace the big steam engine with a big electric motor.

This is the dilemma the computer industry is in now. It has an enormous investment in big machines and big software programs, and the only thing the industry can do right now is to use the new microelectronics as it fits into the existing system.

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new technology—ability improved by a factor of 10,000 to do the logic where we need the logic done. We have computer power coming out of our ears. What we need is the kind of systems we would like to have in our automobiles, in our telephones, in our typewriters—where people now spend vast amounts of time on the repetitive and mundane operations involved in keeping track of a lot of little things.

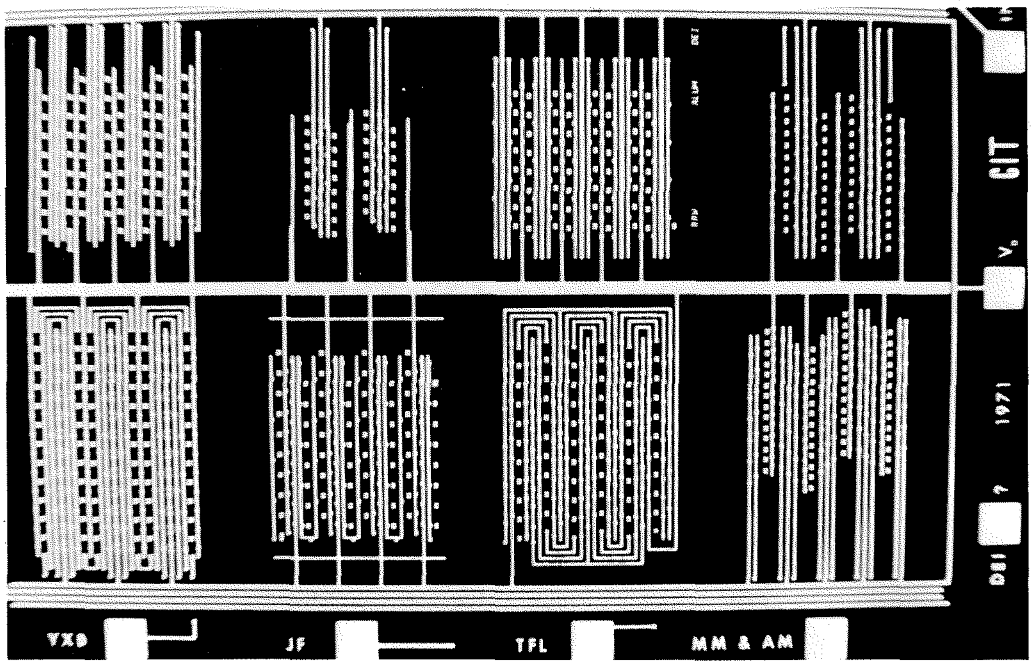
The average man keeping track of his bank account (or even the typical engineer or scientist working on typical problems) very seldom faces huge computational problems; he usually deals with many small calculations. A large general-purpose computer, with the appropriate software, and serving a multitude of users on a time-shared basis, is the present approach to solving his need. Helpful as this may be, a small, extremely powerful calculator is much handier. I am convinced that time-sharing, as such, will gradually disappear as small electronic machines of more and more power become available at lower and lower prices.

Another area of potential development is the special-purpose machine—the self-contained, stand-alone machine having nothing to do with computing—a nurse-medicine machine, a chromosome-microscope machine, an oven-cooking machine. There are hundreds of examples.

Let's look at a few in detail.

In recent years a number of hospital activities have been computerized. One particular set of functions that resist computerization are the duties of the medicine nurse, whose activities during a shift are an object lesson in how to get old fast. She doesn't have time enough on her shift to do a proper job, yet all she has to do is make one mistake and a patient is dead. All her effort is aimed at one simple problem—to translate the doctor's written orders for particular dosages for particular patients into the correct medication in the correct dispenser. And she must do this for 50 to 100 people three to four times a day.

But basically this is a simple problem with a simple answer: Design a system where all she has to do is go to



These designs were conceived by Caltech students as part of the class in microelectronics. After being reduced to a tenth of an inch, each circuit is etched on a silicon wafer. The end product must be an integrated circuit in which transistors, diodes, resistors, capacitors, and interconnectors operate as a single unit.

the medicine room, punch a patient's name into a machine, and wait briefly for the right medicine to pop out.

If this is done with a large general-purpose computer, it requires a broad data-base and extensive software programming. But the performance of such a system can be variable. The probabilities of error are rather high. If something isn't typed in just the right way, if the program isn't just so, the computer will give the nurse three pills instead of one, and the patient may die. Such variable performance is too costly in this situation; the system has to be as close to zero error as possible. A small, powerful, special-purpose computer designed to meet the specific needs of the nurse and her job eliminates most of these error-causing variables. Each hospital floor could have separate local "medicine machines" with the reliability such an operation needs. The more hardware you have —and the less software—the closer you are going to come to that zero error.

If you give the nurse such a system, she doesn't have to be solely a medicine nurse any more. She can do what she was trained to do—care for people. She can pay attention to how they are feeling. The system relieves her of inhuman kinds of activity, of doing the things that machines can do better.

Another example of work now done by big machines that could be done more efficiently by small machines is the chromosomal analysis project at Caltech's Jet Propulsion Laboratory (*E&S*, February 1971). Chromosomes are microscopic threadlike bodies present in every plant and animal cell. They carry genes that determine hereditary characteristics. They occur in pairs running from one to over 100 pairs per cell nucleus, depending on the species. Man, for example, has 24.

At JPL a large general-purpose computer with proper programming and software has been able to scan photomicrographs of chromosomes as they occur in a cell. These are then digitally reconstructed by a computer that determines the pairs by detecting the similar shapes. Using this information, a composite photograph of the chromosomes in pairs can then be prepared for study by geneticists. The present disadvantage of such a system is that only the largest hospitals and institutions can afford it.

A small special-purpose processor built right into the microscope would make such analysis available to any hospital or clinical laboratory. Anyone who does chromosome analysis could have his own. All he would have to do is to stick his sample under the microscope, position it, and push a button. In a minute or so, out would come a photograph. Such an apparatus is not only possible with the use of microelectronics, it wouldn't even be hard to make.

We could go a step further and design a multipurpose microscope adaptable to a number of special-function modules. To do chromosomal analysis would only require plugging in the module marked "chromosomes." Someone else who is doing blood cell counts would have his own module to plug into the same microscope.

With the use of microcircuitry we are putting power where it belongs, in the hands of each individual user. It has nothing to do with computing. All the researcher or technician knows is that he has a microscope that will present a photograph of what he wants, the way he wants it, by his simply pushing a button. He doesn't even have to know data processing is involved. He doesn't need to know there is any electronics in it. All he knows is that he has the world's greatest microscope. We have a user-oriented machine, not a machine-oriented user.

The computer business as structured today is a fantastic anomaly—as a business. We don't normally find businesses that are based on the nature of their technology. Businesses are characterized by the nature of their product. The automobile industry is not called the gear and wheel and pulley industry. It is called the automobile industry. The telephone industry is providing a service that can take information from here and put it there. It doesn't have anything to do with whether there are relays or transistors in the central switching system.

The computer industry, in contrast, is the only one I know that is still characterized by the nature of its technology—digital machinery. It is becoming a very mature industry, and it is inconceivable to me that at this late date it should still be characterized by its technology rather than its market.

The reason for this peculiarity lies in how computers came about. They started with vacuum tubes and were extremely unreliable. They required a covey of technicians fluttering around them to mother them through every problem. They were hard to use because they were implemented with what we now call "machine language." We then had to have people who lived, slept, and breathed this language, turning it into something that was useful.

This concentration of functions requires a big installation. And once the technicians are gathered, it is prohibitively expensive for them not to be at work solving problems. Thus, the big computing center evolved.

Now—after we have developed a relatively reliable machine and a rudimentary language—there are two alternatives. We can build another machine with a language that is more suitable for problems other than computations, or we can write some software that makes the machine with its computational language easier to use for other problems.

It is here that we run into the "frozen-in" phenomenon. It would make more sense to take the first alternative, but the industry is frozen into the second because of the vast

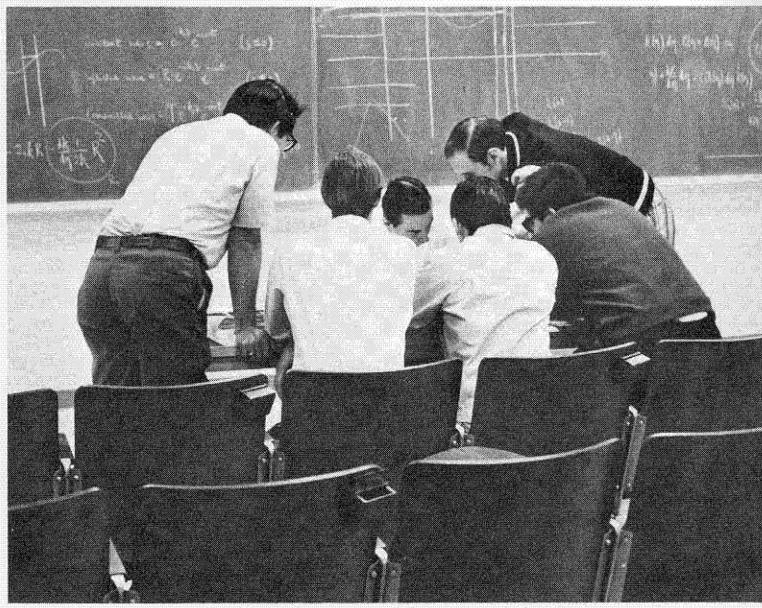
Carver Mead teaches the "little guys" who will build tomorrow's user-oriented machines.

In the view of 37-year-old Carver Mead, professor of electrical engineering, the humanization of computers will come about only through the intercession of the "little guys"—the scientists and engineers who have an intimate and working knowledge of both computers and microelectronics, but who are not a part of either technology.

It will be these men, he believes, who will build the special-function, user-oriented machines that will provide a counterbalance to a computer technology that now demands machine-oriented users.

Mead has already put this philosophy to work in a unique class—EE 281, *Semiconductor Devices*—where about 20 students from a variety of scientific and engineering disciplines receive an intensive introduction to microelectronics and its present and potential applications. Some design rules are developed in the class, and each of the students—few of whom have seen an integrated circuit before—is asked to build one on his own.

A grant from General Electric bought the computer software for Mead's class, and several local firms donate



Microelectronics technology has an exciting potential—the humanization of our automated society. And Carver Mead's class (EE 281) is the place to learn about it.

What these new developments in microelectronics will do is to make machines understand human beings rather than the other way around.

investment in the software that has already been developed.

Machines have become bigger and faster, and computer languages are sophisticated to the point where some truly amazing feats are being performed. But what has not become apparent—and the reason microelectronics technology has not yet had much of an impact—is how terribly inefficient the software approach is to many problems.

How much less costly it is to have a compact, special-purpose machine to deal with a special-purpose problem instead of having a great general-purpose machine programmed with a huge software package to try to turn it into a simple special-purpose machine. For many functions it is possible right now to design, build, and debug a special-purpose machine faster and cheaper than it would be to write the software for a big machine to do the same function. But, as it is, we are dealing with the general-purpose machines on *their* terms. What these new developments in microelectronics will do is to make the machines understand human beings rather than the other way around. People should be able to talk to these machines in English and not have to learn funny little codes.

The change probably won't come from the big companies. It will come from the little guys who are willing to change things. The next five to ten years will be crucial. That is the period in which we will decide whether the large general-purpose or the small special-function machine becomes dominant.

Large computers, elaborate software systems, and computer centers will continue. But they will do what they can do best: solve the large problems, the large accounting and filing tasks, and the scientific calculations. Probably for a while there will be a market where the choice can be made either way. Some will go for large computers and others for small. It will be a bloody battlefield by the time they are through—and we find out what the economics really are.

The next ten years are going to be a turning point for the computer industry—and society as a whole. A great many contributions can be made using the rapidly evolving technology of microelectronics to do things other than just grind numbers finer and finer. We can use it for doing operations of tremendous importance to the everyday life of society—operations which have not yet received any attention at all.

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services. Burroughs Corporation makes time on its photoplotter available, and Intel Corporation processes the silicon wafers. With this aid, Mead and his students are able to go through the whole design and fabrication process in about one-fifth the time it would take in industry. By the end of the year-long course his students are able to create "chips" the size of pinheads with as many as 10,000 transistors and the ability to do a complex variety of functions.

