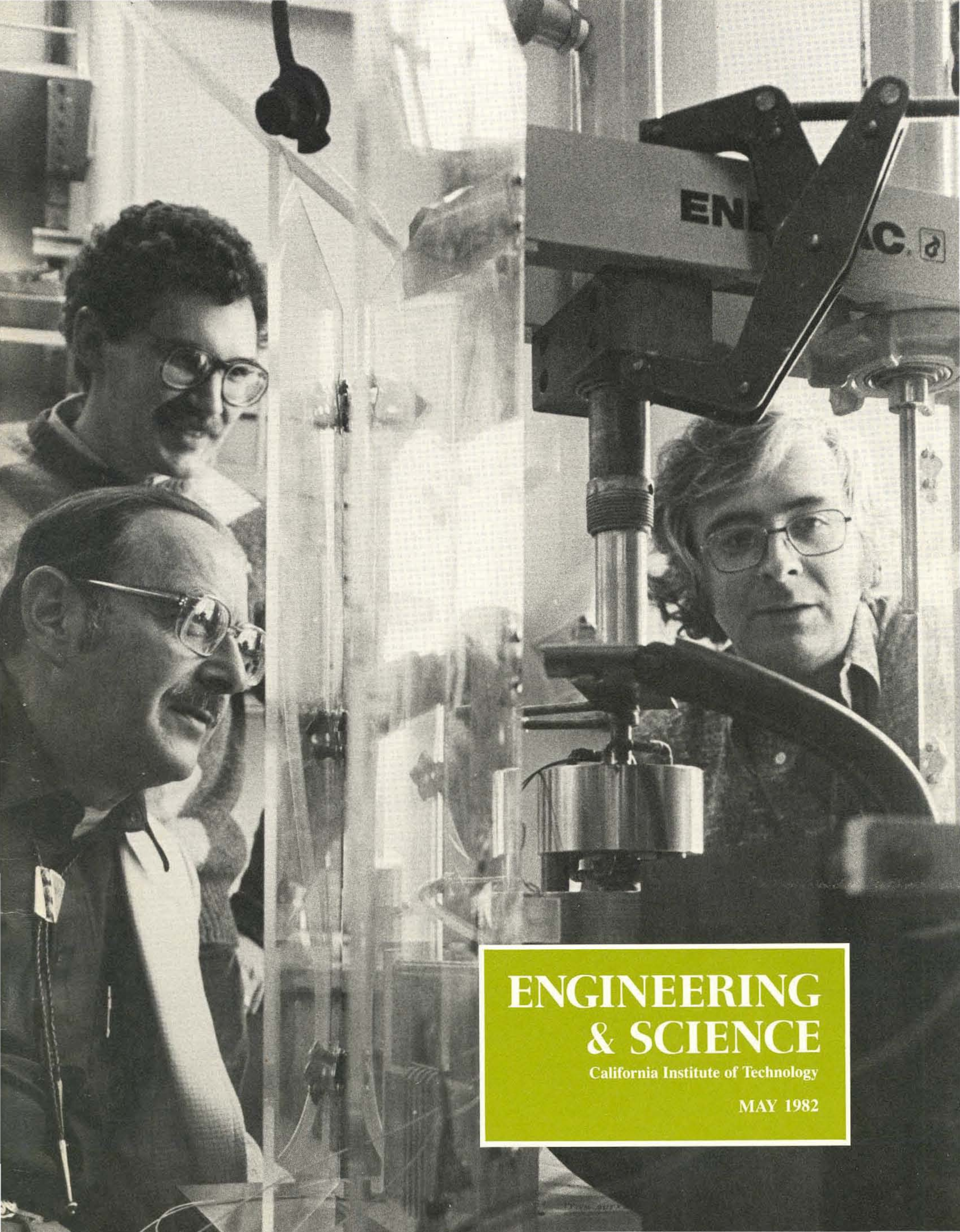

ENGINEERING & SCIENCE

California Institute of Technology

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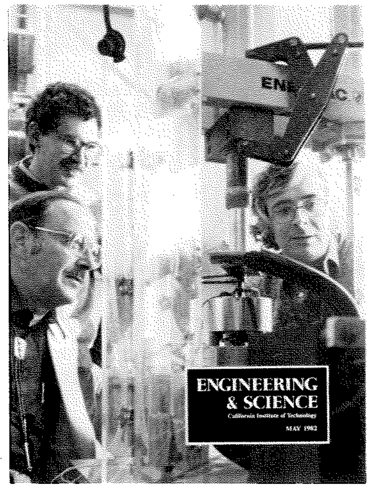
In This Issue



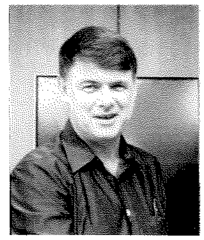
Collaborators

On the cover — three men in a geology laboratory looking at a miniature piston cylinder apparatus. From left to right, the men are Edward Stolper, assistant professor of geology; Gerald Wasserburg, MacArthur Professor of Geology and Geophysics; and David Walker, a geologist from Harvard, who is currently a Fairchild Scholar at Caltech and who has modified this apparatus for experiments to determine whether the Soret effect is the cause of anomalous chemical variations in magmas. The lab actually belongs to Stolper, who works with Walker, but every now and then Wasserburg is also called in for consultation.

This is just one example of the kind of interaction that has been going on at Caltech for the last nine years between Institute faculty and visitors who are invited here under the Sherman Fairchild Distinguished Scholars program. More details on this project and a sampling of others are described in "The Ripple Effect," which begins on page 8.

Scientific benefits are the chief value of this program, but there are many others as well, including some for communities much larger than Caltech's. Fairchild Scholars have delivered a number of Watson Lectures at Beckman Auditorium, for example, and five of them have contributed articles to this magazine, for which we thank them again.

Saving Space



One of the people who can speak with real authority about the past, present, and possible future of space exploration is Bruce Murray. It has been the focus of his professional interest for more than 20 years, beginning in 1960 when he first came to Caltech as a research fellow in space science. In 1963 he became the Institute's first professorial appointment in planetary science. He was an active participant in the scientific teams that planned, observed, and analyzed the Mariner missions to Mars, Venus, and Mercury. In addition to doing research, he has made countless talks, served on boards and committees, and written both books and articles on the subject.

Murray recently announced his impending resignation from the directorship of the Jet Propulsion Laboratory, a position he has held for the past six years. During that time the pace of his interest and the weight of his responsibility have, of course, been greatly intensified. He has become increasingly concerned not only for space science itself but for the role of the United States in future space exploration. In January he discussed these issues in a Watson Lecture at Beckman Auditorium. An adaptation of that talk, "Where Do We Go Next In Space?" begins on page 2.

Chemical Action

John Baldeschwieler came to Caltech in 1973 from Washington, D.C., where he had been for two years deputy director of the Office of Science and Technology. That was, however, just an excursion out of academia. He had previously been on the faculties of Harvard and Stanford universities. For his first five years at the Institute Baldeschwieler had to divide his working hours between administrative duties as chairman of the Division of Chemistry and Chemical Engineering and continuing his research activities as professor of chemistry. Then, after six months' leave of absence spent as a visiting scientist at Bell Laboratories and the Stanford Synchrotron Radiation Laboratory, he came back to Pasadena and plunged into the work described on page 14 in "Tiny Bubbles" by Dennis Meredith, director of Caltech's news bureau.

Of course, he plunged into a few other things too. Some 30 of the more than 200 publications listed under his name have been written since then, and he has continued to serve and/or take on new responsibilities with a number of national committees, including the Committee on Scholarly Communication with the People's Republic of China. He also serves as a consultant to a number of industrial firms.

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Departments

Where Do We Go Next In Space?

by Bruce Murray

From the Moon, Apollo 8 views the rising Earth in 1968 – a preview of the "golden decade" of planetary exploration.

VIEWED from an intellectual perspective, the decade between 1971 and 1981 was one of the most extraordinary in recorded history. It was a golden decade, characterized by a phenomenal increase in humankind's knowledge and perception of the solar system in which our planet Earth is situated. One of the reasons for our looking back on this as a golden age is that the next decade is not going to be that way. In fact, perhaps my title should have been "The End of the Beginning." From the apogee in the 1970s of man reaching out to explore the environment of his home planet, there is going to be at least a leveling off in the 1980s and probably a decline in some ways. Beyond that time, I don't know.

I do know, however, that we can anticipate our future to some extent by understanding our past. That past — the origin of the golden decade — really goes back in a direct line to Yuri Gagarin, the first Soviet cosmonaut to go into orbit. By virtue of an accelerated launch-vehicle development program, the Soviets were able to put a spacecraft, Sputnik, in orbit in 1957, and a man in 1961. Both achievements were earlier than we had anticipated or prepared for. In a Cold War sense they challenged us to race. It was a highly visible race, and it caused fear and consternation in this country.

Our response was the Apollo program, and with it a determination to put a man on the Moon by the end of the decade of the 1960s. That response was one of the great political, technical, and economic decisions in the stream of American history since World War II. It demanded performance at the very limit of our national capability. Apollo was the most complicated thing we could attempt, and it was beyond anything the Soviet Union could do. And, equally important, Apollo was an entirely peaceful, adventuresome, open use of advanced technology. Nothing better describes the positive and most likeable aspects of our society than Apollo, except perhaps Voyager, a lineal descendant of 1961's Apollo impetus happening some two decades later.

So the United States felt challenged, and we determined to respond with a big space effort, the centerpiece of which was going to be the Apollo program. The planetary program, of which JPL became the leader, likewise arose in an environment of competition with the Russians. The principal theme in our program became a search for life on Mars — a theme that was already a part of our culture. Ever since the time of the astronomer Percival Lowell at the turn of the century, we in the United States have been fascinated with the idea of human habitation of Mars. As we became more sophisticated, we clung to the possibility that there was at least plant life on Mars.

A second theme spun off in the latter part of the 1960s. We wanted to use a rare alignment of the planets to make what we called the Grand Tour. It was an opportunity (that normally happens less than once a century) to go to Jupiter, use the gravity assist there to get to Saturn, go on to Uranus, and then on to Neptune. In fact, we didn't commit to do the whole Grand Tour because it would have involved building a very complex and expensive spacecraft, but we are doing a more moderate adventure in its place with the Voyager spacecraft. Subsidiary themes have been several missions to Venus, all of which have been of very high scientific yield, and one mission to Mercury with the Mariner 10 spacecraft.

The Russian planetary response has been much larger than that of the United States. They have invested far more in rocket launches and in spacecraft for missions to Venus and Mars. With the exception of Venus, these efforts have achieved very little. They have not been able to go either in — toward the Sun and Mercury — or out — toward the outer planets. They did some automated exploration of the Moon after the end of the manned phase there, and then focused on Venus, where they have gathered most of the important knowledge of that planet that exists.

We are all aware of the popular impact of space exploration in the decade from 1971 to 1981, but I would like to point out some of the highlights of the scientific impact of that exploration. We have, for example, learned an enormous number of things about the Moon, and one of major significance is that the Moon's surface, when

analyzed chemically, does not date back to the time of the formation of that satellite 4½ billion years ago. For the most part, the surface records the end of an enormous period of bombardment about 4 billion years ago. The Earth also formed about 4½ billion years ago, and it also shared that heavy bombardment, but no validated trace of it has been found on our planet. By looking at the Moon, then, we have learned something about our Earth that we could otherwise never have discovered.

In 1974 Mariner 10 flew by Venus and obtained the first images of its upper atmosphere, which rotates 60 times faster than the surface, and both atmosphere and surface rotate in the opposite direction from all other planets. Altogether we have recognized that Venus is the epitome of "fossil-fuel burning." It has a naturally high greenhouse effect due to high carbon dioxide content, and there is an intense natural sulfuric acid rain. We earthlings need to learn about our kinfolk on that uninhabitable planet so we don't tend to emulate them through unintended large-scale climatic modification of the Earth. Other discoveries came out of the Soviet landing on the surface of Venus. They learned that the atmosphere of that planet is 100 times more dense than that of Earth, that it is highly corrosive, and that the temperature is well above the melting point of lead. The surface pictures show that there are active processes going on there, amazing for an atmosphere so dense.

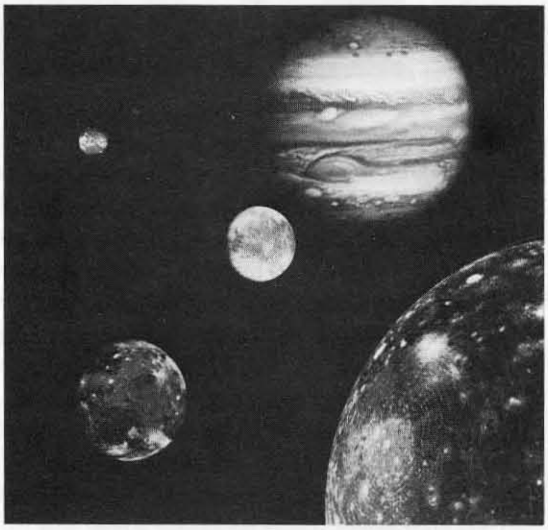
Mariner 10 went on to Mercury from Venus and found a surface there much like that of the Moon. We had previously thought that was not so. Furthermore, Mariner 10 found a small but surprisingly earthlike magnetic field at Mercury. So Mercury became a real place scientifically as a result of that mission.