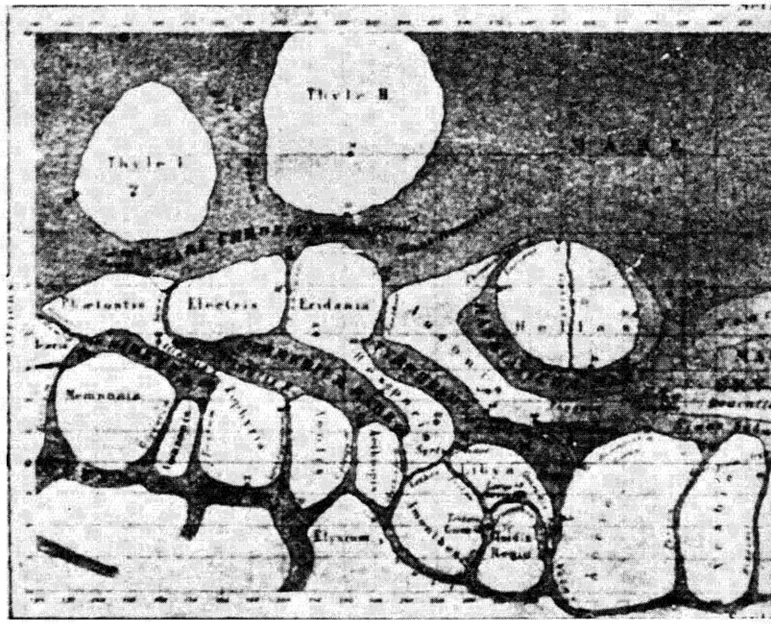
Mead hopes to continue teaching EE 281 to train people who can develop their own ideas for special applications of digital electronics and make the microcircuits that will do the job. He wants to create an essentially new class of scientists and engineers: people who know the technology of computers and microelectronics but are not restricted by the shibboleths and taboos inherent in each. These students, he says, will go into a dozen different fields, taking their knowledge with them. And it will be these "little guys" who will build the powerful special-purpose electronic machines that will make people more efficient in their jobs and put more power at their fingertips—and yet leave them in control.

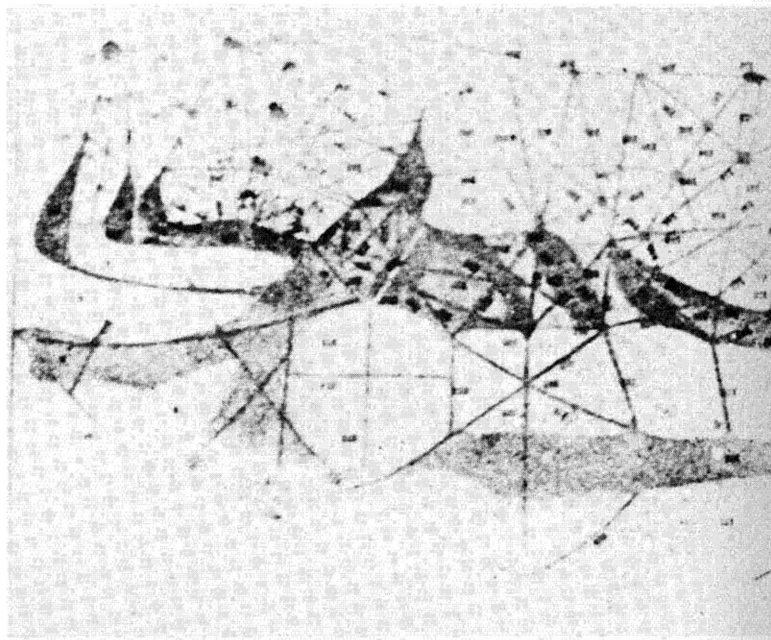
Mead has applied his philosophy with satisfying results. For example, as consultant to Lexitron Corporation of Los Angeles, he helped design and build a sophisticated electronic typewriter for use in high-volume business offices. There are, of course, a number of automated typewriters on the market now. In addition, several computer companies have attempted to design software programs to meet this specific need. But both approaches, Mead points out, require machine-oriented users. In the software approach the cost of redesigning the programs and the terminals for each specific application is about 80 percent of what it would be to simply design a new machine to do the job. Why spend so much on a system that requires people to learn its ways when spending only a little more would yield a special-purpose, user-oriented machine?

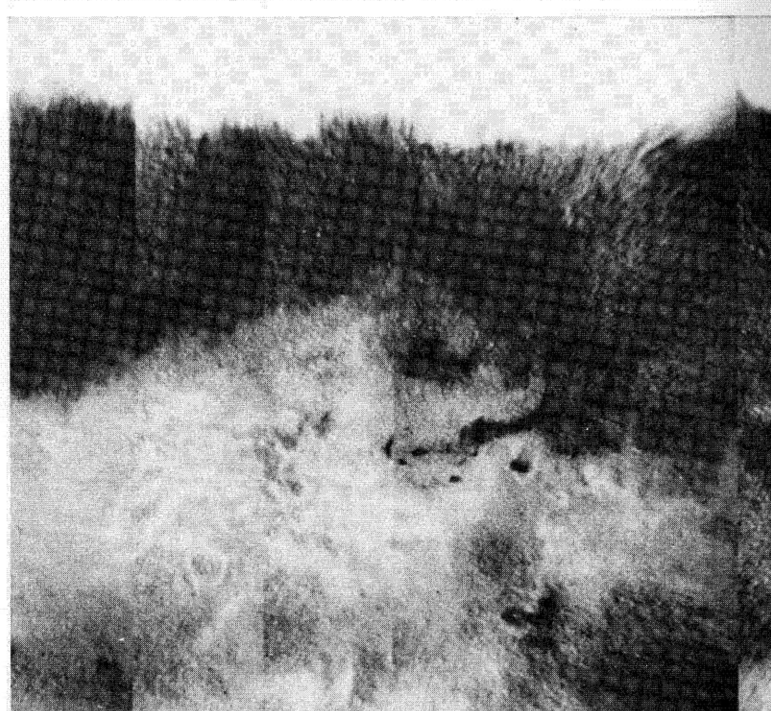
This is what has been done with the electronic typewriter he helped design. It has a TV-like screen for visual display and for all corrections. No paper is necessary until the final letter-perfect document is typed. The keyboard and printer operate independently of one another, allowing a typist to prepare new text while a completed document is being printed out. Corrections are made in an easy, natural way. Instead of having to retype the entire manuscript to add or delete a letter, a word, or a sentence, an integrated circuit memory rearranges the document before final typing.

Mead is a product of Caltech. He received his undergraduate and advanced degrees in electrical engineering here, and he has taught at the Institute since receiving his doctorate in 1959. He also acts as a consultant to a number of electronics and financial firms.

Do the Mariner 9 results increase the possibility that life exists on Mars? No, says Bruce Murray— but Carl Sagan disagrees (p. 16).







Mars: Science Fiction to Science

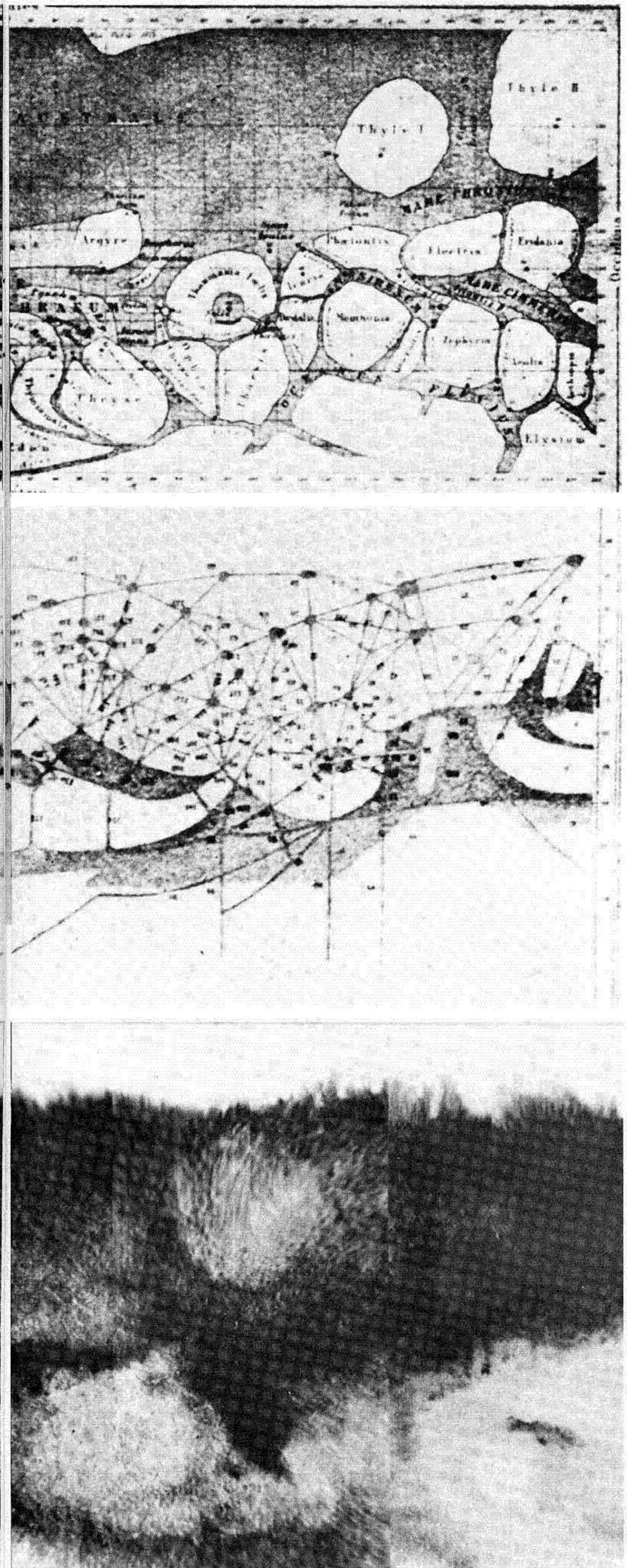
by Bruce Murray

In the last six years Mars has been plucked from the mists of science fiction and scrutinized with the dispassionate eyes of four Mariner spacecraft. As a result, the supposed likeness of Mars to Earth has now nearly vanished. Instead, Mars is now recognized as an independent planetary object, exhibiting on its surface the results of a unique planetary evolution that is still taking place.

But at the same time Mars is also an interesting sociological study. A look at the history of the observations made of the planet and the conclusions drawn illustrates that scientists, despite all their protestations, are human beings. (It is my feeling that they are perhaps a little *more* human than most people.) They are far from objective about the subjects they study—despite their great attempts to be so—and the study of Mars has been particularly good as an illustration of the difficulty the scientist has in knowing when he has really removed all prejudice from his mind and is dealing only with the observed facts in front of him.

I suggest that we have probably not yet reached that point in regard to Mars.

Throughout recent history, especially from the time of astronomer Percival Lowell in the late 19th century, our observations of Mars have been biased by the belief that the planet was similar to Earth. When we look at a really good, Earth-based telescope photograph of the planet, it is easy to understand why such biases exist. The planet, after all, is not strongly marked. So, if we are really looking for features, we can read almost anything into the the drawings and photographs. Mars varies from a rather dusty orange color to a somewhat darker color that could be taken for green. But there is no true green on the planet at all. There are white polar caps as on Earth. The cap changes in each hemisphere in conjunction with the Martian seasons, just as the Earth's would if viewed from space. Those light and dark markings do change their appearance throughout the Martian year in a sometimes regular, sometimes irregular, pattern. When viewed



through telescopes at the turn of the century, Mars could easily be assumed to be like Earth—and was.

In addition, by a remarkable coincidence, the planet Mars has the same length day as the Earth, to within 35 minutes; and its axis is offset from the plane of the ecliptic by exactly the same amount, 23 degrees.

Given these similarities, it is not hard to imagine why it has been assumed that Mars is like Earth or how this view colored early scientific opinion. To some extent it is still a legacy from the past. I call it "Lowell's Legacy." For it was he who staked the most—and lost the most—on his belief in the Earth-Mars similarity. In fact, he lost his professional reputation as a scientist.

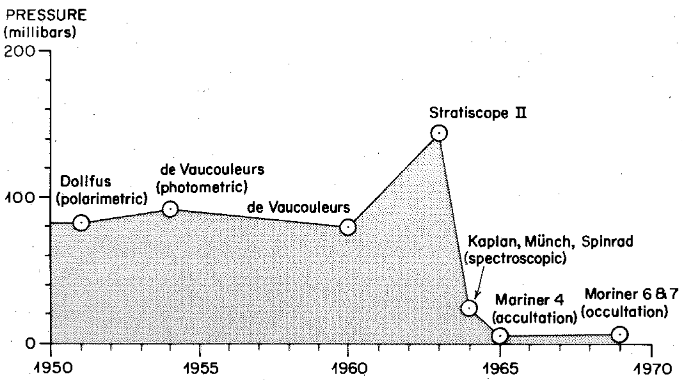
Lowell's classic grandiose book on life on other planets contains a collection of maps done in the period between 1860 and about 1912. Following them in chronological order shows the maps gradually changing in appearance.

One map of Mars drawn by the Italian astronomer Giovanni Schiaparelli in 1877 depicted circular features that show quite accurate observation, but Schiaparelli later attempted to "improve" this map by indicating nice sharp linear features. In the period from 1881 to 1884 the features started getting narrower and more organized. They began to connect, and then finally in 1894, when Lowell came on the scene, they became nice straight lines intersecting at what appear to be nodes of some kind. By 1905 dual canals had appeared in some places on his maps.

This is how the idea of artificial "canals" rather than natural channels or breaks originated. Lowell concluded from his "observations" that the canals intersected at oases. They were, he wrote, canals for transporting water. He believed they were evidence of a dying civilization whose planet, eons ago, was like the Earth. But, being smaller, it lost its atmosphere and most of its water—an idea that was dismissed by most serious scientists at the time. What wasn't dismissed was the idea that plant life might exist there. Rather crude ways of studying the Martian atmosphere existed then, and the results indicated a strong resemblance to the Earth's atmosphere in constituency and pressure.

Lowell's Legacy remained with us even as late as 1969

The features of Mars have not changed drastically in the last 100 years, but astronomers' views have. And not always for the better. Schiaparelli's crude 1877 map (top) is not only more accurate than Lowell's 1894 rendition (center), but even resembles the actual 1969 photomosaic of the same region.