Mars, of course, has always been an important place in our minds, but Mariner 9 and then the Viking spacecraft gave us a great deal of detailed and unexpected information about it. We were astounded at the gigantic features that characterize Mars, many of them the result of volcanism. We had once thought of Mars as perhaps the most earthlike of the planets, but we have found that though the processes that go on on Mars are similar to those on Earth, the features are totally unlike. Therefore the history and composition of Mars differ from Earth's in profound ways. The two Viking landers found no life of a type that could be detected by any instruments we could conceive, the reason being that, because of the almost unimpeded ultraviolet radiation from the Sun, there is no organic material in the soil of Mars.

Both Voyager spacecraft were launched in 1977, and we have learned a great deal from them. We now know, for example, that the flow of energy through the atmosphere of Jupiter is quite different from what happens in the terrestrial atmosphere. Earth is heated by absorbed sunlight at the surface, and its atmosphere, which is transparent, responds to that surface heating. In the case of Jupiter, there is a significant component of internal heat as well as heat from the outside, and they combine to create very different atmospheric properties.

In flying by the Galilean satellites of Jupiter, the Voyagers discovered that they were extraordinary worlds in their own right — from Callisto, whose icy surface has probably survived from a very early time, to Ganymede, which shows evidence of internal heating at an early stage, and Europa, which has undergone heating fairly recently and is probably still undergoing it, to Io, which is dotted with active volcanoes indicating

Apollo 17 astronaut Harrrison Schmitt (left) takes a walk on the Moon in 1972. Such extraordinary scenes, and the close-up views of our neighboring planets have become almost commonplace over the past decade. Mariner 10's television cameras, for example, took 3500 pictures of Venus as the spacecraft flew by enroute to Mercury in 1974. One of these images of the planet's upper atmosphere is shown in the center. Mercury's pockmarked Caloris Basin (right), surrounded by a rim of mountains up to 6500 feet high, looks very much like the lunar surface in this enhanced set of Mariner 10 photos.



The Viking 1 Orbiter in 1976 provided images that formed the basis for the artist's conception (above) of the great Martian volcano, Olympus Mons. The 15-mile-high mountain, 357 miles across at the base, has a caldera (crater) 50 miles across. Jupiter and its four planet-size moons were photographed in early March 1979 by Voyager 1 and assembled into this composite picture (right). The moons are not to scale but are in their relative positions. Io is upper left, Europa at the center just below Jupiter, then Ganymede, and Callisto is at the lower right. Jupiter also has nine other satellites.

that its interior is currently boiling.

We came to understand that these four large moons orbiting Jupiter interact with each other in the same way our Moon interacts with Earth, creating tides in each other. The very powerful gravity field of Jupiter acts to place huge stress on the innermost satellite, Io, and keep it boiling; a similar but probably less strong force acts upon Europa. By the time it reaches Ganymede and Callisto, the force is probably very small.

Both Voyager spacecraft have now passed Saturn, and the biggest surprise there has been the rings. We expected to see something as simple as a three-string guitar, and we found the intricacy of an organ instead. The human perception of Saturn has forever been altered as a consequence of Voyager's findings about the complexity of the ring structure and processes. We learned a number of things about Saturn's great moon Titan as well. From ground-based telescopes we had known that Titan had an atmosphere that was composed of methane and probably hydrogen. Now we know that in a general way Titan's atmosphere is like that of Earth; it is mostly nitrogen, and methane is relatively less abundant but far more important than we had been led to expect. It plays a role similar to that of water in Earth's atmosphere; that is, there is methane rain, ice, liquid, and vapor.

What about the future? The first thing to note about the 1980s is that there was very little reinvestment during the 1970s. That is important because of the inevitable time lag between investment in and realization of an actual mission. The things that happened in space in the 1970s were the consequences of investments, or at least decisions, in the late 1960s. Voyager was finally decided upon in 1972, and since then there has been very little reinvestment in this kind of endeavor. There are no doubt many reasons — the polarization because of Vietnam, the disillusionment of Watergate, the frustration with inflation and interest rates, and becoming dependent upon imported oil and the effects of that on foreign policy. The outcome is that as a nation we have lost our commitment — to being number one, to looking to the future and to investing in it. The result is that the course of space exploration in the 1980s is already pretty well determined.

In the case of the planet Mars, for example, the United States has no plans to follow Viking and little prospect that anything will develop. But the Soviet Union has been licking its wounds over Mars, because the Soviets have spent more on its exploration than we have, and they have virtually nothing to show for it. My guess is that they will resume that exploration; they have the technology, the launch vehicles, and the commitment. Informally, there has been some discussion of a Soviet mission to land on the Martian moon Phobos.

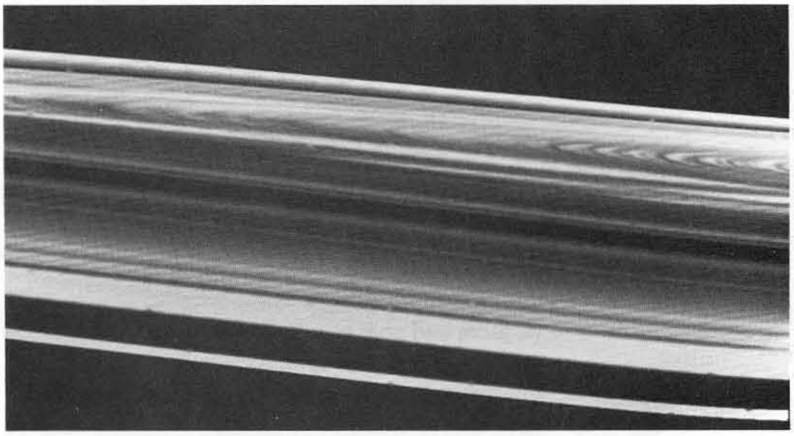
Since the end of the Apollo program, the United States has done nothing at all on the Moon. Maybe one of the aftereffects of the kind of effort that went into Apollo is the creation of a near-vacuum afterward. I believe the Soviets will make some efforts on the Moon, and in addition, the European Space Agency, which represents the 14 nations of western Europe, is very serious about a modest lunar polar orbiter. The Japanese also have an interest, so something is probably going to happen, but at the moment it does not seem that the U.S. will play any part in it.

In the case of Venus, the orbiting portion of the Pioneer Venus mission launched in 1978 is still operating and is collecting some useful data. (Subject to budget cuts!), we have no further plans at present. In contrast, the Soviets have just launched two large Viking-class (in terms of weight and launch-vehicle capacity) missions to Venus. They are expected to do so again at the next opportunity, which is a little over a year hence, and they have committed themselves to the one after that because it's a dual mission that would go on to Halley's Comet.

The international scientific community had also developed the idea that since we've been exploring the plane of the ecliptic (the plane in which the planets move about the Sun), it was important to try to explore what is in the space away from that plane. In so doing, we would get a chance to observe the Sun from a direction we can never do on Earth, namely, looking (from our point of view) up or down at its polar regions. That mission was entitled the International Solar Polar Mission. Two spacecraft were planned, one to be developed by the Europeans, one rather more ambitious by the U.S., both to be launched by the U.S. on some kind of high-energy upper stage of the Space Shuttle. The two spacecraft were to go together out to planet Jupiter and use the gravity of Jupiter like a great slingshot to toss one of them "up" to observe the Sun and its emissions from "above" the plane of the ecliptic. The other was to perform the same kind of observations simultaneously but from "below." Unhappily, one of the casualties of the last year of budgeting was the outright cancellation by the U.S. of its spacecraft for that mission.

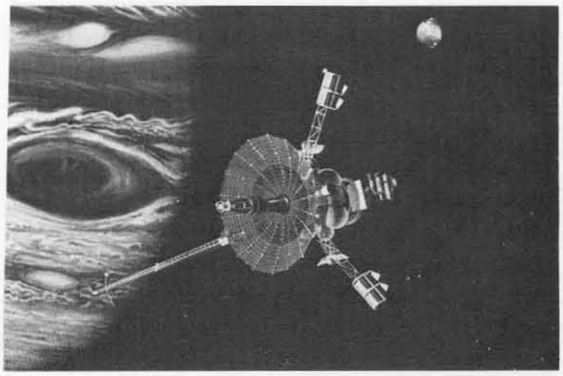
There has been a lot of agitation for each of the spacefaring nations to do whatever possible in the way of space missions when Halley's Comet returns to the vicinity of Earth in the early part of 1986. The U.S.S.R., for example, is moving its planned two spacecraft missions to Venus in 1984 around so as to be on a trajectory that will subsequently intersect Halley's Comet. They have substantially upgraded and changed the payload for that new purpose. The Europeans are sending a smaller spacecraft with a dust shield to pass very close to the nucleus of Halley's Comet, and the Japanese are also sending a very small spacecraft (actually two of them, but one is really a test vehicle). It will not be navigated close to the nucleus of Halley or the coma, but it will provide ultraviolet observations otherwise not available. The obvious thing is, of course, that the United States will not be there, so Halley's Comet will make its once-every-76-years visit to our neighborhood without our country contributing significantly to understanding what its properties are.

All is not lost, however. As an introduction to Voyager's trip to Uranus and to the Galileo mission, which we *will* be doing in the late 1980s, I'd like to describe to you what our strong suit really is — interplanetary navigation. When we went to Venus with Mariner 2 in 1962, the first successful interplanetary mission of any kind, the window of uncertainty in our aim was much larger than the size of Venus itself. By the time we went to Mars in 1964, the area of uncertainty had been vastly reduced, to less than the size of Earth. On our mission to Mars in 1969 we were aiming at an area about the size of the United States. By 1971, the aim uncertainty of Mariner 9's orbiter amounted to roughly 100 by 100 miles, something like the size of southern California. When Voyager got to Saturn's moon Titan — the most challenging navigation feat of all — we were operating at approximately a billion miles from Earth, and the miss-distance there was 400 square miles. That is very fancy shooting, and it was the result of a combination of tracking accuracy and computing ability on the ground and of the precise maneuvering that is possible with the spacecraft. Just as navigation accuracy was once the key to circumnavigating the globe reliably, so it is the key to exploring our solar system.



Voyager 2 took this wide-angle image of Saturn's rings just before the spacecraft crossed the ring plane. The enormous complexity of the planet's rings was one of the most startling surprises of the Voyager missions.

The Galileo mission, which is our centerpiece for the latter part of the 1980s, has a target area smaller than the size of Pasadena. At Jupiter, where the gravity field is tremendous, Galileo will use the Jovian moons as sources of gravity to modify its orbit so as to cruise in the vicinity for nearly two years. This will require very sophisticated navigation, moving the orbit around and changing its plane (as well as its dimensions)



Galileo, the only surviving new interplanetary mission for the 1980s will demonstrate the United States' strength in sophisticated navigation as it orbits Jupiter for about two years, using the satellites as sources of gravity.

simply by close passage of each moon.

In January of 1986, Voyager 2 will arrive at Uranus, and will do an Earth and a solar occultation of both the planet and its rings in this passage. The gravity of Uranus will keep Voyager properly aimed to go over the top of Neptune and make a close passage of its large moon Triton plus another Earth and solar occultation, and then the spacecraft will move on out of the solar system. What we don't know is whether it will still be alive and able to tell us what it is sensing.

All this depends upon the navigational accuracy. It is a kind of technology, a kind of exploration, that is uniquely American. No other country has even done its first simple swingby like our 1974 Mariner 10 mission to Venus and Mercury.

What conclusions about space activities in the decade ahead — the 1980s — can be drawn from all this? My first conclusion is that the Soviet Union will be the major player in the inner solar system, that is, in the exploration of Mars, Venus, Halley's Comet, and perhaps the Moon. The major player in the outer solar system — Uranus, we hope Neptune, and certainly Jupiter — will be the United States. So we're not out of business. In some ways it's a 50/50 split.

There are some other factors we should be aware of, however. First of all, the European Space Agency and Japan, at least, will definitely be entering the scene. And that's good. It is good that more nations will be responding to their own aspirations and capabilities to reach out beyond Earth. It is a positive thing that the competitive Cold War race between just two countries that started space exploration is going to change.

But while we will still have a major (though not a dominant) role in the 1980s, we need to ask ourselves whether we will be investing in the 1990s. If we do not, we will not even be a significant player in the future. The decision we will have to make soon is how much we care about the future; it is the same decision we blew in the 1970s.

I can't predict the outcome; it's a free society that decided to go with Voyager, for example, in response to popular appeal. And that program managed to survive four Presidents and six Congresses. The representatives of the same society decided not to go to Halley's Comet, and you just have to accept that.

What is clear to me is that to the extent that we influence the future and participate in it we must do so internationally. Our period of dominance is over, and it is unlikely to return. What is more likely, and certainly more desirable on a long time scale, is that the United States will help to coordinate international efforts, not just in determining what we will do in space but in how we will deal with our neighbors on Earth. That, I think, is our challenge and our hope.

I must say that, as a country, we do not seem to be very expert at doing this at present. The way we have handled the demise of the Solar Polar mission and to some extent the Halley's Comet mission has left bitter wounds among our very best friends overseas. We have a lot to learn, and we have to want to do so, but the longer it takes us, the less likely we are to become a part of the future.

The 1990s and beyond are harder to predict than the current decade, so I'd like to bracket a range of possibilities for planet Earth. The first possible scenario is that history will repeat itself; that there will be another Apollolike nationalistic race between the United States and the Soviet Union to reach, say, Mars with men. I think that is unlikely, though the Russians may choose to go unilaterally.