Throughout the 1950's various estimates of the atmospheric pressure on Mars were uniformly an order of magnitude too large—and so did their share to contribute to other erroneous ideas of the planet's similarity to Earth.

(see graph above). In the 1950's it was still believed that plant life of some sort existed on the planet even though a number of techniques had been developed to bring more precision to the study of Mars. Measurements in 1950, 1955, and 1960 cut the estimates of Martian atmospheric pressure down to something like 10 percent of the Earth's at ground level (101.3 millibars). This is roughly equivalent to the air pressure at the top of the Peruvian Andes.

At this pressure—low as it is—many of the conditions present on the Earth might prevail. For example, liquid water could exist on the surface of Mars.

In the early 1960's, however, Guido Münch, professor of astronomy, and two others at the Mt. Wilson Observatory used spectrographic techniques and came up with a figure of about 25 millibars, which is less than 2.5 percent that of Earth's. Finally, in 1965, Mariner 4 yielded a figure of 5 to 8 millibars (about ½ to 1 percent of Earth's pressure). This range was verified by Mariners 6 and 7 in 1969 and by the present Mariner 9. It is obvious now that water cannot exist in the free state on the surface of Mars; there is too great a vacuum. The water evaporates. And therefore the chances of any sort of plant life sufficient to cause surface markings are minimal.

Yet, even as we were getting more precision into our measurements of Mars, Lowell's Legacy persisted. An incident during one of the closest appositions of Mars to Earth in 1956 shows how much we are captives of the past.

Using first a small telescope and then, in 1960, the 200-inch Hale telescope, observations were made of Mars in the invisible wavelengths beyond the red—the infrared—in which plants have characteristic reflections. The compound chlorophyl has an absorption feature in this range that is easy to spot, and absorption features in Mars' spectra in the wavelength region characteristic of chlorophyl were detected. It was concluded that these features were in the spectra from the dark areas on Mars, but not from the light areas. Now, if that were true, it would suggest that there is plant life on Mars in the dark areas and not in the light. If these observations had been made on the Moon, the results would have been checked to see if something wasn't wrong.

As it was later reported, something was indeed wrong. What were actually being observed were the spectral characteristics of HDO, which is similar to the "heavy water" used to make the early atomic bombs. There was no chlorophyl on Mars. However, even after this important discovery was made, the earlier mistake was compounded. It was asked why there was HDO on Mars. The answer would have delighted Lowell: Mars once actually had an ocean and then lost all its water! The heavy-water-like HDO was the enriched fragment that was left over.

Thus, two mistakes in a row were made before the final explanation became clear. The absorption features had nothing to do with Mars. What was being measured was absorption in the Earth's own atmosphere. The original measurements had been made at times when there were slightly different amounts of water vapor—and HDO—in the atmosphere.

Lowell's Legacy persisted even as late as 1969, as an incident related to the Mariner 6 and 7 flights indicates. By that time, because of what we had learned from Mariner 4, we were fairly sure that the north and south Martian frost caps were frozen carbon dioxide—dry ice—rather than water. This was one of the issues Mariners 6 and 7 were to settle. They carried two instruments that could tell us something about that. One was an infrared radiometer to measure temperature. The other was an improved infrared spectrometer similar to the one that led to the spurious identification of vegetation on Mars in the 1950's. The radiometer flying over the caps sent back information suggesting that the surface temperature was very cold—about 150 degrees absolute (or 190 degrees below zero Fahrenheit). This finding supported the idea that the frost was carbon dioxide.

The infrared spectrometer saw some strange features, marked X and Y on the chart to the upper right. These features are about where we would observe methane and ammonia gas in the spectrum if we looked at a mixture in the laboratory. These substances, of course, are by-products produced when living organisms decay, and initially they were interpreted in that sense. It was announced that the white stuff of the polar caps was frozen water and that Mars was a veritable paradise for living things.

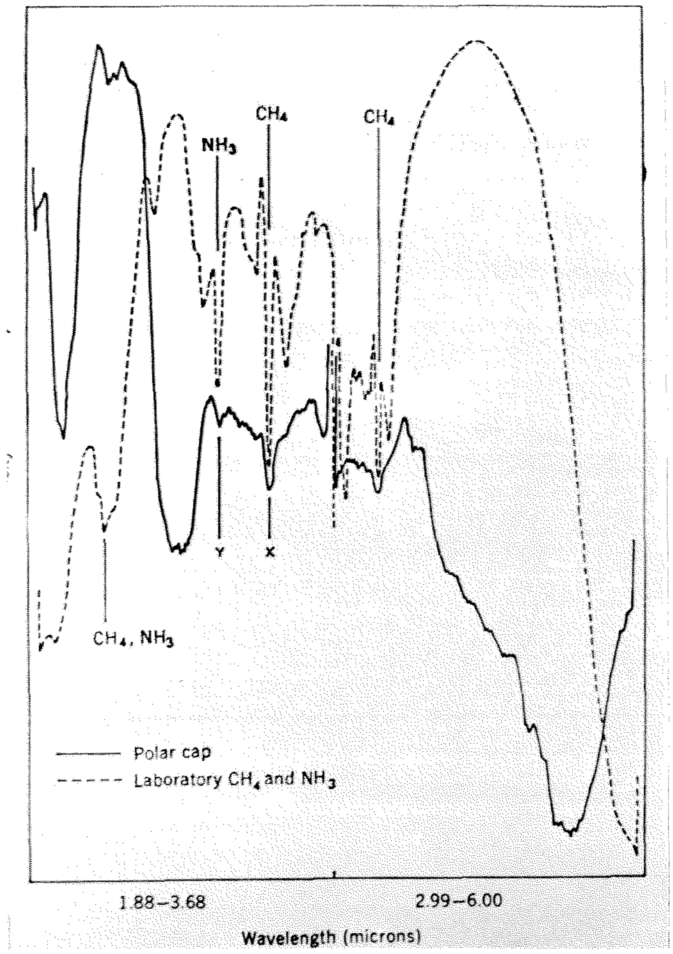
Eventually, with more careful work, it became clear that something else had features X and Y—very, very dry solid carbon dioxide. The spectrometer had not discovered evidence suggestive of life, but of a more hostile environment than had ever been supposed!

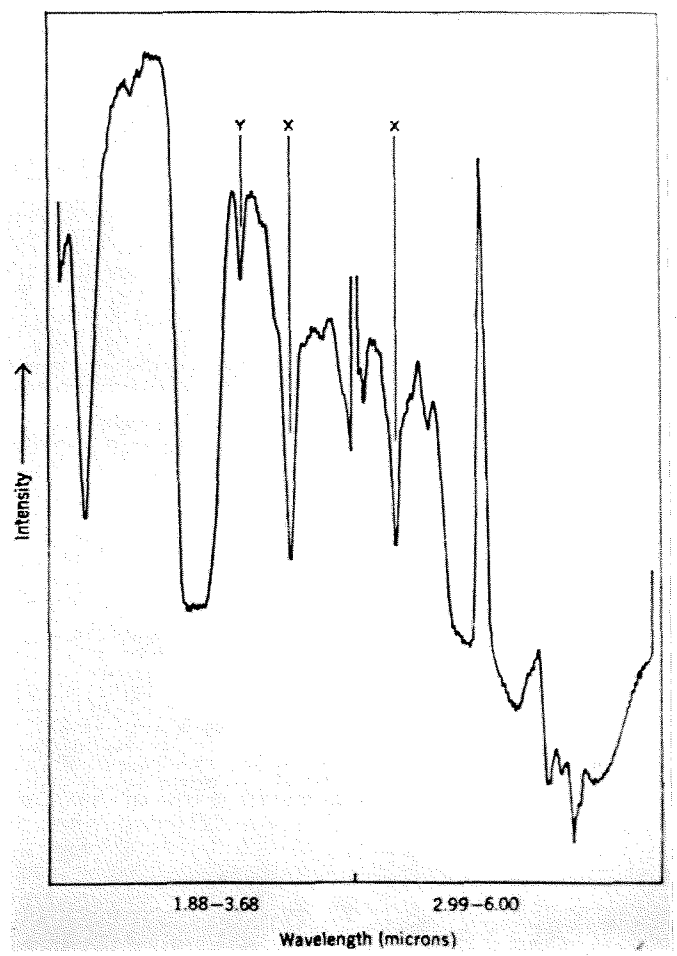
Why were all these mistakes made in favor of the existence of life? Why were pressure measurements estimated high instead of low? Why would a scientist assume he was detecting Martian chlorophyl rather than terrestrial heavy water? Why would someone assume the existence of ammonia and methane in a carbon dioxide atmosphere rather than solid dry ice itself?

The only explanation I can imagine is that those who made such interpretations suffered from the preconceived idea that such evidence of a terrestrial-type environment suitable for plant life might be found.

The results from the current Mariner 9 probe—and to a lesser extent from Mariners 4, 6, and 7—will do much to drive this bias from the minds of most scientists. It is clear that there is little similarity between the Earth and Mars. Some of the planetary processes we have observed bear more resemblance to the Moon. Many, it appears, are uniquely Martian.

The Mariner 4 pictures were stunning in their apparent similarity to the Moon. They showed no mountains like we have on Earth—no folded mountains, no evidence of





The strong similarity of the spectral characteristics of the Martian polar caps (sent back from the Mariner 6 and 7 flights in 1969) and the spectral features of ammonia and methane in a laboratory setting (top) initially led to the conclusion that these two chemicals —which are strongly indicative of life—were present on Mars. Later, more careful analysis, and comparison with the spectra of carbon dioxide (bottom), proved the polar caps were really very dry ice.

These Martian canyonlands are part of a 72,000-square-mile complex photographed by Mariner 9 from a distance of about 5,050 miles. Each of these "Grand Canyons" is about ½ to 1¼ miles deep and 5 miles across with a gentle slope to the bottom. The curving segments of the canyon walls seem to be parts of incomplete craters. Probably the canyons are the result of geological fracturing, followed by sculpturing and erosion of some sort.

oceanic depressions, no signs of island arcs—none of the characteristics of earthly processes. The Martian surface, as far as we could tell from the handful of photographs we obtained, was cratered like that of the Moon. Other instruments indicated that—also like the Moon—Mars has no magnetic field. This means the planet is not shielded from the very intense solar radiation that would be hitting its surface. It suggests that maybe the planet has not boiled and differentiated, which would have given it a core like the Earth's.

Mariners 6 and 7 verified the dry-ice polar caps, the carbon dioxide atmosphere, and the moonlike topography. But they also yielded a couple of surprises. One was a view of jumbled chaotic terrain near the Margaritifer Sinus area. That area, clearly, was not like the Moon. This kind of structure on such a scale was not like anything on the Earth either. It was the first evidence of truly Martian phenomena.

The other surprising area was the circular desert, Hellas, near the equator. This bright region, 1,200 miles wide, is devoid of craters even in the closeup pictures. We are satisfied that the area was not obscured by a dust storm at the time it was photographed, that it is indeed featureless. This indicates that something is either scraping craters away or obscuring them from view. Both areas suggest a current kind of activity. They suggest that Mars is not a completely fossil planet, but an active one—at least in some areas.

The Mariner 9 photographs have been a real shock. We seem to be looking at a different planet from the one we were led to expect by the earlier Mariner results. And, so far, we have only a portion of the 5,000 useful photographs we expect to receive—even though the dust storm during the early weeks of the mission delayed our schedule for receiving them.

One area of cratered terrain photographed by Mariner 9 is totally different from any observed by earlier Mariners (*E&S*, January 1972). These do not appear to be impact craters in any simple way. They are not impact craters that have been modified. They appear to be craters caused by subsidence and collapse as material is withdrawn. This could be due to volcanic activity. The melting of vast quantities of ice beneath the surface of Mars could lead to such features. However, the volcanic origin is the one favored by the photographic team.

An area we call the "Grand Canyon" is spectacular. It consists of a whole series of valleys, each about 5 miles across and 1½ miles deep. The whole area is about 80 miles across. It is a huge feature, comparable in scale to the canyons that break up the Colorado River plateau, including the Grand Canyon. There is widespread evidence of deformation, of things breaking up, of linear features developing. They appear to be relatively uniform plateaus broken up by these huge valleys in an irregular pattern. I don't think they were formed by water. What probably occurred was fracturing to form the breaks, and this was followed by sculpturing and erosion on a grand scale by as yet unknown means. There is nothing on the Moon, there is nothing on the Earth, there is nothing on the earlier Mariner photographs that looks like this.

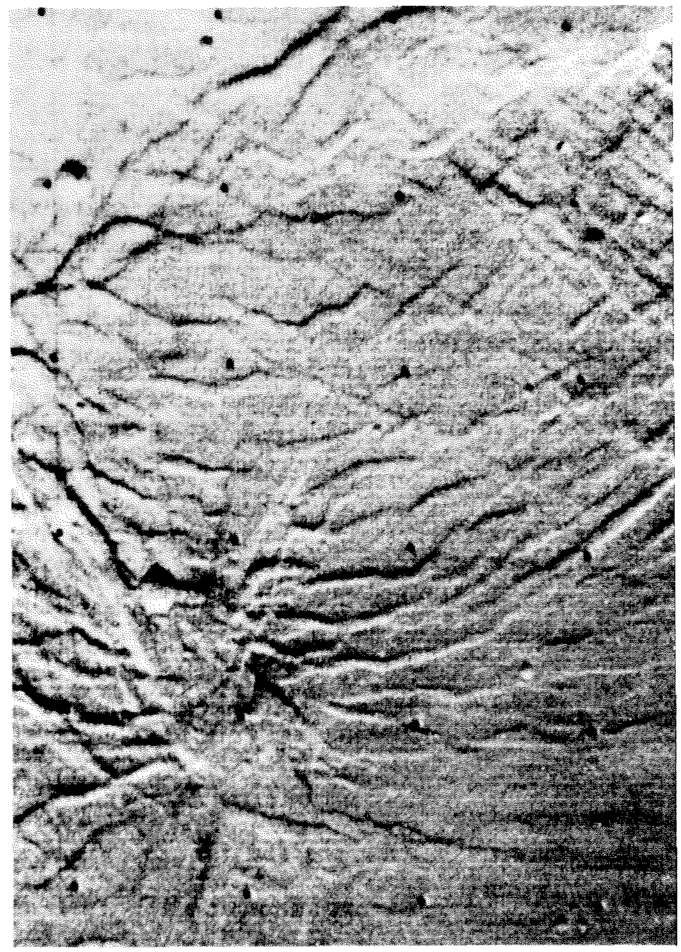
It was a shock. It still is a shock that a planet could be so different.