Another possibility that is probably more plausible is what I call the "Antarctic Analogy." An earlier nationalistic race was to the South Pole, though it was dominated more by personalities and less by national interests. In the winter of 1911-12 it was Scott against Amundsen, and Amundsen won. Very little happened in the Antarctic for some time afterward because we had two world wars that distracted from interest in it. But a by-product of those two wars was the development of relatively cheap transportation technology. So after World War II it was reasonable for the U.S. Navy to support some Antarctic scientific exploration. From that was born the International Geophysical Year, in 1957, which launched a continuing program of low-level exploration and scientific measurements in the Antarctic by many countries.

The motivations for that are not entirely altruistic. Almost all the countries want to maintain a presence there because of potential territorial claims, or at least because resources in the Antarctic will eventually become valuable. The shrimplike krill are already beginning to be harvested in the Antarctic seas, and they are viewed as a major source of food for the Earth. And there are mineral and probably oil deposits that will be exploited in the coming three or four decades.

So the Antarctic parallel may be a better guide for space. In that case, the Apollo syndrome would not repeat itself, but rather there would be a lull during which space transportation technology would get cheap for reasons that had nothing to do with the solar system. Eventually it would become more affordable to do somewhat utilitarian programs.

A third possible way to go is what I call the "Look Inward and Downward" alternative. Some kind of combination of war, terrorism, and ecological disaster could so weaken the industrialized countries of the world that the reaching-out process would just stop. And the planetary exploration phase, of which we have witnessed the apex, would *really* become a historical anomaly.

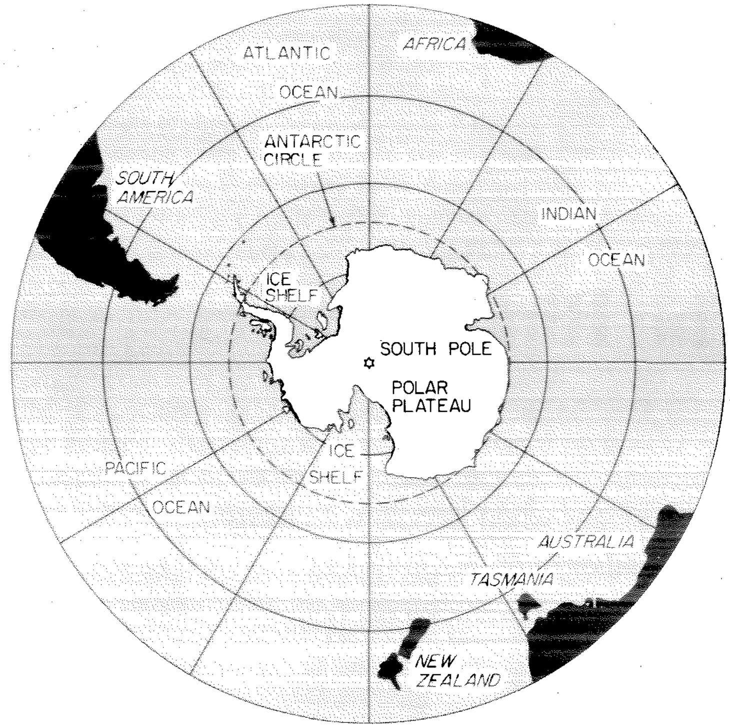
Finally, the fourth of my scenarios for a possible future is what I call "Some Unforeseen Compelling Event." For example, there is a growing concern about climatic change occurring on Earth. A natural fluctuation in climate over, say, tens to hundreds of years could be driven by solar phenomena — perhaps fluctuations in both the magnitude and the kind of solar radiation and other materials with Earth. A climatic change could also be induced by human activities, especially by the burning of fossil fuels, which adds large amounts of carbon dioxide to the atmosphere, increases the self-heating capacity of Earth, raises the temperature, causes the ice caps to melt thus raising the sea level, and leads to a number of bad effects. These effects could eventually alter the sources and global availability of food and the habitability of the seacoasts. One of the responses that would make a lot of sense would be to invest in understanding solar radiation and its interaction with Earth both at present and historically. On a mission like the Solar Polar one we could measure what is going on around the Sun right now, and the best place to look for the history of solar action is probably on Mars, where (because there are no oceans) the effects of a small fluctuation in solar radiation are amplified. Given the prospect of real climatic problems on Earth, we might find scientific fact-gathering space missions observing the Sun or even to the polar areas of Mars suddenly becoming "affordable."

A second example of an unforeseen compelling event (and a very fanciful one) would be if an Earth-crossing asteroid hit the Earth. Such an event — with about ten megatons equivalent energy — actually happened early in this century in Siberia. If a search — either intentional or accidental — were to reveal the existence of an asteroid or a family of them in an Earth-encountering orbit in, say, 100 years or so, it would certainly get people's attention. There would no doubt be a sudden interest in understanding all the objects of that type that we ought to know about and where the potentially dangerous ones actually are. For the modest-sized ones, it's feasible that we might even develop the technology to change their orbits.

I don't think either of those things — climatic change or the asteroid-impact idea — is likely to happen in just the way I hypothesized. But something might occur that would re-energize solar system exploration, not just for the U.S. but for the world. In any case, our national role will have to be part of a larger global scenario. We cannot see the future simply in American terms, because once you stop being the leader — as we are surely doing — you have to be more responsible to the rest of the system.

So whatever U.S. efforts occur beyond the 1980s they will reflect in part what is happening globally. And they will also reflect what is happening here in the United States of America. Will we decide that our destiny is to lead internationally through effective means of coordination? Will our position ten years from now still be one of confusion about our role? Or will we have decided to withdraw from the 20th century?

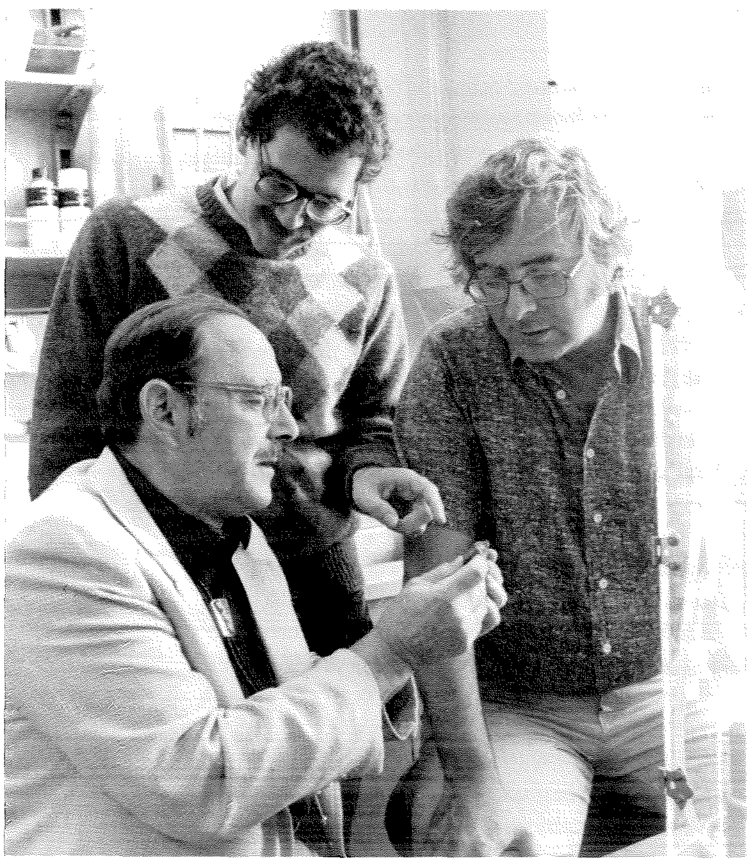
Regardless of which global scenario comes up, regardless of what degree of leadership, if any, we choose to exert, the phase that is drawing to an end was the beginning of *Homo sapiens* reaching out to physically understand the environment in which the species is growing up. It has been a remarkable time for all of us — the golden decade that marks the end of the beginning. My own belief is that 100 years from now the solar system will be very familiar territory. It will be utilized and internationalized intellectually in a very broad way in the human population. The men and women of that time will go to the Smithsonian of the day and look at what we did — a Viking or a Voyager spacecraft — as incredibly tiny scratchings but of tremendous import. And we will be honored very greatly for having done those things. □



The history of Antarctica provides an analogy for a possible future scenario in space. Though it was first opened up to exploration in the early 20th century, it was only after the development of relatively cheap transportation after World War II that interest in our southernmost continent gradually increased. After the initial push of the 1970s, further space exploration may also wait until transportation technology becomes cheaper.

The Ripple Effect

What happens when people with ideas come together in an environment that encourages communication?



All it takes for a discussion is three geologists and a rock. The geologists are (left to right) Gerald Wasserburg and Edward Stolper of Caltech, and David Walker, a Fairchild Scholar from Harvard.

THE ripple effect of a stone in a pond is a homely metaphor for describing what goes on when an idea strikes a research medium. But that is how science begins, and the Sherman Fairchild Distinguished Scholars program makes it happen at Caltech many times more often than it otherwise would.

David Walker, for example, is a senior research associate at Harvard University, holder of the Clarke Medal of the Geochemical Society, and well known to fellow geologists for his imaginative scientific ideas. More particularly, he is known for his development of new experimental approaches to understanding the genesis of rocks, especially those of igneous origin. Walker is currently spending six months at Caltech as a Fairchild Scholar and working with his former student Edward Stolper, assistant professor of geology, to understand the circumstances under which anomalous chemical variations occur in particular magmas and those in which they do not. They want to find out if the Soret effect is the cause of this variation and, if so, under what conditions it operates.

The Soret effect, which is concerned with the diffusion of heat and mass in liquids, is an obscure enough phenomenon that geologists are seldom aware of it. But petrologists like Walker are increasingly interested in finding out why the composition of lava from one volcano differs from that of another or, for that matter, why there are anomalies within the chemical variations in the lavas from the same volcano. As a first step in that direction, Walker and Stolper hope to be able to demonstrate experimentally that the Soret effect is of sufficient magnitude and that it works at a geologically reasonable rate.

Walker has already done initial studies at Harvard of the Soret effect on silicate liquids. Now he and Stolper, whose current interest is in infrared spectroscopy, will try to characterize the different molecular arrangements of water in magmas to find out how they fit into the overall thermal diffusion scheme in molten lava. Neither infrared spectroscopy, however, nor the electron microprobe that Walker usually uses to analyze major and trace elements in magmas is capable of discriminating the isotopes of some of those elements. For that, they will depend on the expertise of Gerald Wasserburg, Caltech's MacArthur Professor of Geology and Geophysics, whose laboratory is noted for isotopic analysis of many materials — lunar rocks, meteorites, and oceanic basalts, for example.

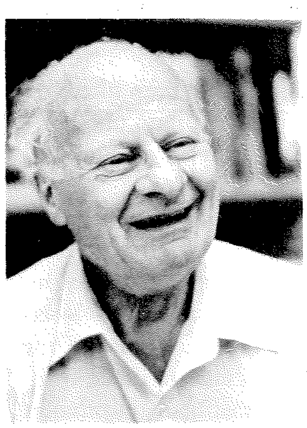
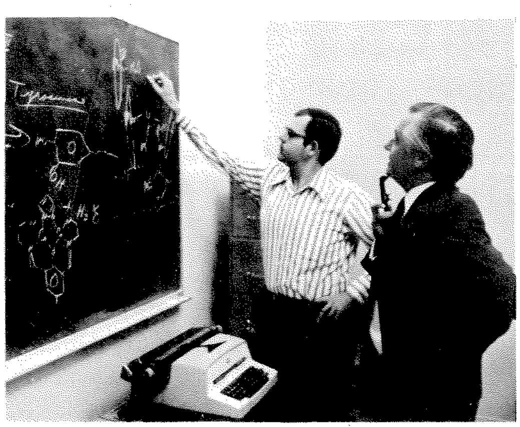
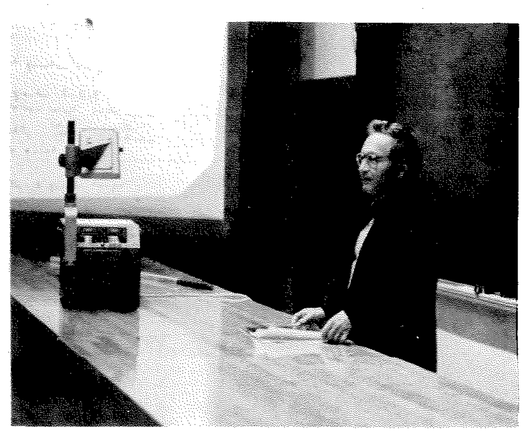
As research with immediate geological relevance goes, coming to understand the Soret effect may be a relatively minor undertaking. It is, however, an excellent example of how all good science starts. Someone's idea drops — or is thrown — into the right mental "pond," where it begins to create a thousand ripples for others to note and analyze and build upon. Volcanism is one of the major processes going on in the earth, and it has wide-ranging long- and short-term effects, many of which are not well understood. Walker, Stolper, and Wasserburg are scientists getting together in an environment that encourages communication. Out of their ideas and interaction may come one more piece for solving the terrestrial puzzle.

Getting people like that together for a reasonable period of time is not always easy, financially at least, for today's university. In fact, ever since the springs of research dollars began drying up in the late 1960s, colleges across the nation have been facing some very stringent financial conditions. Caltech has probably suffered less severely than many a less prestigious or less science-oriented institution. Nevertheless, a dozen years of diminishing research grant funds and rising costs have taken a considerable toll. With a "mild recession" blanketing the economy and the probability of still further cuts from Washington, the outlook for the future of federal grants makes past problems seem relatively mild.

One partial solution is, of course, to persuade the private sector — industry, foundations, and individuals — to dig more deeply into its financial pockets to support the basic research that is the foundation upon which science and engineering at Caltech are built. Many institutional and individual efforts are made in that direction, and fortunately some of them succeed beyond all expectation. Caltech has greatly benefited, for example, from its early foresight in asking the Sherman Fairchild Foundation to underwrite a program that over the last nine years has financed the visits of some 200 distinguished scholars to the Institute — including that of David Walker. This pilot program has made it possible for Caltech to stoke the creative fires of its faculty and students without having to enlarge its permanent staff. And while the fiscal benefits of such a program are substantial, the intellectual ones are impressive — and probably even more important to those fortunate enough to interact directly with the visitors.

The Fairchild Program is somewhat different from most visiting scholar programs in that, for example, applications are rarely received for it, and invitations to participate are extended only after considerable thought and review. In addition, the scholars have no formal responsibilities while they are at Caltech. Both the Caltech community and the visitors find that this freedom plus the chance to interact in many situations with other distinguished scientists make for a high order of stimulation. If communication is the lifeblood of an educational enterprise, how many transfusions does a visiting scholars program offer? At a very basic level, some counting can be done. In 1980-81, for example, 21 different Fairchild Scholars were in residence for periods varying from three months to a full year. Between October and May, the *Caltech Weekly Calendar* announced 22 departmental seminars to be led by them, one scholar spoke for the Caltech Y "Evening Spotlight Series," one gave a Watson Lecture, and two former Fairchild Scholars returned to the campus and gave seminars.

Much more numerous interactions take place

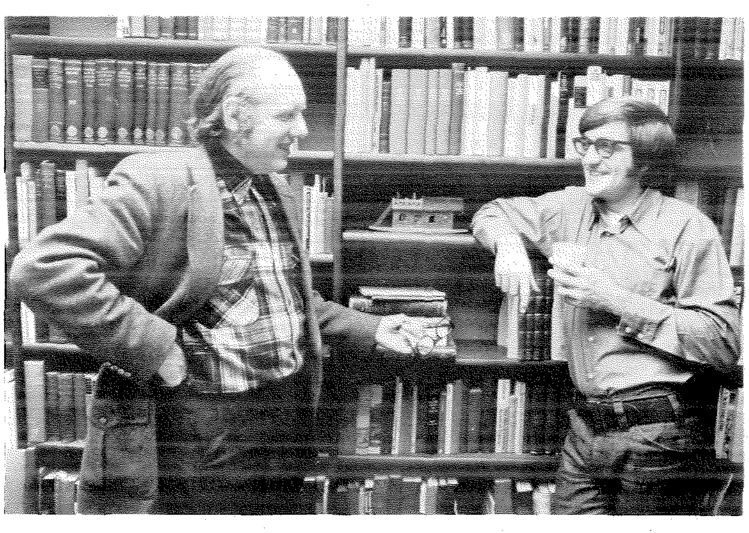
Three Nobel prizewinners have been among Caltech's Fairchild Scholars: Hans Bethe (left), Sir George Porter (center right, with Robert Gagne, who was at that time a Noyes research instructor in chemistry), and Philip Anderson.

on a less public and formal basis, with hundreds of one-on-one or -two or -three encounters in an office, or a lab, or a hallway. In seismology, for example, there is a long tradition of everybody in the department gathering every morning and afternoon for coffee and conversation, and that includes visitors. "I don't know how many ideas for new research have come out of those coffee klatsches," says Clarence Allen, professor of geology and geophysics, "but it's a lot, and the level and diversity of the ideas of people as creative as the Fairchild Scholars we've had is incredible."

"Incredible" is a hard word to quantify; by definition, Fairchild Scholars are already distinguished in their fields or show unusual promise of becoming so. It would seem that we should expect creative thought processes from them. But another way to look at it is to note some of the ways they have been recognized by their peers. A once-over-lightly look at their credentials recently revealed that 120 of the 200 scholars who have visited Caltech since 1973 are citizens of the United States. Of those, more than half are members of the National Academy of Sciences or of the National Academy of Engineering — or both. Sixteen hold named professorships at their home institutions. Three are Nobel laureates. Of the scholars from foreign countries, 20 are listed as members of the equivalents of our National Academies in their own countries. One Fairchild Scholar is unique in being the only scientist/astronaut in the Apollo lunar exploration program, and he has gone on to become United States Senator Harrison Schmitt from New Mexico.

But what have they done for Caltech? "Stretched our minds," says Roger Noll, Institute Professor of Social Sciences and chairman of the division of the humanities and social sciences.

William Riker (left) in a 1974 visit to Caltech as a Fairchild Scholar with Morris Fiorina, who was assistant professor of political science at that time. Riker is currently president of the American Political Science Association, and Fiorina became a full professor in 1977.



"It's easy in a small place like Caltech to become very cloistered. We need to have some external force continually pushing our minds in new directions. In the Fairchild program, we bring in a steady flow of brilliant new people, and it's a challenge to understand what they're doing and learn about it. Moreover, they often have a profound effect on our developing programs."

One of the people who did that for the Caltech social scientists was William Riker, a political science professor who is University Dean of Graduate Studies at the University of Rochester and president of the American Political Science Association. Riker was a Fairchild Scholar in 1973-74. "He is generally regarded as the father of the research methods that have since become known nationally as the 'Caltech School' of political science," says Noll. "He is one of the first people who thought about political science in a scientific way and used tools of economics and mathematics to model political processes. His visit to Caltech was instrumental in getting our program started.

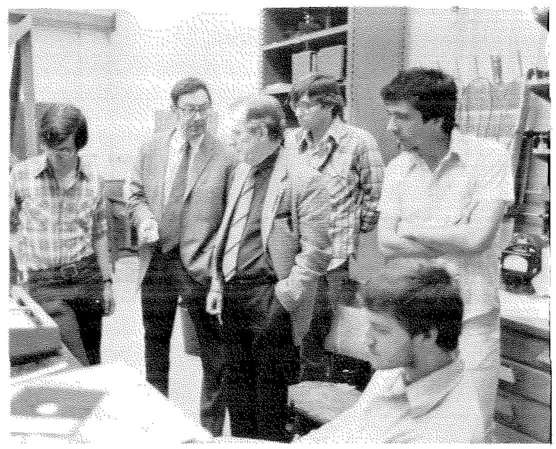
"Subsequent Fairchild Scholars in the areas of economics and political science — Theodore Anderson, Richard Easterlin, G. S. Maddala, and Vernon Smith, for example — have continued to enlarge our perspectives and enrich our program. This year, Donald Brown of Yale has been with us. He is a highly creative thinker in mathematical economics and cooperative games. We have also had several historians, among them Charlotte Erickson, Allan Bogue, Allan Lichtman, and Peter Payne. These scholars have been instrumental in helping us build a bridge between social science and history and in making Caltech today unsurpassed in the world in the field of quantitative, social scientific history. For the future, we intend to invite scholars in philosophy and literature to help us achieve national distinction in those disciplines."

Noll points out that many Fairchild Scholars also become advocates of the Institute, helping, for instance, in the placing of graduates. Since John Ledyard, professor of economics at Northwestern University, was here in 1977-78, four Caltech social science PhDs have been hired there, and two excellent Northwestern undergraduates have come to Caltech for graduate study in economics.

"The Fairchild program leads to an enormous expansion of what we do," says Harry Gray, Beckman Professor of Chemistry and chairman of the division of chemistry and chemical engineering, "and this takes place in several ways. Those who come tend to talk about their research with faculty members here, and that is the inspiration for many a new approach to a problem — for them and for us." Gray and Carl Ballhausen, professor and head of physical chemistry at the University of Copenhagen, collaborated on a book on molecular electronic structures while Ballhausen was here as a Fairchild Scholar in 1979. Ballhausen also worked on a problem dealing with the coupling of vibronic electronic states, and presented his results in a seminar to the division.

The model of interaction that Gray is also closely acquainted with is that of the Fairchild Scholar acting as a "kind of glue" to get existing separate groups together and doing joint experiments. Exactly this happened with his group and that of Sunney Chan, professor of chemical physics and biophysical chemistry, when Bo Malmström, professor of biochemistry and head of the department of biochemistry and biophysics at the University of Göteborg, Sweden, arrived in the fall of 1980. Malmström's work has been mainly on the structure and function of enzymes, with emphasis on metal-ion-containing protein systems and the role played by the metal ions in enzymatic activity and biocatalysis. Much of this is in the same general area that Gray and Chan are interested in. Malmström, says Gray, "came off the plane with liquid nitrogen tanks of his copper enzymes. He rolled up his sleeves the first night he was here, with a bunch of our students around. We literally started talking about experiments from the first hour, and the next day people were starting to work."

Chan points out that this isn't likely to happen in the normal course of things; it takes someone from the outside to look at the separate things different groups are doing and put them together. For example, one of the projects undertaken during Malmström's stay was an investigation of the reactions of nitric oxide with tree and fungal laccases. These copper-containing enzymes, which the Gray group has been studying recently, catalyze the reduction of dioxygen to two molecules of water. At the time of Malmström's arrival, Chan's group had just completed a study of the reactions of nitric oxide with cytochrome *c* oxidase (an oxygen-reducing metalloprotein important in the energetics of cellular respiration), which greatly clarified the structure of the metal centers in this enzyme and their functional roles in electron transfer, energy conservation, and activation of dioxygen. Malmström, whose interests include both cytochrome *c* oxidase and the laccases, realized that a similar study with the laccases might help to elucidate the structure and function of the metal centers in these proteins as well. The results, which turned out to be quite different from those with cytochrome *c* oxidase,



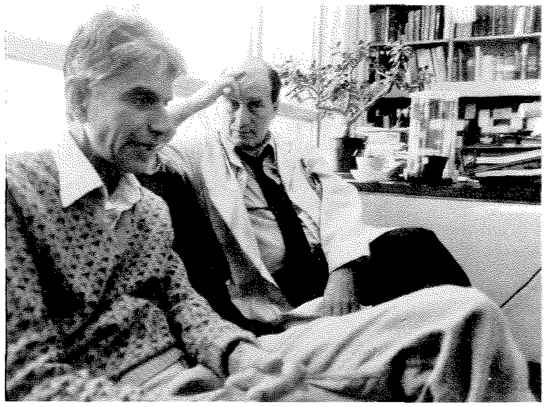
Bo Malmström came from Sweden as a Fairchild Scholar in 1980, and in early 1982 he was back for a visit with the group he had worked with. Top (right to left) graduate students Craig Martin and Robert Kanne with Sunney Chan of the chemistry faculty and Malmström. Left, Martin, Kanne, and Malmström are joined by chemist Harry Gray and graduate students Gary Campbell and David Blair (seated).

have led to a better understanding of the mechanism of dioxygen reduction by the laccases.

Incidentally, Malmström's period of being a Fairchild Scholar took place two years after an invitation was first extended to him. That offer got lost in the mail, so a rather bewildered chemistry division wondered why he didn't respond. The delay turned out to be fortunate, however, and when he finally did arrive, both the state of his science and that of the Gray and Chan research groups were at a point where collaboration was most profitable. Two interesting interruptions occurred during Malmström's visit. Because he is chairman of Sweden's Nobel Prize committee for chemistry, he had to make flying trips home in October (to participate in the final selection process) and December (to attend the presentation ceremony).

The research done while he was here (and continued since) included not only the laccase-nitric oxide work previously mentioned, but also a systematic study of the spectroscopic properties of a large number of copper-containing proteins, supplied by both Malmström's group in Sweden and

A conference between Fairchild Scholar Obaid Siddiqi and biology professor Seymour Benzer, at the right.



Gray's group here at Caltech. Several papers are currently being written as a result of this collaboration, and one paper has already been published, appearing in *Biochemistry* (1982, *20,* 5147) under the names of Gray, Malmström, and Chan, but the names ahead of theirs are those of graduate students Craig Martin, Randall Morse, and Robert Kanne.

In the biology division, an interesting Fairchild Scholar/Caltech faculty interaction has been that between Seymour Benzer, Caltech's Boswell Professor of Neuroscience, and Obaid Siddiqi, head of the molecular biology unit at the Tata Institute of Fundamental Research in Bombay, India. Each worked earlier in molecular biology; each has switched to neurobiology; each uses the fruit fly *Drosophila melanogaster* as his research organism. Benzer changed from bacteriophage to Drosophila several years before Siddiqi, and has done important research on the genetics of behavior through the isolation and characterization of mutant species of the fly. Siddiqi started working with Drosophila about ten years ago, largely through the influence of Benzer and his work. He has studied neural physiology of temperature-sensitive paralytic mutants, but more recently he has become interested in how an organism perceives smell.

Drosophila seems to be an excellent organism on which to do this work. First, a lot has already been done on the smell mechanism of insects (in the hope of learning to control them). Second, building on the extensive work already done on mutant strains of Drosophila at Caltech, he should be able to manipulate the genetics of the smell receptors so as eventually to dissect their anatomical and functional organization and relation to behavior in response to various specific odor molecules. Siddiqi is doing both electrophysiology and biochemistry on this problem, and he and Benzer constantly discuss the results and work out new paths to try.

Two Fairchild Scholars who have visited the division of engineering and applied science are Hiroshe Inose (left) and John Lambe.