Another feature, affectionately termed the "elephant hide," looks the way water draining across a tidal flat would look if it were photographed on Earth. Again, this is a large feature: The whole area is about 45 miles across. It is on a plateau about 3½ miles above the mean elevation of Mars. Each fault valley is about 1½ miles across. This too is unlike anything we have seen before.

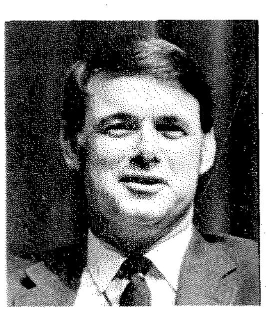
Mariner 9 found that much of the south temperate zone has irregular light and dark markings not present in Mariner 7 images of the same area taken in 1969. Some of the splotches are contained within craters; others appear to wash over craters. The largest are between 100 and 200 miles across. Mars is alive and well. If it's got a disease, it's measles—or something that makes it look funny. But the planet is very active.

All these photographs indicate that obviously Mars has many different kinds of terrains that reflect a variety of processes, or at least a varying magnitude of processes; and they clearly involve internal activity. And that is something we could never say before.

These Mariner 9 photographs are showing us whole new domains, whole new continents, and we don't really understand yet exactly what they mean. We are still in a state of shock, and it's going to take quite some time for us to digest and react to their real significance.



This "elephant-hide" feature, in the area of Phoenicis Lacus just south of the Martian equator, is a plateau about 3½ miles above the mean elevation of Mars. It was photographed by Mariner 9 from an altitude of 4,000 miles just as the great dust storm was clearing. Scientists believe the area is relatively young geologically, possibly covered by volcanic deposits at one time and later broken into faults that cut the rocks into mosaic-like fragments.



"Mars—Science Fiction to Science" is adapted from a talk given by Bruce Murray for the Caltech Lecture Series at Beckman Auditorium on January 10. Murray, who is professor of planetary science at Caltech, is also one of the co-investigators on the Mariner 9 television team. The View from Space *by Murray and Merton E. Davies (Columbia University Press, 1971) gives further details of the photographic exploration of the planets.*

Do the Mariner 9 results increase the possibility that life exists on Mars? Yes, says Carl Sagan— but Bruce Murray disagrees (p. 10).

Is There Life on Earth?

by Carl Sagan

If the inhabitants of Mars set out to do preliminary exploration of Earth, what would they have to do to detect life here?

There are three spacecraft in orbit around Mars. We know that at least one of these—Mariner 9—is taking superb data. For the first time, the planet is being exposed to a detailed and rigorous scientific scrutiny.

Despite widely advertised opinions that Mars is lifeless, Mariner 9 has discovered surface conditions that significantly improve the chances of life there. The planet is revealed to be geologically young and active, shielded at least in places from ultraviolet radiation by atmospheric dust, and possessing enigmatic, sinuous, dendritic features which look for all the world like terrestrial river beds.

In view of the current closeup reconnaissance of Mars and the many questions about the possibility of life on other planets, it is of some interest to reconsider the appearance of our own planet as seen from space. If the inhabitants of Mars set out to do preliminary exploration of the planet Earth, what would they have to do to detect life here?

They could, for example, characterize the terrestrial environment. Ground-based telescopic observations would reveal temperatures, atmospheric pressures and composition, the presence of liquid water, frost caps, and the bright and dark markings which outline the continents and oceans. On the heels of these observations would be speculation about whether the terrestrial environment was suitable for life. There would be arguments that the great excess of oxygen in the Earth's atmosphere surely excludes the possibility of life because all organic compounds would be completely oxidized to carbon dioxide and water. There would probably be arguments that the temperatures on Earth were much too warm by Martian standards.

But other Martian scientists would object, and argue that such a view was much too chauvinistic and that perhaps life can be constructed on slightly different principles—inhabiting somewhat different regimes of temperature, pressure, and composition. The most bizarre hypothesis would be that terrestrial organisms breathe the well-known poison gas, molecular oxygen.

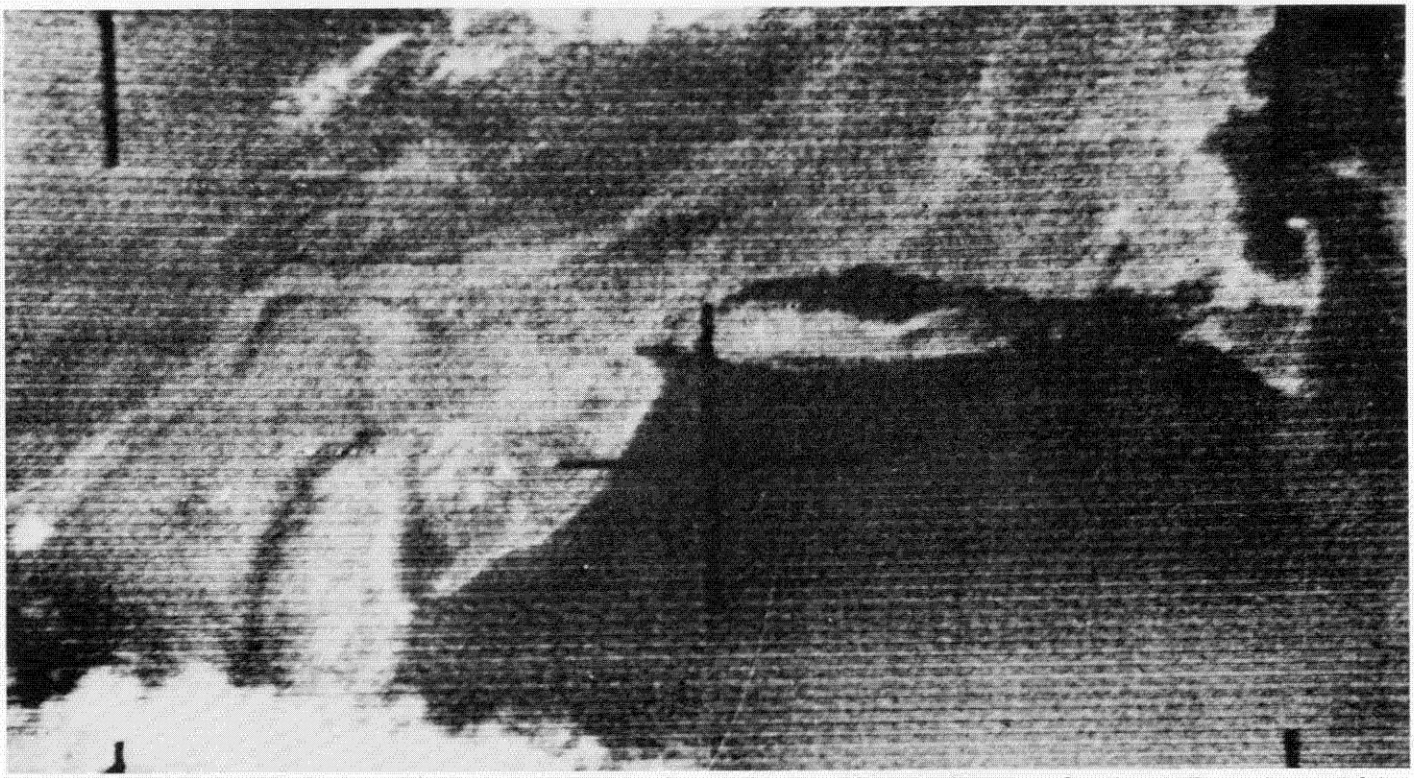
I believe that such debates would, there as here, be inconclusive. What is needed is more data.

One very simple search method for intelligent life (which, indeed, would take all the fun out of the game) is to point a small radio telescope at the Earth at the appropriate frequency. When the North American continent turns toward Mars, there would be a blast of radio emission that would knock the observer off his feet. Prolonged scrutiny would probably reveal a minimally intelligent content to the television signals, and a low form of life on Earth would thereby be discovered.

But this method works only if the Martians observe during the precise epoch in terrestrial history after radio was discovered, but before the widespread introduction of cable TV and other methods of economical usage of communications power. They would have to be observing during one or two hundred years out of the several billion in which life has existed on Earth.

Another approach would be to put radio astronomical searches aside and assume a Martian photographic search in daylight for life on Earth. With a small telescope, scientists on Mars would certainly see the Earth go through phases just as we see the Moon and Venus do. But not much about the Earth would be discernible. With larger telescopes more detail would appear. The wispy white changing features would be revealed as an atmospheric phenomenon, clouds—but of unspecified composition. Once the temperature structure of the atmosphere was determined, it would be clear that these were water clouds and not carbon dioxide clouds or dust clouds.

Beneath the clouds are brownish continents which would probably be called bright areas. The more bluish or blackish areas would at first be called dark areas. But then



Tiros photograph of the eastern seaboard of the United States reveals no visible sign of life—intelligent or otherwise—in Boston (upper right), New York City, or Washington. The effective resolution is a few kilometers.

it would be noticed that these dark areas would occasionally exhibit a bright glint of specular reflection, and the existence of oceans would eventually be revealed. The rotation and obliquity—the deviation from the plane of the ecliptic—of the Earth would be determined. But at this sort of resolution it would not be possible to detect life.

At occasional times of exceptional clarity—when the thin Martian atmosphere was free from dust—scientists using a large telescope on Mars could achieve a resolution of about one kilometer on the Earth. With such a resolution, it would be possible to detect features of fair contrast if they were larger than one kilometer in extent. But features smaller than one kilometer, even if of high contrast to their surroundings, would not be visible.

Would this be enough to detect life?

The Tiros and Nimbus weather satellites photographed the Earth at one-kilometer resolution, and we examined several thousand of these pictures. We found the photographs to be biologically uninteresting. No sign of major engineering works or of the largest metropolises could be found. It has been argued that, for reasons of economy and geometry, technical civilizations tend to construct rectilinear features that have a markedly artificial appearance. But the number of such features visible at one-kilometer resolution is very few. Only about one in a thousand of the Tiros and Nimbus photographs showed evidence of rectilinear geometry on the Earth. And most of these features were natural, rather than man-made—as peninsulas, seif sand dunes, sand bars, and possible jet stream clouds.

At one-kilometer resolution there is no sign of life—intelligent or otherwise—in Washington, Boston, New York City, Moscow, Peking, Melbourne, Berlin, Paris, London, or any other major population center.

Although we believe we have severely reworked the surface of the Earth and have made a profound influence on our planet, we are in a fundamental way still undetectable at a resolution of one kilometer.

Better resolution could be obtained by a space-vehicle reconnaissance of the Earth. Just as we are able with Mariner 9 to examine Mars at 100-meter resolution, our hypothetical Martian scientists might perform spacecraft observations of the Earth at the same resolution.

Would they detect life?

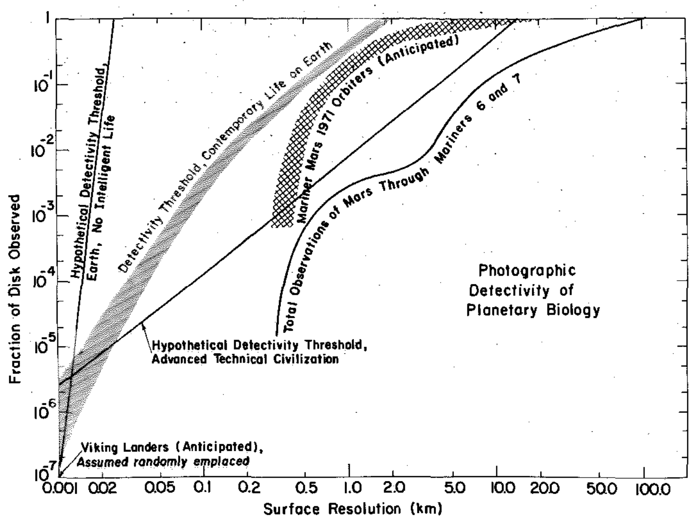
We have closely examined 1,800 selected high-resolution color photographs of the Earth obtained by astronauts aboard the Apollo and Gemini flights. Most of these photographs are at approximately 100-meter resolution. Our sample applied to cloud-free areas. Since the Earth is on the average about 50 percent cloud-covered, this corresponds to an effective non-selective inspection of 3,600 photographs of the same resolution. Dozens of rectilinear or highly geometrized features were uncovered. Of these, 60 have been classified as geological and 20 as meteorological in origin.