One of the many Fairchild Scholars who have visited the engineering and applied science division is Hiroshe Inose, a professor of engineering at the University of Tokyo, who has taken back to Japan the first draft of a book that he wrote with John Pierce, professor of engineering emeritus at Caltech. Inose arrived last September and left in November, but in that short time he and Pierce were able to put together *Information, Technology, Civilization: The Intersection*. The book will be used as a basis for discussion at an international meeting of the Club of Rome that will be held in Tokyo in October 1982.

Not all Fairchild Scholars come from academia, and one who did not was John Lambe, who was for some years principal staff scientist for the Ford Motor Company. While here as a visitor, he worked with the research group of Thomas McGill, professor of applied physics, and the outcome has been the development of long-term collaboration in the area of electronic transport in very small structures.

Not all Fairchild Scholars have been men. One woman scientist was Lynn Margulis, a biologist from Boston University, who crossed divisional lines to work with the geology division at Caltech in 1977. She has been interested in the origins of life, particularly its evolution in the Precambrian era. It was her interest in tracing this history through study of evidences of life forms found in rocks that led her to geology. While she was here, she testifies, she also learned to use the gel electrophoretic apparatus in the laboratory of fellow biologist Elias Lazarides, the high-speed film equipment in the laboratory of Theodore Wu, professor of engineering science, and the scanning electron microscope under the direction of Caltech's Ruddock Professor of Biology, Jean-Paul Revel. "With these tools," she wrote after returning to Boston, "we made unprecedented discoveries at a rate I have never been able to work at previously in my career. To set up this quality equipment at Boston University would probably have cost over a million dollars and, of course, was unthinkable." Margulis also gave a lecture, "Life on the Early Earth," on the evening Athenaeum series.

Another woman Fairchild — in 1980 — was Alexandra Bellow, professor of mathematics at Northwestern University, who is a world leader in her field of martingale theory and theory of liftings. She later wrote to the Fairchild Program at Caltech that working with Caltech mathematicians in the areas in which the Institute excels — analysis, combinatorics, and number theory — helped her devise new techniques for attacking the problems she was studying here — ergodic theory and measure theory. Having no teaching or administrative duties, she "luxuriated," she says, in having an uninterrupted block of time for mathematical work. "Uninterrupted," however, needs some qualification, because in the three months she was here she also gave several colloquium lectures at Caltech, two at UCLA, and one at UC San Diego, and she spoke at a conference honoring the 85th birthday of mathematician Einar Hille at UC Irvine.

It has been eight years since February1974 when Stephen Hawking stunned the astrophysical world with a paper in which he proposed that black holes — contrary to Einstein's classical laws of gravitation — actually emit a steady stream of particles and eventually explode. That September he arrived in Pasadena to spend a year at Caltech as a Fairchild Scholar from Cambridge University, discussing his ideas and developing his theories in interaction with the relativistic astrophysicists and other physicists at the Institute. Among that group was a constellation of brilliant scientists, including three other Fairchild Scholars brought here in roughly overlapping periods under the aegis of Kip Thorne, now Kenan Professor of Theoretical Physics. Those three were Edwin Salpeter, professor of physics at Cornell University, who has made major contributions to theoretical particle physics; Werner Israel, professor of physics at the University of Alberta, Canada, who is famous for his pioneering work in the physics of black holes; and Robert Dicke, Brackett Professor of Physics at Princeton, who is known for his theoretical interpretation of blackbody radiation as a remnant of the big bang that created the universe, for the Brans-Dicke Theory (which stimulated tests of relativity), and for tests of the equivalence principle (the fundamental assumption in Einstein's theory that gravity acts the same way on all matter). Before Hawking returned to England, he formulated a new principle of physics which says that every singularity in spacetime (including the big bang) produces particles in a completely thermally random manner.

Four distinguished physicists who were at Caltech as Fairchild Scholars during 1974-75 were (top, left to right) Robert Dicke, Werner Israel, Edwin Salpeter, and Steven Hawking. At the Institute this spring and working in the same general field is Fairchild Scholar Marcus Grisaru (lower picture, left) with visiting associate Anders Karlhede and research fellows Warren Siegel, Richard Grimm, and Sylvester Gates.

Research in this field has not stood any more still than time has. Hawking's principle has come to be generally accepted, but some of his later formulations are more controversial. Several people at Caltech are trying to understand his concept of spacetime foam, for example. "Spacetime foam" is Hawking's somewhat whimsical name for the very complicated and turbulent way spacetime looks when viewed from a very short distance — 10^{-33} cm (the Planck length), for example — which is in considerable contrast to its smooth appearance on a large scale.

A current Fairchild Scholar now consulting with a group of Caltech's theoretical physicists is Marcus Grisaru, professor of physics at Brandeis University, who works on a theory called supergravity, which may represent a long step toward the unification of those two seemingly contradictory theories, the general theory of relativity and quantum theory. Physicists' and astrophysicists' attempts to find a completely consistent quantum theory of gravity now build on this work, which may be the essential element in attempts to unify the fundamental forces — and eventually to understand the nature and origin of the universe.

Usually, the ripple effect has no such cosmic implications. A child tossing a stone in a pond can cause it — and so can a scientist expressing an idea to another scientist. The Sherman Fairchild Distinguished Scholars program is boosting the number of ripples at Caltech. □ – *J.B.*

John D. Baldeschwieler, professor of chemistry, and a test tube full of mouse, ready for the lab equivalent of a ride on a very slow merry-go-round.

Tiny Bubbles

by Dennis Meredith

The day may soon come when minuscule drug-carrying spheres injected into the body will home in on tumors and diseased organs. When it does, we can thank Perturbed Angular Correlation spectroscopy.

INSIDE the modern Noyes Laboratory of Chemistry at Caltech is the laboratory of Professor of Chemistry John D. Baldeschwieler. Inside this laboratory is a modest-looking machine featuring four cylindrical gamma ray counters, each at 90 degrees to its neighbor and aimed at a slowly rotating translucent tube.

Inside this rotating tube rests a standard, white, laboratory mouse, who looks so relaxed that you might think he is enjoying the ride. Inside this white mouse circulate millions of microscopic hollow spheres, each about one-hundredth the size of a cell and made of phospholipid, a common building block of living membranes.

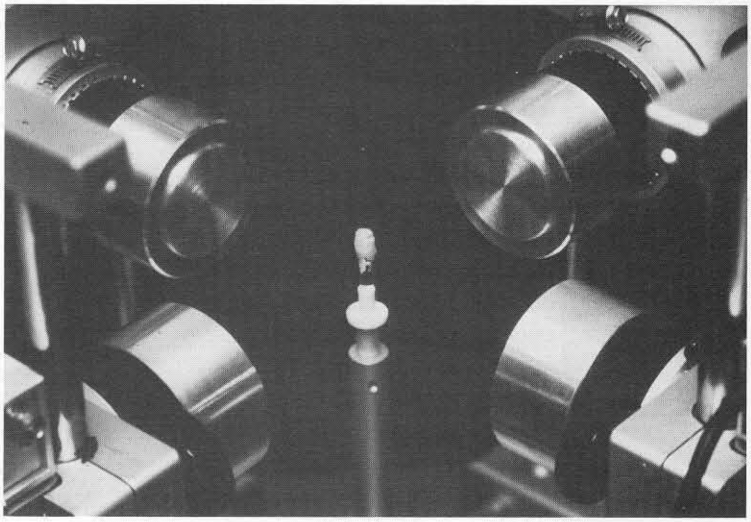
And inside each of these spheres — called vesicles — is a load of radioactive indium, each atom clutched within a molecule known as a chelator and emitting a rapid-fire salvo of two gamma rays as it decays.

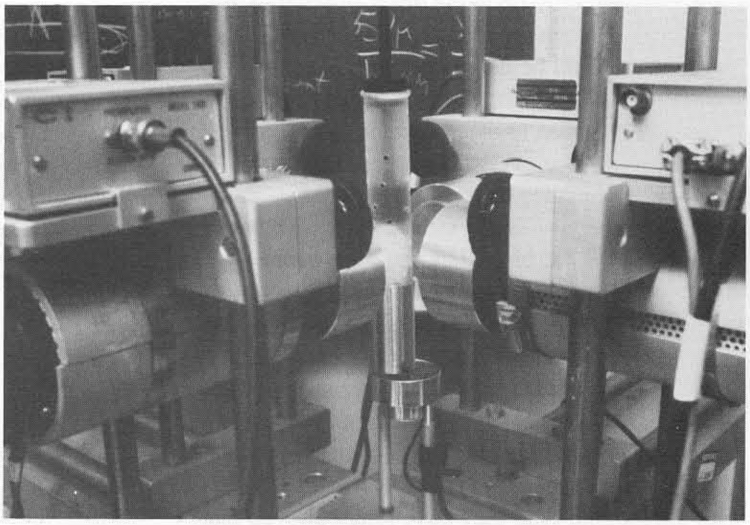
The experiment is an elegant one, say Baldeschwieler's colleagues, and it could significantly advance the day when microscopic man-made vesicles are used as the medical equivalent of guided missiles. Injected into the body and containing a dose of either drugs for treatment or radioactive tracer for diagnostic tests, they would home in on diseased organs. Such vesicles, lodged in a tumor, for example, might be designed to be enveloped by the tumor cells, where they would be attacked by protective enzymes. An opened vesicle would prove to be a lethal surprise package, because its contents would kill the cell with little or no injury to other healthy body tissues. Or, the vesicles might be built with special substances that would allow them to fuse with a cell, like two soap bubbles joining, and then to inject their contents to kill the cell or treat a disorder.

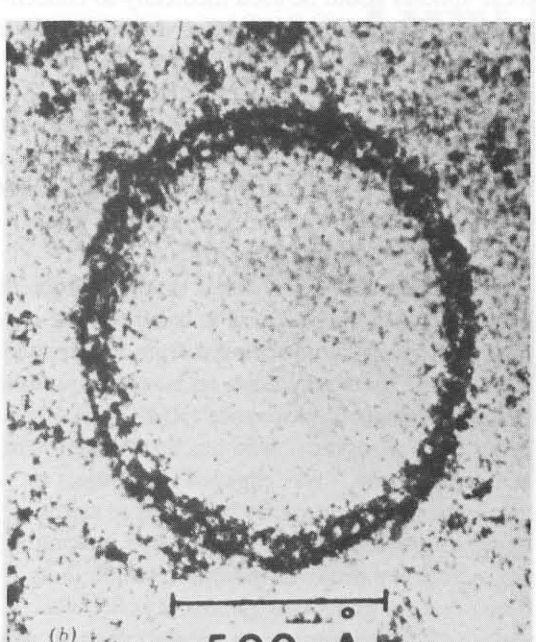
Vesicles designed to rupture only at certain temperatures could be injected into patients to deliver medicine only upon the onset of fever. Similarly, such vesicles carrying growth hormones or insecticides could be introduced into plants, where they would wait until just the right point in the growing season to discharge their cargo. The vesicles also make excellent experimental models of living membranes, since phospholipid — their main constituent — is the same as that of natural membranes. Thus, biologists can build membranes of their own design to test theories of membrane structure and activity.

For over a decade, scientists have known that phospholipid molecules — gangly structures with an ionically charged "head" end and "tails" consisting of two organic carbon chains — tend to form closed spheres in solution when agitated with ultrasound. And they have long believed that these spheres could be used medically to concentrate drugs or other substances at desired places in the body. But despite the promise of the little globes, serious problems prevented their use. Scientists had yet to learn how to construct precisely the little bubbles; to load them with chemicals; to "address" them to the right organs; to track them in the body; and to determine where and when they rupture to deposit their loads.

John Baldeschwieler's attack on these problems began — as do many efforts in basic science — with a discovery quite removed from its eventual application. Baldeschwieler, an inventive pioneer in nuclear magnetic resonance (NMR) and other forms of spectroscopy, who has been called "the Mozart of NMR," was engaged in a project to develop a new spectroscopic method to study biological molecules in 1967. He was looking at the radioactive decay of indium^{111}, which in its decay process emits two gamma rays 85 nanoseconds (billionths of a second) apart. It was known that the two gamma ray emissions show an angular correlation. That is, when the decay of







The instrument for studying the path of vesicles inside a mouse features four cylindrical gamma ray counters focused on a central upright (top), on which is mounted a test tube carrying a mouse (center). Inside the mouse circulate millions of phospholipid vesicles loaded with radioactive indium. A scanning electron micrograph of a vesicle is shown at the right. The 500 Å indicated on the scale is the equivalent of about two-millionths of an inch.

a sample of indium^{111} is studied using detectors placed at different angles to one another, it can be shown that the indium atom tends to emit its two gamma rays at certain angles with respect to each other.

He discovered that this angular correlation could be used to reveal how fast an indium-containing biological molecule was tumbling. A molecule free in solution would display one characteristic set of angular correlations, but quite a different set when it became stuck to a surface or to a larger molecule.

The process is called "Perturbed Angular Correlation (PAC) spectroscopy. It was intriguing; it was unique; and, at first, it was useless. The phenomenon was, as Baldeschwieler describes it, "a classic case of a cure looking for a disease." Then, in 1976, he began to investigate the possibilities of using PAC in the promising-but-unfulfilled area of phospholipid vesicles. What was at first merely intriguing became transformed into a powerful research tool.

His research group, sponsored by the National Science Foundation, the National Institutes of Health, Merck, Monsanto, and Caltech Associate Lester Finkelstein, first developed methods of constructing the vesicles from carefully synthesized phospholipids, and of loading them with indium. The loading process, developed by then research fellow Ronald Gamble, represented a major advance, for it allowed the chemists to pump high levels of indium into the vesicles without damaging them.