Some phenomena, such as dunes, are undeniably rectilinear, but are not of biological origin. Other phenomena, such as coral atolls, are undeniably of biological origin, but would almost certainly not be so identified on the basis of their geometry, without further knowledge of terrestrial biology. Some river basins have a remarkably striking geometry as seen from space, as do some cloud features. Likewise sandbars and craters have striking similarities but are not indicative of life on Earth.

A sizable number of the photographs—57—are so regularly geometrized as to defy non-biological explanations. With the knowledge about the Earth's features that we have (but an extraterrestrial explorer surely would not have) these pictures break down as follows: roads, 29; canals, 5; agricultural geometrizing of the environment, 15; jet contrails, 4; industrial pollution, particularly smokestack plumes, 4. Some cities, laced with extensive highways, such as Dallas-Fort Worth, are easily detectable. Other cities of large size (Cairo, for example) are much less detectable. Perhaps the most striking signs of intelligent life on Earth are the checkerboard patterns of agricultural and urban territoriality.

The conclusion is that with a fair number of photographs at a resolution of 100 meters or better it is very easy to detect intelligent life on Earth. At resolutions worse than

A portion of an Apollo 6 photograph of a typical populated region of the planet Earth—at a resolution of about one-tenth of a kilometer—reveals a fine checkerboard pattern which is the result of the human passion for order, geometry, and territoriality.



In this diagram, three thresholds for the detection of life on Earth—one actual and two hypothetical—are compared with past, present, and future observations of Mars. A previous analysis of photographs of the Earth with similar resolution to photographs of Mars indicates that Mariner 9 will almost surely rule out the possibility of civilization—but not of life—on Mars.

one kilometer, it becomes difficult to impossible.

Human beings have been around for only a few million years, and human beings capable of reworking the Earth to this extent have been around for only a few thousand years. A Martian exploration vehicle coming to Earth in any previous epoch would not have uncovered any of the artifacts we have just described because they have only recently arisen. Yet, for something like four billion years there has been life on the planet Earth.

What about detecting life that does not rework its environment as human beings do?

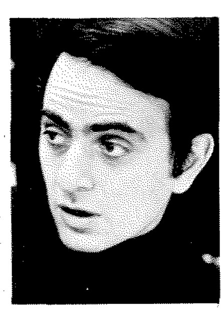
At one- to ten-meter resolutions it becomes possible to detect large plants (especially trees) and animals. Because of their top-heavy geometry, the biological origins of cows, for example, would be rapidly deduced. A cow is remarkaby unstable dynamically, which is a good sign that it is a cow and not a rock. Life forms, in general, are characterized by such disequilibrium phenomena—chemical, physical, dynamic, and otherwise. Although I do not think it is possible to predict in any detail what the manifestations of life on any other planet would be, it is clear they would be characterized by strong departures from equilibrium—departures we would search for in the biological exploration of another planet.

Because there are so many more plants and animals than technological reworkings of the Earth's surface, the photographic detection problem becomes much easier as our resolution becomes much better than 10 meters. This is shown clearly in the diagram at the left, which indicates what fraction of the Earth's surface must be observed at a given resolution to detect life.

At what point in our exploration of Mars could *we* detect a biology even as rich and diverse as our own? As the diagram at the left shows, all the observations of Mars made by mankind through Mariners 6 and 7 would not have detected even a civilization much more advanced than ours.

Mariner 9 offers the first good chance of testing (and probably putting to rest) the persistent speculation about the existence of intelligent beings on Mars. But it is unlikely to have any direct bearing on the most fundamental issues—whether Mars can be a habitat for simpler forms of life. In my view this question remains entirely open—at least until landing missions of the Viking-class journey to Mars in 1976.

Carl Sagan, professor of astronomy and director of the Laboratory for Planetary Studies at Cornell University, is currently a visiting associate in planetary science at Caltech, and a co-investigator on the Mariner 9 television team. "Is There Life on Earth?" is based on a talk given to the Caltech Women's Club on January 13, and on the paper "A Search for Life on Earth at 100 Meter Resolution," published in the December 1971 issue of Icarus. *A further discussion of the detection of life on Earth can be found in Sagan's book* Planetary Exploration: The Condon Lectures. *University of Oregon Press, 1970.*



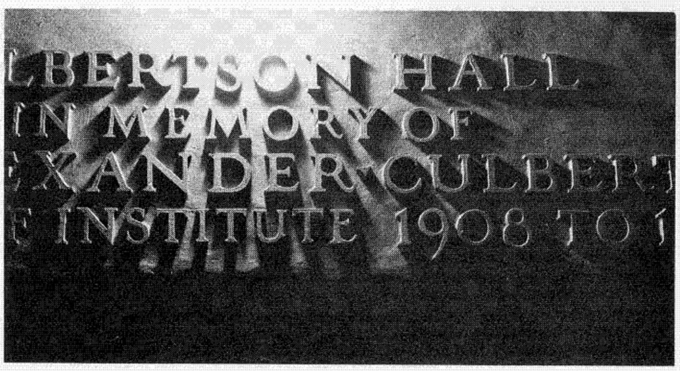
Culbertson Gives Ground

After 10 years of planning and construction—and 50 years of service—Culbertson Hall makes way for a new laboratory of geophysics and planetary science.

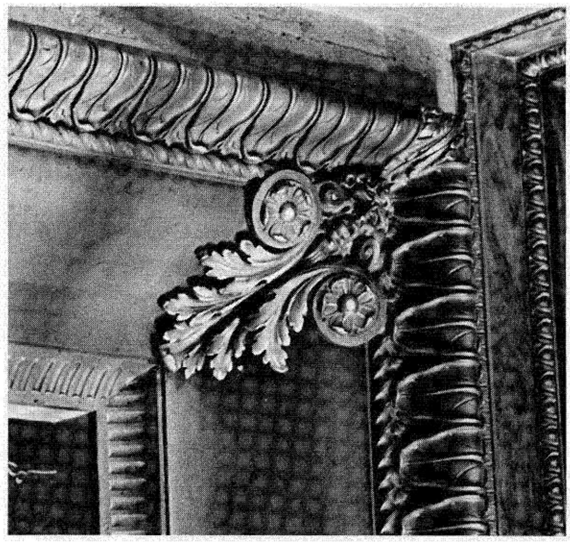
It took a wrecking crew only a few days in mid-February to make the walls of Culbertson Hall come tumbling down. The demolition was not solely for the sake of progress but also to make room for a new laboratory of geophysics and planetary science. And Culbertson's hollow clay tile walls were, like those of Throop Hall and Gates Laboratory, somewhat shaky from the effects of last February's earthquake.

Culbertson Hall, the fourth building to be erected on the present Caltech campus, was the culmination of a town-and-gown dream. As early as 1910, trustees and influential members of the community were making plans for an auditorium here, and fund-raising for it continued for a decade. Much of the $80,000 cost was raised by members of the old Pasadena Music and Art Association through a series of public lectures, cultural events, and extension courses in science, literature, and music. Among those whose performances helped the cause were President Theodore Roosevelt, ballerina Anna Pavlova, and violinist Gabriel Ysaye. The finished building was named in honor of James A. Culbertson, one of Caltech's early benefactors and a trustee from 1908 until his death in 1915.

Designed by architect Bertram Goodhue in an adaptation of Italian Renaissance style, the auditorium featured an elaborate coffered ceiling with a central skylight (long since blacked out), a colonnade of wooden columns with decorative capitals around the balcony railing, and ornate moldings almost everywhere—all richly painted and gilded. What appeared to be natural wood grain or the veining in stone in many instances was plaster "staff" work, an architectural embellishment much used in exposition buildings. (Examples can still be seen in the buildings designed by Goodhue for the San Diego Exposition of 1915.) One memorable ornament from Culbertson Hall has been preserved: the bas-relief (also of plaster) of the nine Muses that hung at the top of the proscenium arch. Using a light touch and lots of padding, workmen removed this in one piece, and it will be stored until a suitable new location is found.



Upon its completion in 1922, the auditorium was described as a "building of wonderful charm" and as a community and college center for "assemblies, social gatherings, concerts, and exhibitions." For many years students were required to attend the assemblies—and each one began with "devotional exercises" conducted by a local minister. The original equipment for the building included several hundred hymnals.


Culbertson has, in fact, been a home for a wide range of activities—classical dramas that utilized all-male casts, modern comedies, and musicals about faculty achievements; folk dancing classes for the children of the faculty, ballroom dancing classes for students, and modern dance classes for anyone with an interest and the necessary agility; Glee Club rehearsals and concerts; an occasional student wedding; and a succession of film series. One of the last exhibits in Culbertson was a display of moon rocks from the Apollo 11 mission. Thousands of people visited it.

The bench that ran around the perimeter of the auditorium was the only permanent seating, so it took a certain amount of stamina to attend the Culbertson offerings. Anything that lasted too long tended to induce anatomical agonies from the slatted wood seats on the main floor or the vision-blocking pillars in the balcony. Nevertheless, Culbertson's official 500-seat capacity was often taxed, and a really popular speaker was likely to have 50 to 100 people clustered behind him on the platform in addition to a full house out front.

Originally the lower level of Culbertson included stage dressing rooms, rest rooms, a kitchen, and a six-table billiard room. Beginning in 1941 this part of the building was for 17 years the home of the Caltech Industrial Relations Center, except during World War II when the whole building was taken over by the Air Force.

After completion of Beckman Auditorium in 1963 there was less and less need for Culbertson, and eventually the space it occupied became more valuable than the building itself. Baxter Hall—with its Ramo Auditorium, humanities lecture hall, and its exhibit rooms—opened in 1971 and almost eliminated use of Culbertson's increasingly shabby and outmoded facilities. Earthquake damage and Caltech's need to house its expanding program in geophysics and planetary science supplied the final push in the decision for demolition.

Research Notes

Piping Up the Shock Waves

When Bradford Sturtevant, professor of and executive officer for aeronautics, takes the lid off his "pipes," Guggenheim Laboratory becomes the noisiest place on campus.

Despite the cacophony, he is actually seeking ways to curb—and possibly eliminate—the racket from motorcycles, from jet engines, and even from sonic booms.

The objective of Sturtevant's research is to find ways to break up the shock waves produced by these "noisemakers" at their source rather than trying to muffle the resulting sound waves.

Shock waves are very abrupt increases in atmospheric pressure, density, and temperature and are major disturbances compared with sound waves, which are very weak pressure variations. The shock waves dissipate as they pass from the source into the atmosphere, degenerating into sound waves.

The key to Sturtevant's work is a simple open-ended acoustical pipe. He has discovered that, as far as the physics of sound is concerned, this is much like the exhaust pipe of a gasoline engine or the inlet compressor of a jet engine. While it might appear that an open-ended pipe allows the energy to dissipate too quickly into the atmosphere to produce the shock effect, Sturtevant finds that sounds produced by it are so strong that they could rupture the eardrums of a person standing close to the pipe while it is generating the waves.

The discovery that shocks are produced with one end of the pipe open, even when the driving action is as smooth as that of a reciprocating piston, makes it even clearer that shock waves may be much more prevalent in sources of intense noise than might have been otherwise suspected.

The ear-splitting noise of a motorcycle engine attached to an open-ended acoustical pipe demands distance or discretion. Brad Sturtevant and his co-workers wisely choose to wear heavy ear pads.

Sturtevant's shocks are produced by the piston of a motorcycle engine that uses a three-inch acoustical pipe as its cylinder. The length of the pipe can be varied from 2½ to 15 feet by adding or removing sections. Sturtevant places wire mesh and metal rings of various sizes and configurations in the pipe to test their effects on shock waves. The resulting noise level is of very high intensity—about 200 decibels, which is the same magnitude of disturbance as that generated by such sources as motorcycle engines. By comparison, the sounds of a hard rock discotheque reach about 110 decibels.

So far, Sturtevant has dared to turn the piston up to only 6,000 revolutions a minute—about 100 shocks a second. Shock waves up to 1½ times the speed of sound have been produced. He plans to take the piston up to 10,000 revolutions a minute, which will produce a more powerful shock wave and a greater potential for noise. Out of consideration for his colleagues who do not wear the heavy ear pads he does, Sturtevant confines the louder phases of his research to evenings and weekends. That is when he takes the lid off his pipe. The pipe is instrumented with pressure gauges to record the shocks. A sophisticated data acquisition system designed by Donald Coles, professor of aeronautics, puts the information on tape in digital form.

The problem of controlling noise from motorcycle and chain-saw engines is difficult because they are two-cycle, one or two cylinder engines. In engines like these, the loss of power due to muffling is much more critical than for automobiles. Also two-cycle engines are inherently noisier than four-cycle ones (such as autos have), because the exhaust and explosion occur at the same time; in four-cycle engines the exhaust takes place one stroke of the piston after the explosion. Some motorcycle engines actually use the shock waves in the exhaust pipe as a supercharger to get more gas into the cylinders. This is done by keeping the waves in phase with the engine at high speeds. The result is a series of shock waves that decay in the atmosphere into sound waves of many frequencies, producing loud, discordant noises.

Sturtevant's work may also shed some light on the nature of the shrill "buzz saw" scream emitted by airline jet engines, which is due to the inlet compressors. The noise has been somewhat suppressed by classical acoustical methods without taking into consideration that shock waves play a role in creating the disturbance. Acoustical liners have been used in jet engine inlets and have been reasonably successful, but no one understands the way in which they break up the shock waves, or how to design a better absorber.