Basically, loading involves first constructing the vesicles of a purified phospholipid and cholesterol, which is a necessary substance for stable membrane formation. Inside the vesicle at formation is a load of nitrilotriacetic acid (NTA), a chelating molecule that entraps small ions within its structure. Built into the vesicle walls are other specialized molecules called ionophores. These "porthole" molecules create channels in membranes that allow small ions, but not larger molecules, to pass through. The resulting vesicle is the molecular equivalent of a lobster trap, because when such vesicles are immersed in a dilute solution of indium chloride salt, the indium finds its way into the vesicle, but is trapped and held there by the chelator.

In a typical experiment, loaded vesicles are then injected into a mouse, and the animal is placed amid the gamma ray detectors. As long as the vesicles are intact, the indium and its captor chelating molecule tumble about rapidly inside. But once the vesicle breaks, the freed indium, which tends to be more attracted to cellular proteins than to the chelator, escapes the chelator and binds to a large protein or a cell wall. Then its tumbling slows markedly, producing a sort of alarm signal from the instruments, revealing that the vesicle has broken. In their first experiments, Baldeschwieler and his colleagues quickly found PAC to be both highly sensitive and to work well *in vivo* — an absolute necessity because earlier researchers had discovered that vesicles behave far differently in the test tube than in living animals.

The Caltech chemists confirmed this difference in their first studies. They found, for example, that vesicles made from phospholipids with 16-carbon-atom tails survived intact in test tube solutions until blood serum was added, whereupon they began to leak badly. Such vesicles were similarly fragile when they were injected into mice. On the other hand, vesicles made from 18-carbon-atom phospholipids proved stable even in the animals.

The research group then tested vesicles of different compositions over a wide range of pHs and temperatures. They learned to vary these conditions to produce vesicles with varying lifetimes in the body, and vesicles tailored to destruct only within a narrow range of pH or temperature. But by far their most intriguing finding has been the first discovery of a way to "address" the vesicles to specific tissues in the body.

The key to their success was the finding within the last decade that living cells use various sequences of sugar molecules on their surfaces as recognition markers. Scientists at other research centers had found that there may be as many as 100 different sugar molecule structures found on cell surfaces and recognized by receptors on other cells. Blood type, for example, is determined by such multi-unit sugar molecules arrayed on the surface of blood cells.

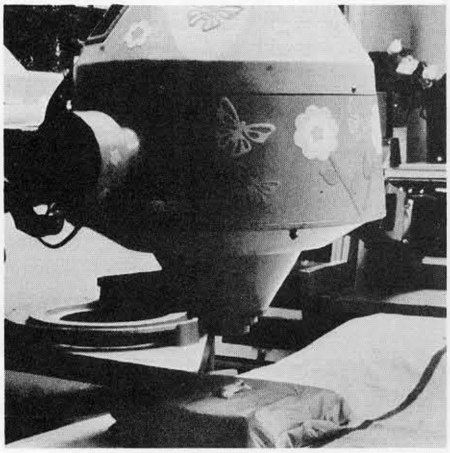
The Caltech scientists began their targeting studies by incorporating into vesicles cholesterol with sugar molecules attached by a sulfur atom "bridge." The sulfur attachment was necessary because the body would readily cleave sugar molecules attached with the usual oxygen linkage. Collaborating with researchers at Merck and Co., who produced the specialized molecules, Baldeschwieler and his colleagues tried modifying the outside of their vesicles with some 15 to 20 different sugars.

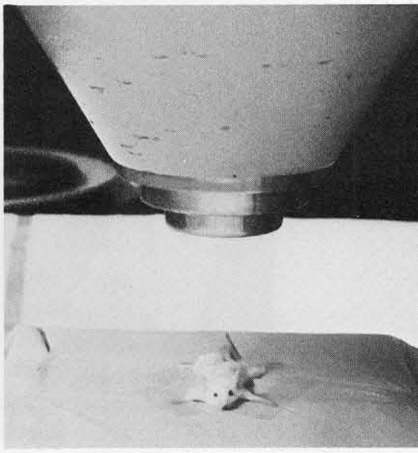
The most dramatic finding in this effort at code-breaking was the discovery by postdoctoral fellow Marcia Mauk that vesicles modifed with aminomannose sugars showed enormously enhanced survival times — lasting some 600 hours in the body versus 20 hours for plain vesicles. Such vesicles also showed considerable tissue specificity, tending to deposit first temporarily in the lungs, and finally accumulating in the liver and spleen. These findings were revealed by histological studies of the mouse tissue done by Raymond Teplitz of the City of Hope Medical Center, Duarte, California, and were confirmed by studies with isolated cells in culture by Caltech research fellow Po-Shun Wu.

This initial discovery of specificity, first reported in 1980, represents only the beginning of a long process of biological code-breaking, but it is already on the verge of being turned to medical use. Intrigued by the Caltech researchers' discovery — as well as by their ability to manufacture precisely and load vesicles with high levels of indium — three other City of Hope investigators — Cary Presant, MD, director of the division medical oncology; Richard Proffitt, assistant research scientist and the 1982 Fred Marik Research Fellow at the City of Hope; and radiological physicist Lawrence Williams — have begun to use the vesicles in diagnostic tests for cancerous tumors.

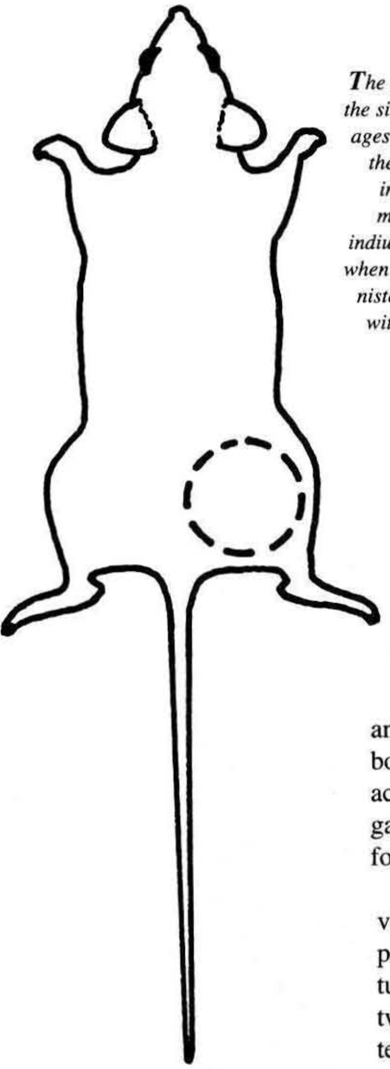
Beginning work in late 1980, the three performed detailed studies of the travels of aminomannose vesicles inside mice. Their basic approach has been to inject the vesicles into mice that have tumors implanted into their thighs. After being anesthetized, the mice are positioned beneath a device called a gamma camera, which can produce a picture revealing the distribution of gamma-emitting isotopes in the body. The camera consists of a 10-inch-diameter sodium iodide crystal, within which a flash of light is produced by each emitted gamma ray. The flashes are detected by an array of photomultiplier tubes, and the resulting signals are interpreted by a computer, which can create an image from the data.

These City of Hope scientists quickly discovered they could obtain excellent images using the vesicles. First of all, indium was already employed as a useful isotope for diagnostic work; its double gamma ray emission yielded good images,

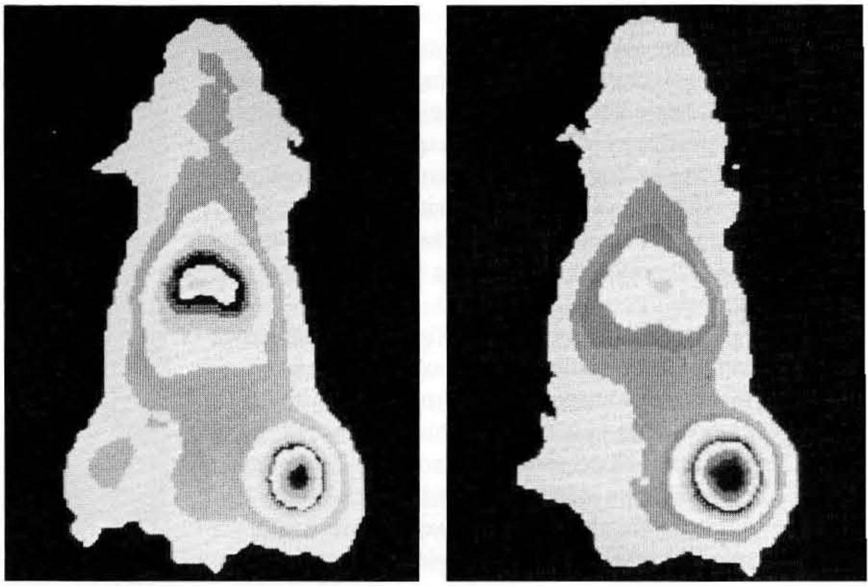




The gamma camera used in diagnostic radiology focuses on a very small patient. The mouse is anesthetized, and feels neither pain nor fright.



The drawing shows a mouse approximately the size of the one in the gamma camera images at the right, the broken line indicating the location of the implanted tumors. The image at the immediate right is that of a mouse injected with vesicles loaded with indium^{111}. At far right is the image obtained when the indium-loaded vesicles were administered after blocking the liver and spleen with vesicles packed with aminomannose.



and it was a substance that tended to linger in body tissues. Second the high loading levels achieved by Baldeschwieler and his colleagues gave the medical researchers the maximum bang for the vesicle.

In early experiments, the gamma camera revealed that the aminomannose vesicles did lodge preferentially in the liver and spleen but not in the tumor. This was an expected result because the two organs are among the sites of the body's protective reticuloendothelial system, which removes such foreign bodies. Most promising, however, was the discovery that a significant fraction of other types of vesicles also lodged in the implanted tumors. Although the scientists have some preliminary theories about why this happens, the phenomenon is not well understood. Dr. Proffitt hypothesizes an altered vascular permeability near tumors — that is, the way materials diffuse through blood vessels may contribute to the tumor's ability to concentrate vesicles.

In their next series of experiments, the City of Hope scientists, working with Caltech research fellows Joseph Uliana and George Tin, tried injecting vesicles of varying sizes and surface charges, in an attempt to enhance the tumor uptake over that of the liver and spleen. The results, while promising, were not outstanding, since the researchers were able to achieve uptake by tumors only about equal to that of liver and spleen.

But then, last fall, came an important new success. Reasoning that they might be able to first saturate the liver and spleen, the City of Hope scientists injected mice with "cold" vesicles modified with aminomannose, that is, vesicles with no indium. After waiting an hour, they then injected other types of vesicles loaded with indium. The results were remarkable; the gamma camera revealed that they had achieved tumor indium levels more than two times higher than liver and spleen levels, measured on a per gram tissue basis. The scans showed the tumor as an intense blotch, while the liver and spleen were only faintly visible.

What's more, the method was able to detect tumors smaller than 100 milligrams. This is potentially better resolution than diagnostic techniques that are now employed. For this reason, the medical researchers believe the technique may eventually aid in the solution of one of the major problems in cancer treatment — the need to detect tumors while they are still extremely small.

Presant, Proffitt, and Williams plan further studies aimed at eventual clinical use of the "blocking and tackling" diagnostic technique, and they suspect that they can improve dosages and timing of vesicle injections to achieve even higher specificities. They are also developing early strategies to use the vesicles to deliver anti-cancer drugs to tumors. For example, says Proffitt, many anticancer drugs are soluble in organic solvents, and such substances might be incorporated right into the phospholipid walls of vesicles, where they would be protected from inactivation until the vesicle delivers its contents within the tumor.

Clearly, it may be some time before patients can be treated with guided-missile vesicles to deliver drugs or diagnostic chemicals to body targets. But just as clearly, understanding these tiny man-made bubbles has come a long way since John Baldeschwieler first began wondering how to apply his arcane technique with the jawbreaking name of Perturbed Angular Correlation spectroscopy. □

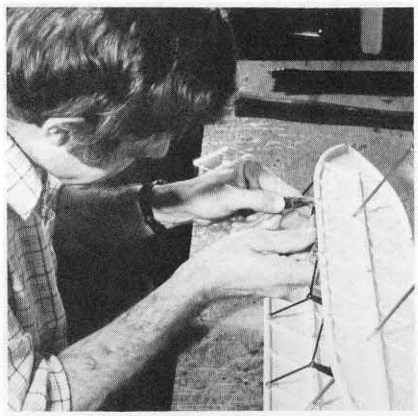
The Wright Way to Fly

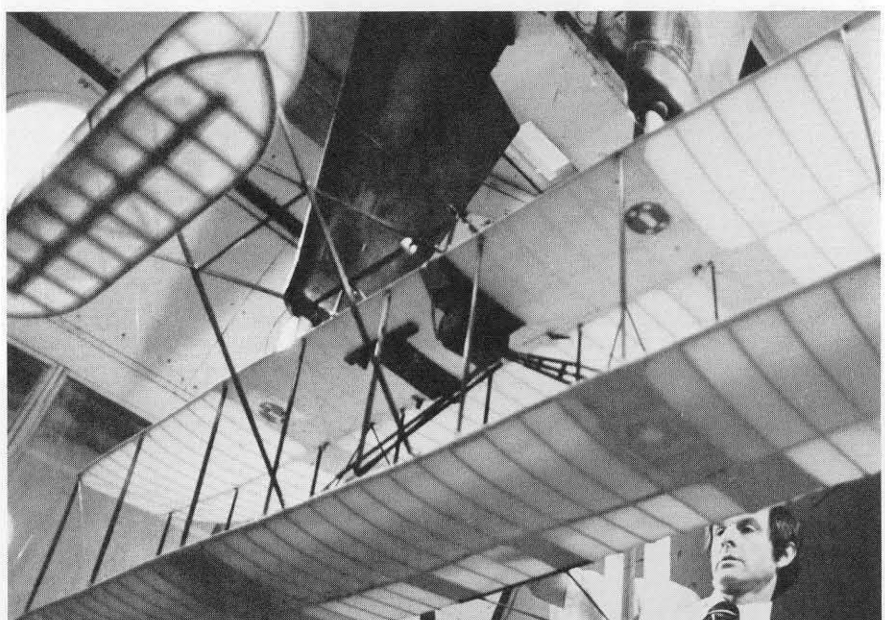
THE Wright brothers' 1903 success, which launched the aviation age, derived largely from their careful attention to the experimental, as well as the theoretical, details of aircraft control. And it was in part their own great desire to fly that inspired Orville and Wilbur Wright to such care. Flying it yourself is an extra incentive to doing it right.

Sometime in the summer of 1983 Fred Culick, professor of applied physics and jet propulsion, will take off in a replica of the 1903 Wright "Flyer," built by the Los Angeles section of the American Institute of Aeronautics and Astronautics. It too, we can be sure, will be done right.

Culick is a private pilot and has long been interested in the history of aircraft, in addition to his research in fluid mechanics, solid propellant rocketry, lasers, and applied aerodynamics. And he's an active member of the AIAA. A group of Los Angeles members conceived the Wright Flyer project in 1978 to replace its replica built in 1953 for the 50th anniversary of the historic flight at Kitty Hawk. That one was destroyed in the 1978 fire at the San Diego Aerospace Museum. (The original 1903 plane, after flying a total of 98 seconds in its career, now resides at the Smithsonian Institution.) With the insurance from the fire, the local section of AIAA decided to try again. But this time it would go itself one better and make not only an exact replica, but one that would really fly. Besides being a lot of fun, the project would demand a thorough study of the aerodynamic principles and engineering innovations the Wrights worked out and promote a truer appreciation of the scale of their achievement.

Along with a hands-on experience of their genius, the project has already stimulated respect for the Wright brothers' nerves. Although the 1903 Flyer repre-





Fred Culick assembles the canard (above, left) and a wing (right) of a 1/6-scale model of the Wright brothers' "Flyer." In the lower picture he readies the finished model for tests in Caltech's 10-foot wind tunnel.

sented the peak of aeronautic technology at that time (and not paralleled by anyone else for several years thereafter), flying it was still an exceedingly dangerous thing to do. This was dramatically demonstrated by Culick's 1/6-scale model, which he tested in the GALCIT 10-foot wind tunnel in December 1979, in the project's early stages. Culick built the model himself with some help from Caltech's machine shop and a small grant from NASA. The model was very similar to the original plane, constructed of spruce and plywood, covered with doped fabric, and with external structural members of aluminum and steel. The propellers were driven by a 1/25 horsepower electric motor.

Wind tunnel data, the first such data obtained on the original Flyer, convinced Culick that "there is no possibility of making that configuration fly as a stable machine." And since Culick and the other pilots have little desire to risk their necks to re-experience *all* the aspects of the Wright brothers' achievement, the replica will have some subtle modifications and "design assistance" from subsequent aeronautic knowledge. The challenge will be to make it stable with as minimal (and invisible) changes as possible. The modern emphasis on safety won't detract from the triumph of the first man-carrying, powered flight on December 17, 1903, and the years of scientific research that led up to it.

Culick's own interest in the Wright brothers was aroused when he saw the AIAA's first replica in the San Diego Museum not long before the fire. He began to wonder just why they built it the way they did, and he is now considered an authority on their work and on early aeronautics generally. His study of their letters and diaries has firmly discredited the myth that Orville and Wilbur Wright were simple bicycle mechanics who just happened onto inventing the airplane. They were serious scientists, theorists as well as experimenters, who were years ahead of anyone else in aeronautics.

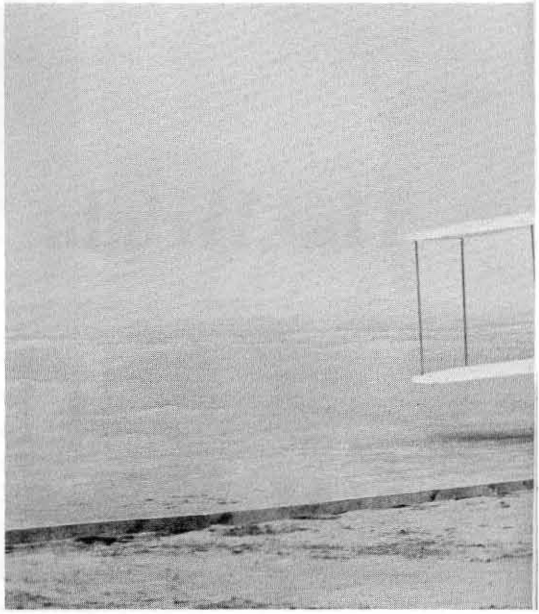
They began experimenting in earnest in 1899, working out their ideas first in gliders flown free and restrained as kites on the North Carolina coast, where winds were favorable at the time of year they could get away from their Dayton, Ohio, shop. The Wright brothers were well acquainted with the prevailing theories of the time; their own research, however — measurement of lift and drag with their gliders and in their own wind tunnel — led them to reject a number of these theories and to embark on some radically different innovations. For example, they did not accept as final the then popular solution of dihedral (wing tips slanted upward) to the problem of lateral stability. Wilbur Wright's observations of buzzards who regained their balance in flight by a torsion of their wing tips led to the invention of wing warping used in all their gliders and in the 1903 Flyer. The predecessor of ailerons in modern aircraft, wing warping not only enabled the Wrights to stabilize the plane in a straight path but also to turn it. They controlled the flexing of the wings, which actually drooped downward rather than upward, by wires attached to a hip cradle (to leave the pilot's hands free).

Previously the tail had been considered the means of steering a plane, like the rudder of a boat. But a plane turns by rotating around its longitudinal axis, which the Wrights accomplished by wing warping. The Flyer's double vertical tail moved only when the wings were flexed, and its true function was its contribution to control of yawing motions about the aircraft's vertical axis.

The oddest feature of the 1903 airplane, and one that ultimately did not survive, was the forward horizontal surface called a canard. This configuration contributed to longitudinal stability, and, although it later proved to work better aft of the wing, the forward position enabled the pilot to see it in the event something went wrong — a decided advantage in 1903. Previous fatal accidents with a rear horizontal surface were a persuasive argument for the front position.

The Wrights designed and built their own 15-horsepower engine, since none could be obtained to their specifications from commercial sources. They also had to design and build their propellers and in the process developed the basis of modern propeller theory, which is credited to others since they never published their work. In this, as in all stages of the Flyer, the Wrights were a complete research, development, and manufacturing team in themselves.

The 50 or so volunteers (Culick was one of the first) in the modern Flyer project are a somewhat larger team but are also learning by doing every step themselves. They are divided into teams for the various technical tasks — aerodynamics and control, propulsion, construction, structures, and testing. In addition to being the first pilot, Culick is also the chief project engineer and coordinates all the technical work. Howard Marx of

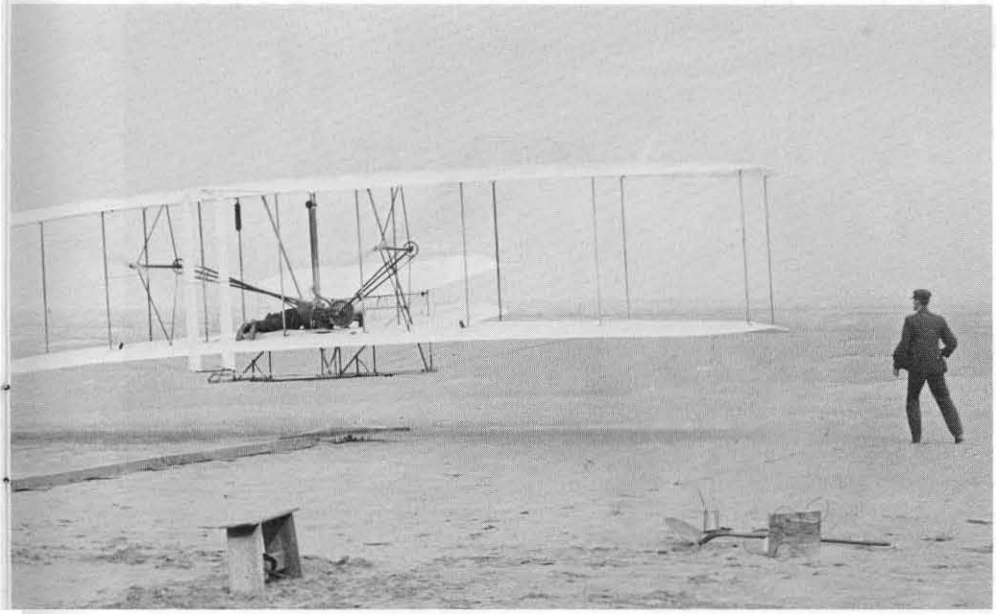


Northrop Corporation originated the whole Flyer idea and was the first project manager, a position now held by Jack Cherne of TRW Inc. Roger Schaufele (MS '52) of McDonnell Douglas Corporation, chairman of the program's advisory board, is one of several Caltech graduates involved.

Bits and pieces of the plane have been built in members' living rooms and garages over the past year, and it is now being assembled in a corner of a Northrop factory in Los Angeles, to be finished by early summer. Actually, two full-size replicas of the Wright plane will be made; the first one, which will be an exact copy externally, will not fly but will be tested in a full-scale wind tunnel. The results will be compared with the analysis of data from the 1/6-scale model. Only the functioning Flyer will need modifications for safety, stability, and structural soundness.

Some of the aerodynamic modifications are ones the Wrights themselves employed in later planes. For example, the canard, the front horizontal surface, will be slightly larger and a bit farther forward. The most important change will be in the shape of the wing section. The airfoil of the 1903 plane was highly cambered, even though the camber had already been reduced from that of earlier wings after the Wrights' discovery in testing that too much curve in the airfoil caused the aircraft to pitch. The replica's wings will have the camber cut down still further, and the trailing edge will turn up slightly, making a much more stable configuration.

A 35-horsepower "Revmaster" engine (a Volkswagen engine modified for air-



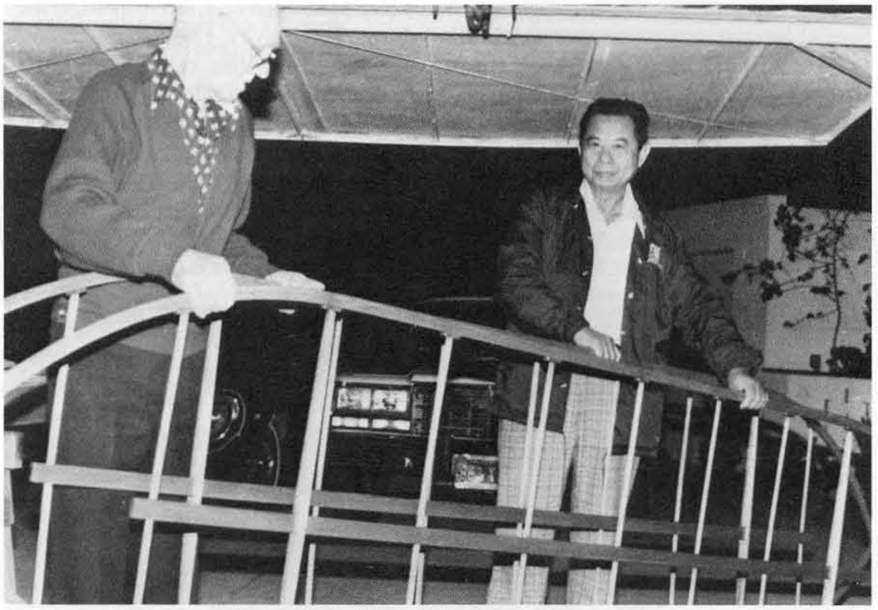
***A**t the left, with Orville Wright as pilot and Wilbur running alongside, the Flyer makes one of four flights on December 17, 1903. The flight covered 120 feet at an average speed of 7 miles per hour over the ground.*

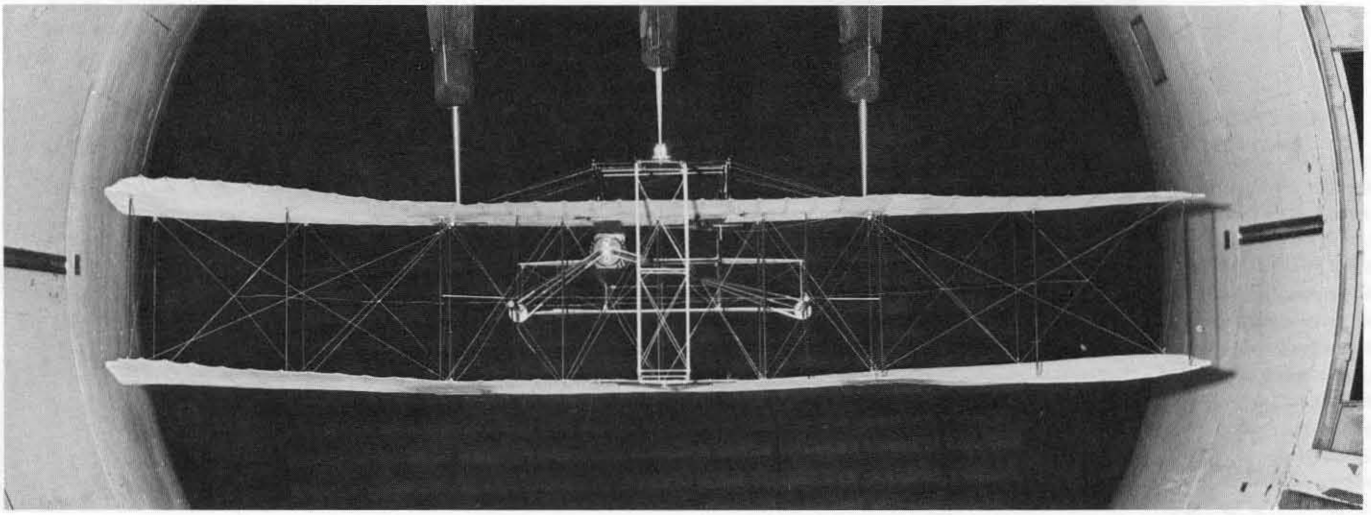
***B**elow, Harlan "Bud" Gurney (left), a veteran of barnstorming days with Lindbergh in the 1920s and now a retired United Airlines pilot, heads construction of the full-size Flyer replica. Here he holds the finished canard framework with Koonwah Lim, retired from McDonnell Douglas.*

***B**ottom, an aft view of the 1/6-scale model in the wind tunnel illustrates wing warping, invented by the Wrights to turn the plane. A system of wires flexes the outer trailing edges of the wings upward on the left and downward on the right.*

craft) will power the modern Flyer, and wing warping will be controlled with a stick instead of a hip cradle. Design engineers are creating a welded steel tube structure to protect the pilot in hard landings; the plane may or may not have a supplementary wheeled landing gear added. Fittings for struts and skids will be designed to improve structural integrity, and more durable synthetic fabric will replace the original cotton.