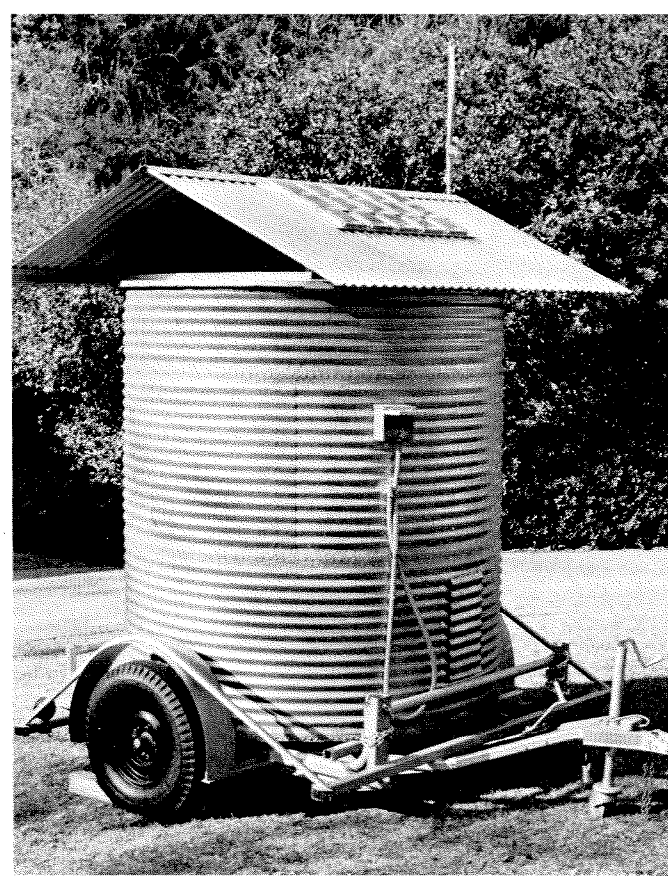
The sonic boom is a shock wave phenomenon very similar to the others, but dealing with it is much harder because, unlike the land-based sources of intense noise, it is extremely difficult to decrease the strength of the shock wave at its source.

Sturtevant's research is supported by the National Aeronautics and Space Administration.

Seismograph Stations Travel Economy Class

Economy in construction, simplicity in operation, and ease in moving from one spot to another are among the virtues of a new series of seismograph stations now being installed around the Gulf of California. Two of the stations are already in place, and four others should be in operation by this summer.

The sun shining on a total of 540 solar cells on the roofs of each of five of the stations will charge the 24-volt



By summer, six of these portable seismograph stations will be installed at 200-mile intervals around the Gulf of Mexico to monitor its earthquake-prone floor.

batteries inside—generating the power to run a recording lamp and drum, a quartz crystal clock, and a radio receiver tuned to a time signal. All this requires less power than is used to run an ordinary electric clock. The batteries should last for three years and will keep operating even if the sun shines only every fourth day. (The sixth station, already installed, uses available electric power.)

A roofed section of galvanized culvert six feet in diameter and seven feet high forms the structure that houses the instruments, and the whole package is mounted on a wheeled platform complete with a trailer hitch. When each station is in place, a seismographic instrument will be buried nearby and connected by electric cable to the recording instruments inside.

The goal of the project is to accumulate data on how the earth's crust is being deformed in the Gulf of California—and thus to understand and predict the behavior of the San Andreas fault system, of which the gulf fault system is really an extension. An international research team for the study consists of Clarence Allen, Caltech professor of geology and geophysics; James Brune, professor of geophysics at UC San Diego and visiting associate in geophysics at Caltech; Cinna Lomnitz, professor of geophysics at the University of Mexico and a Caltech alumnus (PhD '55); and Federico Mooser, chief geologist of the Mexican Federal Power Commission. The U.S. National Science Foundation has contributed $132,600 for the study, and the Mexican power commission, interested because it is developing a large geothermal power generating plant in the Colorado River Delta, has also given significant financial support.

EQL Issues a Warning

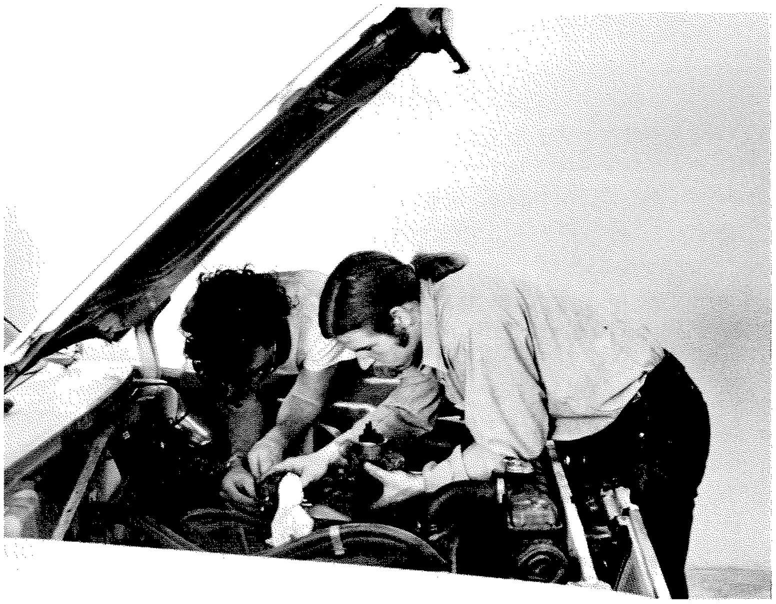
A report issued this month by Caltech's Environmental Quality Laboratory (EQL) warns that time is running out for reducing air pollution in the Los Angeles basin. In fact, the EQL strategy statement—"Smog: A Report to the People of the South Coast Air Basin"—lists drastic steps that will have to be brought to bear within this decade to save us from ourselves.

As a last resort, EQL proposes gasoline rationing in order to reduce driving and, therefore, air pollution. But to prevent such a step EQL offers a $1 billion strategy for reducing air pollution in the basin by about 80 percent by 1975. The strategy includes:

1. Mandatory conversion of about 500,000 fleet and commercial vehicles in the Los Angeles basin to natural gas or propane. This would cut back gasoline consumption by one-third.
2. Mandatory use of evaporative and exhaust emission devices on 1960-1970 used cars.
3. Periodic inspection of all vehicles for emissions.
4. Socioeconomic pressures that would cut back driving 20 percent through a variety of penalties and incentives.
5. More stringent controls that would cut current industrial and power plant emissions in half.
6. A new kind of smog alert during which many vehicles would be banned from the freeways and many industrial and commercial sources of emission would be shut down.

The first series of emissions reductions proposed by EQL would reduce the number of days on which the state's standard for oxidants is violated from 241 in 1970 to 50 in 1975. A second phase would add stringent smog alerts to stimulate the effect of the other measures and cut the violations of the oxidant standard by yet another half: from 50 days in 1975 to 25 days in 1977. The violations of the state standard for nitrogen dioxide would decline from 130 days in 1970 to 10 days in 1975.

The report suggests that the air quality standards set up in 1970 under the amended federal Clean Air Act probably could not be reached by the 1975 deadline. However, the EQL study shows than an 80 percent reduction on smoggy days is possible. The EQL team recommends setting up an interim "management" standard that could be a first step toward eventually reaching the stringent federal air quality standards.



Gary Rubenstein and James Henry are converting Caltech's security car to the use of propane instead of gasoline. Because this car must idle or be driven at very low speeds a great deal of the time, use of propane should improve its efficiency as well as reduce emissions.

The mandatory control devices suggested in the report for used cars are the capacitor discharge ignition optimization system for 1960-65 cars; the vacuum spark advance disconnect for 1966-70 cars; and the device for controlling evaporation from the tanks of 1966-69 vehicles. All were found technically and economically feasible for immediate controls on used car emissions.

Social and economic incentives to reduce the total number of cars on the road include:

1. Emissions taxes, which would be made possible by an emissions inspection system. Motorists would pay the tax in proportion to the total contaminants their cars put into the air.
2. Reserved "fast lanes" for buses and car pools on the freeways during rush hours.
3. Controlled access to freeways during peak hours, giving priority to buses and car pools.
4. Expanded bus, jitney cab, and minibus service.
5. Free parking to car-poolers.

If no combination of these measures can reduce driving, gasoline rationing is proposed as a last resort. The report suggests that demonstration projects are necessary to determine which of the socioeconomic measures are feasible.

The tough smog alerts would begin in 1973 and would be called when oxidant concentrations are 0.2 parts in a million at any station in the basin, compared to the present first-stage alert level of 0.5 parts in a million.

During alerts only low emission cars—such as those burning natural gas—and those vehicles with two or more passengers would be permitted on the freeways.

The Biology of Cancer

When normal cells turn malignant, it is the body's immune system that determines whether the cancer will take hold and spread (*E&S*, January 1972). But what makes normal cells turn malignant in the first place?

One cause of cancer is infection with a tumor virus. There are about 200 different tumor viruses now known to cause cancer in a wide variety of animal species—chimpanzees, monkeys, cats, rats, mice, hamsters, and chickens.

Though human cancer has not yet been shown to be caused by a tumor virus, evidence is accumulating that viruses can cause cancer in man—*and* that the malignant process may be reversible. The infection of cells by tumor virus was discovered by Walter Eckhart of the Salk Institute for Biological Sciences. His talk at Caltech on January 4 was the second of a series of seminars on The Biology of Cancer.

In "Polyoma Gene Functions for Cell Transformation" Eckhart described what goes on inside normal cells—after infection by a tumor virus—that causes them to turn into malignant cancer cells. Much of his research (largely in collaboration with Renato Dulbeco, also of the Salk Institute and formerly of the biology faculty at Caltech) has been with the polyoma tumor virus—an excellent model system because of its genetic simplicity.

There are several advantages to working with polyoma virus:

1. The DNA of the polyoma virus is made up of only five genes as compared to the millions that make up the DNA of an animal cell—thus increasing the chances of determining the functions of each of the viral genes and learning about its role in the cancerous change.
2. There is no need to work with whole animals. Polyoma virus can infect normal animal cells that grow in culture—in laboratory dishes.
3. After infection with polyoma virus, both the nature and behavior of infected cells growing in dishes change markedly; the cells become similar to abnormal, malignant, polyoma-caused cancer cells growing within an animal.

After a cell has been infected with a polyoma virus, it undergoes a *transformation* into an abnormal, malignant cell capable of passing on to its descendants the same cancerous characteristics. And it takes only two of the polyoma's five genes to bring about cell transformation. The function of one of these two genes, called *ts-a*, is needed only temporarily to start the transformation. The function of the other gene, called *ts-3*, is needed continuously to maintain the transformation. If this ts-3 gene function is stopped, then the transformation is reversed; the cell goes back to a normal, non-malignant growth pattern. Thus, only two of the polyoma genes appear to be involved in the cancerous transformation of the tissue culture cells.

Research like Eckhart's is changing an old view that the cancer process is irreversible. If we knew what the ts-3 gene function does within the transformed cell, then we might be able to turn it off and cause cancerous growths (at least those caused by polyoma infection in an animal) to revert to normal tissue. And such a discovery could lead to some clues to the treatment of human cancers that would cause them to revert to normal growth.

Experiments for a New Accelerator

Experiments proposed by Caltech physicists Felix Boehm and Petr Vogel are among the first to be selected for the $56 million proton accelerator now being built at the Los Alamos Scientific Laboratory in New Mexico. The experiments, which are delicate investigations of the structure of the atomic nucleus, are made possible for the first time because the new instrument will develop a sufficiently intense beam.

The studies will have two objectives:

1. To determine whether the particles that give the atomic nucleus its magnetic properties are far inside the nucleus or near its surface.

2. To find out more precisely whether muons (mu mesons) are particles just like electrons by finding how accurately they obey the laws known to be valid for atomic electrons.

Muons are unstable particles present in cosmic rays or artificially produced by large accelerators. Their seemingly complete similarity to electrons—with the one exception that they are 200 times larger in mass—is puzzling to physicists. In fact, it is difficult to find any reason for their existence.

The new linear accelerator at Los Alamos, which should be completed next year, is operated by the University of California for the U.S. Atomic Energy Commission. It will have a more intense meson beam than any existing accelerator.

In the proposed Caltech experiment, the beam will consist of muons, which carry a negative electrical charge just as electrons do. A muon will impact upon a "target" atom and move in an electron-like orbit around its nucleus in a smaller orbit than does the electron. Some of the muons actually orbit partly inside the nucleus. As they do, they are affected by the electrical and magnetic forces in the nuclear interior. These effects will be recorded, and it is hoped that they will yield information about the nuclear particles that are the sources of such forces.

The gamma rays of the nucleus will be measured to detect changes in the nucleus caused by the presence of the muon. The X rays resulting from the muon changing its atomic orbit will be measured as well, to detect the so-called screening effect of the atomic electrons and effects caused by possible dissimilarity between muons and electrons.

Because muons can penetrate deeper into the larger nuclei of heavy atoms than into those of light atoms, the relatively heavy rare-earth atoms will be used as targets for the muon beam. An additional advantage of these atoms is that they have "deformed" nuclei—nuclei that have an ellipsoidal shape instead of a spherical one. The muons have a tendency to readily change the velocity of rotation of such ellipsoidal nuclei. The energy corresponding to these changes is released in the form of nuclear gamma rays.

The instrument that will detect and measure the gamma rays and the X rays caused by the reaction of the muon "bullets" and the rare-earth "targets" is a curved crystal diffraction spectrometer developed and used at Caltech. It is the most accurate tool for the determination of the energies of these X rays and gamma rays. The spectrometer's quartz crystal sorts and focuses these radiations according to their energies (wavelengths). Under favorable conditions, accuracies to within one part in 10 million can be attained.

There is a long tradition of work with curved crystal diffraction spectrometers in the nuclear spectroscopy group at Caltech, dating back to the pioneering work of Jesse W. M. DuMond, professor emeritus of physics, in the 1930's. Among recent achievements with such an instrument is the observation and measurement of the isotope shift in atomic X rays, in which the relative sizes of the nuclei of two or more isotopes of the same element can be deduced from tiny differences in X-ray energy.

The Month at Caltech

Luce Grant

Caltech has received a $225,000 grant from the Henry Luce Foundation, Inc., of New York to establish a Henry R. Luce Professorship in Law and Social Change in the Technological Society. A committee from the Division of Humanities and Social Sciences is already searching for a distinguished jurist to add to the Institute faculty—someone, according to Robert A. Huttenback, chairman of the division, "of humanist principles and wide philosophical perspective who can communicate the concept of a living law to our students."

Although studies within the professorship will emphasize law as an instrument of social change, they will probaby also include constitutional law, the nature of the legal process, and law in theory and practice.

The Luce award is part of a program the Foundation established three years ago to encourage academic innovation through an integrative approach to the study of the humanities and social sciences—an agenda that not only fits some of the Institute's long-range plans but enhances such current projects as the Environmental Quality Laboratory, the Environmental Engineering Science program, and the population studies program being carried out jointly by Caltech and the American Universities Field Staff.

Near the end of the five-year period for which the grant has been made, both the Foundation and the Institute will reevaluate the program toward the possibility of a five-year continuation. The grant cannot exceed a total period of ten years.

Award to Feynman

Richard P. Feynman, winner in 1965 of the Nobel Prize and Richard Chace Tolman Professor of Physics, has been awarded the 1971 Oersted Medal of the American Association of Physics Teachers for "notable contributions to the teaching of physics."

Feynman, one of the world's outstanding theoretical physicists, came to Caltech in 1950 from Cornell University. He was responsible for completely revising Caltech's courses in introductory physics, and his lectures for Ph 1 and Ph 2 were eventually published as the three-volume *Lectures on Physics*. The "Feynman Lectures" are widely used in this country and in many other nations as texts for college freshman and sophomore physics courses.

Lacey Lecturer

Andreas Acrivos, professor of chemical engineering at Stanford University, spoke at Caltech on January 25 and 27 as the fifth recipient of the W. N. Lacey Lectureship in Chemical Engineering.

Widely known for both his experimental and his theoretical contributions in a number of areas of chemical engineering, Acrivos is particularly distinguished in the field of fluid mechanics. Topics for his lectures at the Institute were "Suspension Rheology and the Theory of Isotropic Fluids" and "High Reynolds Number Laminar Flows with Separation. Some New Theoretical Results."

The Lacey Lectureships, named in honor of William Noble Lacey, professor emeritus of chemical engineering who has been a member of the Institute faculty for 56 years, are made possible by a fund established by a number of Lacey's friends and former students. It brings to campus world-renowned experts currently active in chemical engineering or related disciplines.

Courses with a New Look

College students almost everywhere these days are asking that a few helpful "how-to" courses be added to their elective choices, and Caltech students are no exception. The Division of Humanities and Social Sciences has responded this year by offering several experimental courses that at least have pragmatic aspects—for example, not only the theory but also the practice of communicating, in writing, about scientific subjects.

Irving Bengelsdorf, Caltech's director of science communication, is offering En 151, *Science Writing, Communication and Language*, during the winter term. Bengelsdorf, who has a PhD in chemistry and was a postdoctoral fellow at Caltech in 1951-52, served as science writer for the *Los Angeles Times* for almost nine years. He hopes to be able to teach his students to communicate briefly and clearly about science and engineering, not only to their colleagues but to laymen as well. He is covering writing styles and the techniques available for communicating through radio, television, and tapes; something of the history of communication; and enough scientific Russian to give some competence in translating titles of articles in Russian journals. There are lectures and discussions—and learning by doing. Every student writes a 700-word essay on an assigned topic each week, and essays are read aloud and criticized by the rest of the class.

David Morrisroe, director of financial services, took over the teaching of Ec 100, *Business Economics*, last fall. Ec 100 has been part of the Institute curriculum for more than 40 years—

taught almost entirely by Horace Gilbert, professor of economics emeritus. Under Gilbert it was designed to give technically trained students a broad background in economics, management, and investments. But under Morrisroe, Ec 100 emphasizes managerial economics, reporting, and control; while it isn't mathematical, it *is* quantitative. During the first term, the 14 graduate students and 7 undergraduates who enrolled got a foundation in the theory and practice of managerial accounting and the understanding of financial information and control systems. Morrisroe supplemented his lectures with case material, and in problem-solving assignments the students really played the role of a financial manager in a business firm, or of an individual who had to deal with a financial manager. Concentration during second term is even more on case work, but the students are also applying some of the more recent developments in managerial economics to solving the case problems. Morrisroe points out that some of the practicalities of the course are immediate in terms of acquiring such skills as being able to interpret balance sheets, income statements, and fund flows. The long-term benefits should show up when, for example, students later have to set up budgets for research projects, deal with financial organization of an enterprise, or simply invest their personal funds.

Pl 104, *Philosophy of Education,* is being taught this term by Lee Browne, lecturer in education and director of secondary school relations. By the end of the term each of the 14 students in the course will have to design a model school (for some segment of grades kindergarten through high school) and document his reasons for that design. For the documentation he will have such resources as class lectures and discussions, guest speakers, outside reading, and visits to local schools. Each model will have to specify requirements for pupils and staff in terms of skills and personal qualities, organization, curriculum, dealing with problems, relating the model to today's society, and the long-term goals expected of the model.

Browne believes that students need to start planning as early as possible for their careers, and that the schools are responsible for giving intelligent and effective guidance toward that goal to every student—to those who will go into the professions *and* to those who are enrolled in vocational training. He hopes that his students in Pl 104 will learn from their practice in setting up a model school both what *does* and what *could* go into giving the kind of education that will make it possible for everyone eventually to be gainfully employed. And, he suggests, anyone who takes this class and eventually becomes a teacher—even at the university level—may profit from understanding something of the teaching and learning process.

George S. Hammond, chairman of the division of chemistry and chemical engineering, is a leading writer and practitioner in the growing field of development of innovative methods in the teaching of science. These activities grow out of his concern that the sciences, and their implications, change more rapidly than their supporting teaching systems. In the hope of doing something constructive about it—both with and for Caltech students—Hammond and Louis Breger, associate professor of psychology, are jointly teaching Ch 92ab, *Chemical Education* (also offered as Psy 101, *Selected Topics in Psychology*). Using lectures, discussions, outside reading, and movies, Hammond and Breger present elements of both educational and psychological learning theories and then consider how to apply those concepts to a specific body of subject matter—in this case chemistry. More generally, Hammond and Breger are convinced that the complex functions of an educational system profoundly influence society. "We may not be able to reshape educational functionality to suit our tastes," says Hammond, "but we will change it in more reasonable ways and live with it more comfortably if we take a clear look at what goes on." The appeal of this approach doesn't seem to be limited to students: The enrollment of about 20—undergraduates and graduates—is augmented by several auditors from the faculty.


Roy Gould

New Job for Gould

Roy Gould, professor of electrical engineering and physics, has been appointed director of the Atomic Energy Commission's newly established division of controlled thermonuclear research. In this job he will supervise fusion-research efforts being conducted at the Lawrence Livermore, Los Alamos, and Oak Ridge Laboratories; at several private industrial laboratories; and at a number of universities.

Gould is a Caltech alumnus (BS '49, PhD '56) and has been a member of the faculty since 1955. Since April 1970 he has been on leave with the AEC in Washington, D.C.

Detour for the Grand Tour

Funding for the "Grand Tour" of the solar system—under study at Caltech's Jet Propulsion Laboratory for a decade—has been deleted from the 1972 National Aeronautics and Space Administration budget. This means that multiple-planet exploration cannot take place in this century. The favorable lineup of the planets due in the late 1970's will not occur again until about the year 2150.

It was hoped that NASA, in its budget proposal to President Nixon, would ask at least for $30 million in the next fiscal year to finance continued planning for two Grand Tour missions:

1. Two launches, planned for 1977, for flights to Jupiter, Saturn, and Pluto.
2. Two launches, projected for 1979, to scout Jupiter, Uranus, and Neptune.

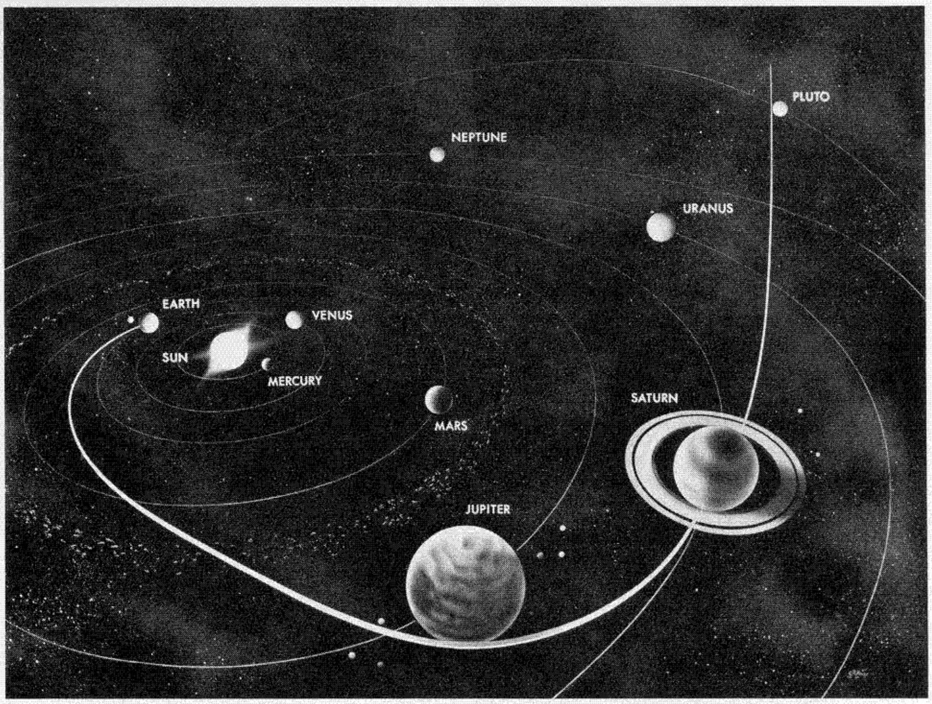
Instead, NASA asked for only $7 million in "study money" in the submitted budget. This would not finance the Grand Tour as originally planned.

The cancellation will have little immediate effect on current JPL jobs or programs because the Grand Tour was not funded and was strictly in the research and drawing-board stage. JPL programs already funded up through 1975 include the Mariner Venus-Mercury flyby and a major portion of the 1975 Viking Mars-lander project.

Although the Grand Tour program is cancelled, there will still be opportunities for two or possibly three planet explorations on a reduced basis with Mariner- or Pioneer-type spacecraft if the money becomes available.

The Grand Tour concept involved using the gravity of one planet to propel a spacecraft in a "billiard ball" manner to the next planet. In this way one vehicle could explore Jupiter, Saturn, Uranus, Neptune, and Pluto in a 9- or 10-year accelerated flight.

Even if there should be a later reversal in the funding decision, JPL will lose more than a year of hard planning, which would make it difficult to get ready to launch between 1977 and 1979.



Cancelled for lack of funding, the Grand Tour would have made possible a fly-by look at as many as four of the outer planets on a single flight—and would have reduced the time ordinarily needed for such exploration by as much as two-thirds.

Sloan Foundation Grant

The Alfred P. Sloan Foundation is making a grant of $610,000 to Caltech to extend research and teaching in the neurosciences. The funds will provide partial support for four research groups for a period of four years.

Headed by Derek Fender, professor of biology and applied science; Felix Strumwasser, professor of biology; Michael Raftery, associate professor of chemical biology; and Richard Russell, assistant professor of biology, these four groups will investigate such key questions in neurobiology and neurochemistry as: How does the human brain work? What is the composition of the synapse (the specialized contact region of the neurons through which they communicate with each other)? How do neurons produce and read out the programs that control the temporal organization of behavior?

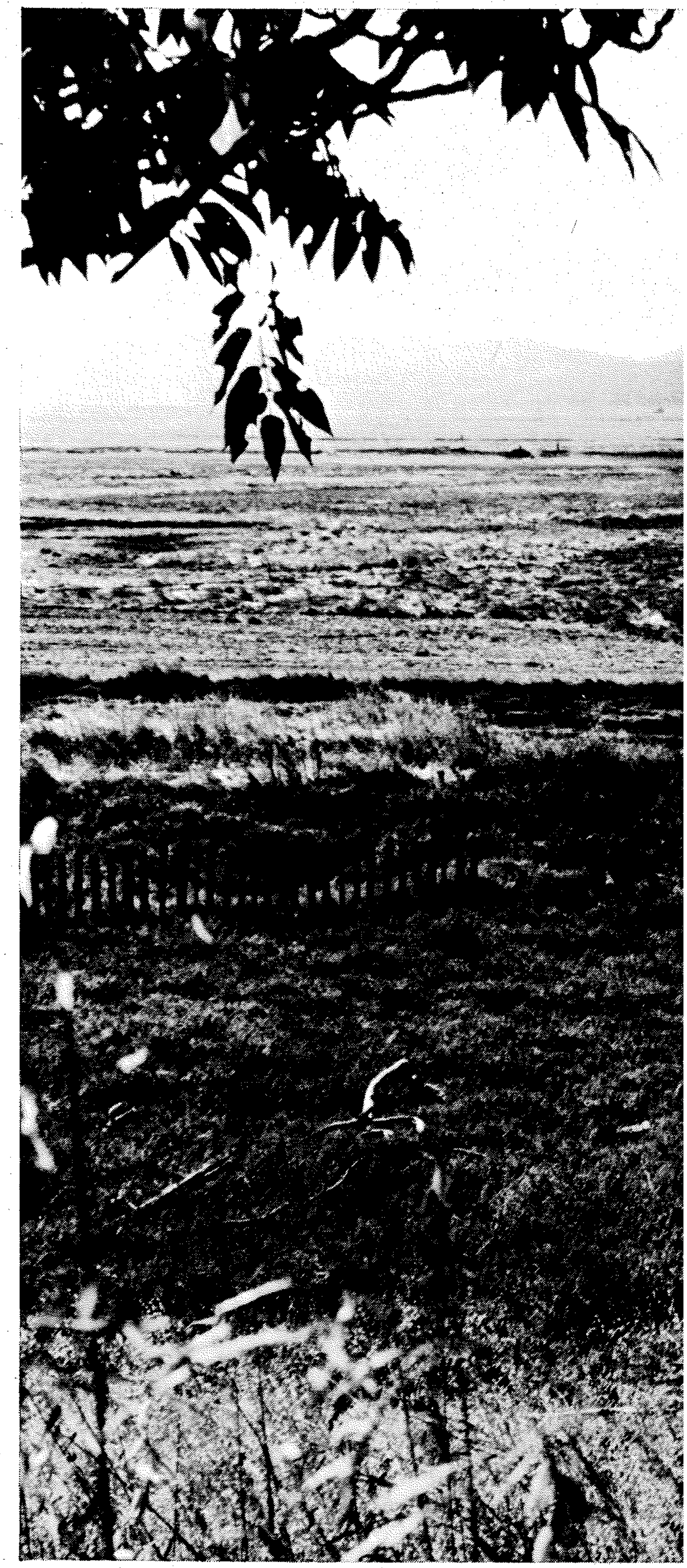
Though these programs are already in progress—with laboratories, techniques, and equipment specifically adapted to this work—the Sloan grant will make possible an increase in their tempo and scope by expanding facilities and adding research people and graduate students to the groups.

Honors to Stern

Alfred Stern, professor of philosophy emeritus, was recently awarded the decoration of Officer in the Order of Leopold II. This honor was bestowed on him by King Baudoin in recognition of the services Stern rendered Belgium before, during, and after World War II and in appreciation of his achievements as a philosophical writer. His latest book, *The Search for Meaning: Philosophical Vistas*, is reviewed on page 32.

Stern also recently delivered the official lecture at the University of Vienna on the occasion of the 50th anniversary of the founding of the university's Philosophical Society.

Marginal land:
the same area raises 30 chickens or 1 ton of catfish



Books

INSTITUTIONAL CHANGE
AND AMERICAN ECONOMIC GROWTH
By Lance E. Davis and
Douglass C. North
Cambridge University Press $10.95

About four years ago, when two economists were talking shop, they realized they were using similar logical structures to analyze two apparently unrelated topics. Continued exploration of this strange overlap has resulted in this important book on economics. The two authors, both professors of economics, are Lance Davis of Caltech and Douglass North of the University of Washington.

The book, which is in three parts, is an attempt to formulate a unified theory of institutional change and to apply the patterns of such change to American economic development in the 19th and 20th centuries.

In Part I the authors develop their model of institutional change, arguing that if external factors make an increase in income possible but not attainable within the existing institutional structure, new organizations must be developed to achieve the potential in income. Their model is designed to explain the type and timing of these necessary changes.

In Part II the authors review the external causes of changes in American economic history over the past 175 years and apply their model to land policy and agriculture, financial markets, transportation, manufacture, service industries, and labor.

Part III presents the authors' conclusions about the changing public-private mix.

UNIONS, PARTIES, AND POLITICAL DEVELOPMENT
A Study of Mineworkers in Zambia
By Robert H. Bates
Yale University Press $12.50

Like most new nations, Zambia aspires to rapid economic development. It also, like many new nations, has an economy based on production of a single major commodity—in Zambia's case, copper. The regulation and control of copper miners therefore represents a crucial political task for Zambia's ambitious elite. In this study, Robert Bates, assistant professor of political science, analyzes the attempt of the government to use the dominant political party and the Mineworkers' Union to enforce a relatively stringent labor code. The leaders of the union and of the party are caught between the government's demands for moderation on behalf of the long-range public interest and their members' demands for continued militancy on behalf of their economic and racial interests. Bates finds that the government's policies largely fail and argues that the dilemma of the union and party is one of the basic reasons for the failure. Because governments throughout Africa attempt to use voluntary agencies for rapid development, these findings have implications reaching beyond Zambia, and they raise some fundamental issues in general development theory.

THE SEARCH FOR MEANING:
PHILOSOPHICAL VISTAS
By Alfred Stern
Memphis State University Press . . $12.50

Reviewed by Charles E. Bures
Professor of philosophy

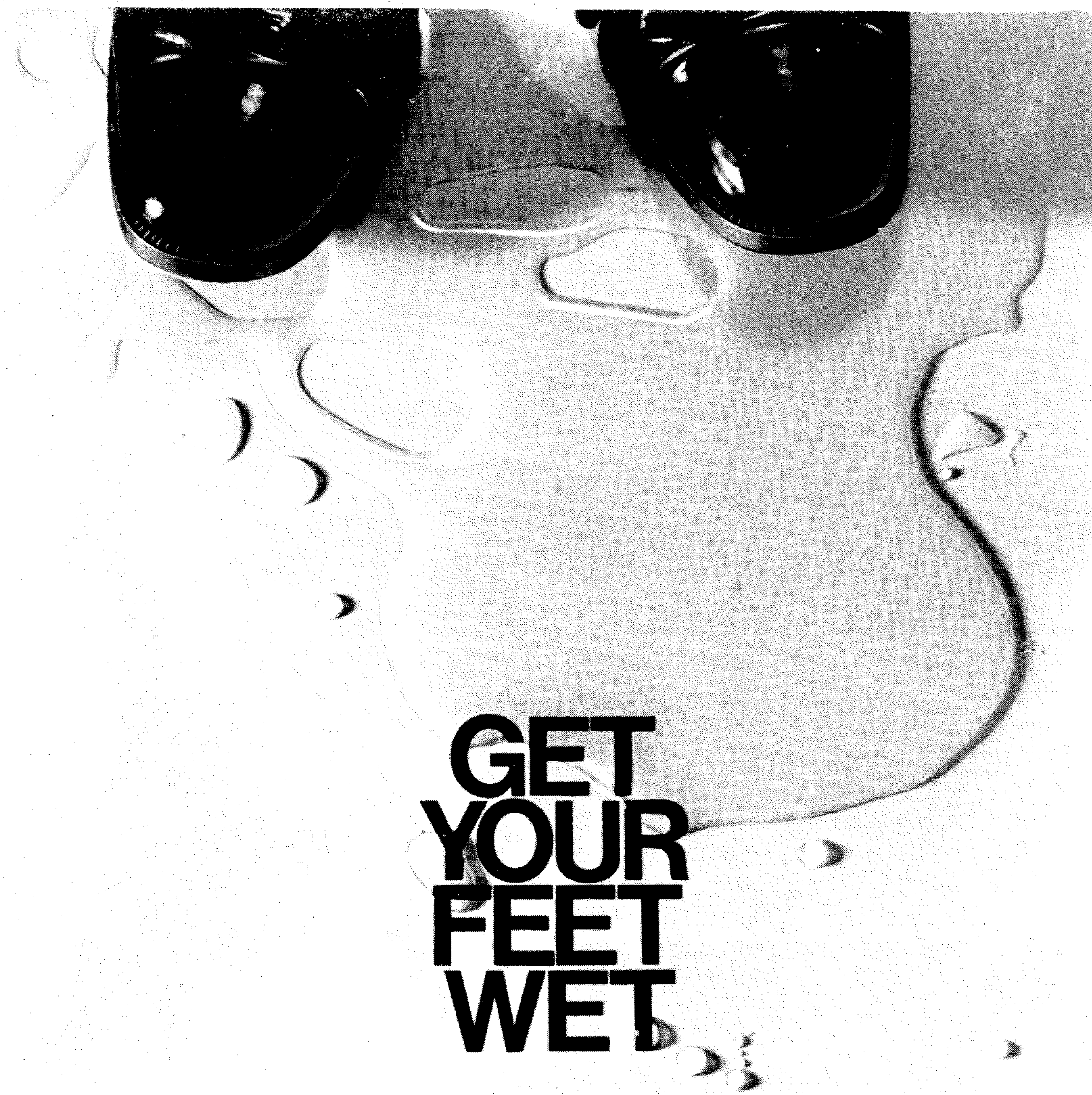
Professor Stern taught philosophy and languages at Caltech for twenty-one years (1947-1968). With emeritus status, he assumed a lifetime appointment as Professor of Philosophy at the University of Puerto Rico in Mayagüez. A consummate linguist, Professor Stern speaks, writes, and thinks philosophically in several languages. He is now teaching philosophy in Spanish. The present volume is a collection of 25 essays, many new, the rest published in different journals over a 25-year period. The heart of Alfred Stern's philosophical career has been the search for understanding, meaning and value in human life. For this reason, he feels a rapport with the Viennese school of logotherapy (the will to meaning) of Viktor E. Frankl. The Kantian tradition has been Professor Stern's major frame of orientation, an outlook that has put him at odds with the positivists and, at least, the more extreme existentialists.

The volume contains three essays on science as one form of the search for meaning. Understanding nature gives it meaning. To Stern, science is a humanistic activity with unavoidable moral responsibility. He discusses the positivism of Bohr, Heisenberg, and Mach, and, in a brief but insightful conversation with Einstein, he shows his sympathy with Einstein's rejection of positivism and of the Copenhagen interpretation of quantum mechanics. Stern finds Einstein's "exterior real world" more meaningful than reductive positivism.

To Stern, values and meanings interpenetrate so intimately that one could speak of value-meanings as central to the search for the meaning of life. Values spring from choices, decisions, justifications. Meanings flourish in definite, concrete contexts and always relate to purposes. Stern relates to voluntarism in the Kantian tradition when he says, "I shall concentrate on the *critical approach,* which is based on acts of human will." (p.6) His central principle is: "If, *logically,* every project presupposes an act of will, we may say that *psychologically* every act of will appears in the concrete form of a project." (p.7) Projects are "the main provider of meanings to man's life . . . ." Every project points to the future. "The future is the main meaning-providing dimension." (p.14) Hence, our search for meaning is always directed toward the future. With this view, Professor Stern opposes both positivism and the here-and-now influence of Oriental philosophy.

So varied are Alfred Stern's talents that one can only catalog them. There are nine essays on salient persons: Nietzsche (two), Kant, Unamuno, Ortega y Gasset, Balzac, Mazzini, Camus, and Jean-Paul Sartre. Six essays concern literature, tragedy, and value; and six essays explore existentialism. "What is man?" introduces philosophical anthropology as a partly speculative search for man's essence. Perhaps central to this book is Stern's mature essay, "What are Spiritual Phenomena?" delivered as his presidential address to a division of the American Philosophical Association, in 1966. To Alfred Stern, spirituality is identical with meaning, and to be truly human one must start the search for meaning in life.

Professor Stern has a reverential, almost courtly, attitude toward the ideas that have been his life. He represents a European tradition of philosophy, which in the 19th and 20th centuries has been the single most influential world view in shaping both science and philosophy. When one considers that one of the main sources of positivism is Kant's formulation of the phenomenal world, then one senses the grand sweep of this influence. Alfred Stern is an excellent exemplar of this movement. Even if this tradition is transformed in the next generation, as it may be, it is a great human achievement, a matrix for the next *Weltanschauung.*


GET
YOUR
FEET
WET

HOW CAN A SHEET OF SILICONE RUBBER HELP TURN A TEN-YEAR-OLD INVALID INTO A TEN-YEAR-OLD ATHLETE?

A few years ago, General Electric engineers developed a silicone copolymer rubber with some remarkable properties.

It's a membrane that permits the rapid exchange of oxygen and carbon-dioxide molecules.

So it's made a revolutionary new artificial lung possible. The GE Peirce lung™ oxygenates blood in much the same way the human lung does.

That's a major engineering accomplishment. But that's not the reason it's important.

The GE Peirce lung works with a minimum of disturbance to blood cells. So it can be used safely much longer than conventional lung machines. Days instead of hours.

That extra time may be what a doctor needs to repair the defective heart of a child. To open the clogged arteries of an adult. Or to save the life of an accident victim whose lungs give out.

That extra time may be all it takes to help put thousands of those invalids back on their feet.

It's a pretty clear example of how a technological innovation can help solve a social problem. A lot of times, the effect of technology on society is rather direct.

That's why at General Electric, we judge innovations more by the impact they'll have on people's lives than by their sheer technical wizardry.

Maybe that's a standard you should apply to the work you'll be doing. Whether or not you ever work at General Electric.

Because, as our engineers will tell you, it's not so much what you do that counts. It's what it means.

GENERAL ELECTRIC