But when Culick takes off in the reincarnated Flyer, these changes will be invisible to all but the most knowledgeable. The flight will be the culmination of the five-year undertaking, and the large crew of workers on the project (not least the pilot) will be eager to see if the replica works. But the real accomplishment lies in the re-creation itself — the actual documentation of a piece of technical history. □ *-J.D.*





Research in Progress

Space Available

FOR $10,000 you can rent five cubic feet on the Space Shuttle for a few days. That may seem like pretty cramped and expensive travel accommodations, but it's a bargain at the price. NASA has made the small self-contained payload canisters, called Getaway Specials, available to anyone with a legitimate research purpose, and a group of Caltech students has been quick to seize the opportunity. They are packing two experiments into a Getaway Special that will investigate growth of seeds and crystals away from the effects of the earth's gravity.

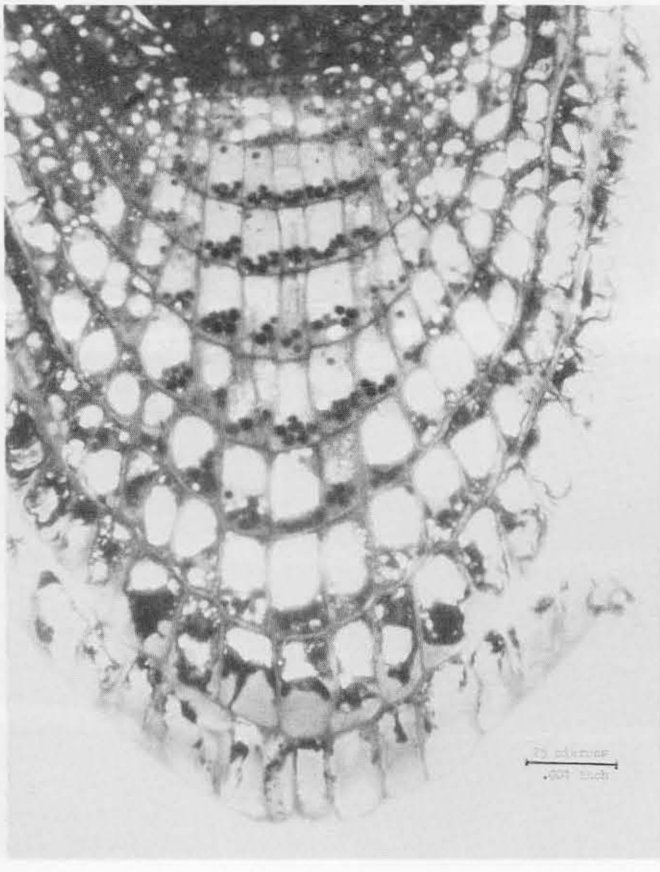
These two experiments emerged from 10 proposals developed over the summer of 1980 by the Student Space Organization (SSO). The organization had been formed the previous winter by Ralph Weeks (BS 1981) and John Whitehead, now a senior in engineering, to manage the space research project from start to finish. It has involved a group of about 15 students, whose ranks shift somewhat every June. Kirk Haselton, a sophomore in applied physics, is currently the project manager.

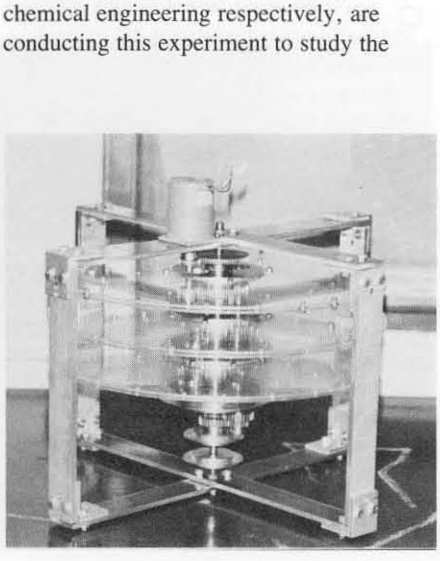
Whitehead originated the biology experiment to explore the mechanisms by which plants perceive and respond to the direction of gravity. One hypothesis holds that dense organelles, called amyloplasts, settle to the bottom of root tip cells and lead to downward growth. To test this hypothesis and to determine the threshold of geotropism, the SSO students are sending radish seeds (because they grow very fast) on a journey into zero gravity, where they can germinate under very low artificial gravitation conditions.

The seedlings will be mounted in small depressions drilled into five Lexan disks, which will rotate at different speeds. Since acceleration is greater at the rim than at the hub of a disk, the seeds will be mounted at four radii across each disk, thus subjecting them to acceleration forces representing 20 data points between 10^{-4} g near the hub of the slowest disk to $10^{-1.5}$ g at the rim of the fastest one. When the Shuttle reaches orbit, a motor will start the disks rotating, and water will be injected to soak the seeds and germinate them. After 30 and 60 hours, a fixative solution will halt seed growth until recovery of the canister.

Then begins the laboratory work, using electron microscopy to determine the position of the amyloplasts within the cells and to observe whether they started to settle at the same stimulus level at which the roots began to grow downward. The student research team is expecting to find that these events do happen at the same time — at about 10^{-3} g.

The crystal in the second experiment will have a four- to five-day growing period. Darrell Schlom and Connie Bennit, sophomores in engineering and chemical engineering respectively, are conducting this experiment to study the





An electron micrograph (right) shows that amyloplasts (the small, round, dark spots) have settled to the bottom of cells near the middle of this radish root tip grown in normal gravity. The student space experiment will test the hypothesis that this settling determines downward growth. The radish seeds will journey into space mounted on rotating disks similar to those in the prototype apparatus shown at far right.

During a visit to Caltech, John L. Robbins (left) and Roger Vernon (right) of Great Western Inorganics (which is sponsoring the Getaway Special) discuss materials to be used in the seed growth experiment with students John Whitehead and Darrell Schlom.

mechanisms of crystallization; Paul Shlichta of the JPL technical staff is principal adviser.

In the presence of gravity a growing crystal creates a convection current in the surrounding fluid, which affects the way it grows. Other crystallization research already performed on Skylab and in simulation experiments indicates that the space-grown crystals develop more slowly than earth-grown ones but possibly are of more uniform composition with more regular defect structure. The student experiment will take photographs of the crystal as it grows and will collect more quantitative data than have previous experiments. This will allow testing of various theories of how crystals grow by molecular diffusion in the absence of gravity.

Candidates for the most appropriate crystal material are currently under consideration; so far, potassium dihydrogen phosphate (KDP) appears the most likely. Warm, saturated solution will be introduced into the chamber containing the crystal, and it will then be cooled, causing the crystal to grow.

Thermal control is going to be one of the more challenging engineering problems of the project, since temperature is crucial, but different, for each experiment, and each chamber must be insulated and controlled separately. Teams of two or three students are attacking specific problems that are common to both experiments and must be coordinated, since the size and weight constraints of the canister (less than 200 lbs.) dictate a minimum of equipment. For example, the battery power source and digitally controlled data storage system are being designed as single units for both experiments. Also, the experimental apparatus must be strong enough (although very light) to survive the vibrations of the Shuttle's launch, so the students must devise some high-technology solutions to the various mechanical design questions.

Like any other research project, this one can't run on enthusiasm alone, and the students of the SSO have been exposed to all the realities of program management, including funding. Great Western Inorganics of Golden, Colorado, has provided the $10,000 for the Getaway Special ticket and has offered to supply any necessary chemicals. Other firms, including Hughes Aircraft Company, TRW Inc., Xerox Electro-Optical Systems, and Northrop Corporation have supplied some funds, and still others have donated equipment, from bubble memory systems (Intel Corporation) and computer chips (National Semiconductor Company) to temperature sensors (Omega Engineering). The biggest funding problem is student support over the summer, when the major portion of the work is performed, since it is impossible to devote full time to it during the academic year.

Most of the remaining work will have to be done this coming summer. If all goes well, the radish seeds and the seed crystal, with all the carefully designed controlling apparatus of the experiments, will be launched into microgravity on the Space Shuttle's seventh flight, now planned for April 1983. □ *–J.D.*

Middle Stages

ALTHOUGH catalysts perform the important function of speeding up chemical reactions, many of them commercially significant, most catalysts have been discovered by chance. As long as they worked and managed to generate appropriate quantities of the desired product, understanding the catalytic process (which promised to be an obstinate problem) didn't seem necessary. But recently, the urgency of developing new sources of energy and increasing industrial production has aroused a growing interest in catalysis. Chemists are trying to look into the transitory steps of the catalytic mechanism and determine what actually happens on a molecular level — how the bonds between atoms are broken and the fragments reconnected in another way. Caltech's Catalysis Group is approaching the problem from a number of different angles.

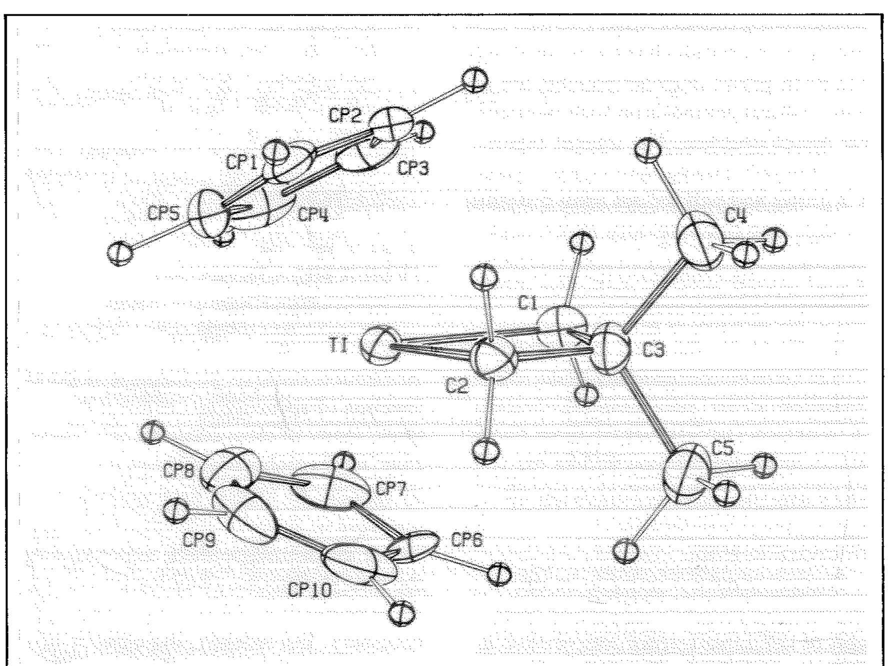
One of the group, Robert Grubbs, professor of chemistry, is studying the intermediate products of catalysis — the compounds that are formed very briefly by the catalyst and the reactants before the end product of the reaction is reached. One requirement of a catalyst, however, is that it remain chemically unchanged; that is, it cannot be consumed in the overall process. Therefore any reactions of the catalyst itself must be reversible, so that it can return to its original form. By their very nature, then, these intermediate products are extremely unstable; they must be stable enough to be produced but unstable enough to react further. In fact, according to Grubbs, if you can actually isolate a product and see it, then in most cases it's probably too stable to be part of the catalytic scheme. How can you go about identifying something that exists too briefly to be observed?

Grubbs starts out by establishing, as models, all the potential mechanisms for the molecular transformation. Then his task is to determine which one of all the possibilities actually takes place — a frustrating problem because the true mechanism cannot actually be proved. Rather, all the others must be disproved. And before you can begin to do that, you have to devise experiments to tell the different models apart.

For example, in their current work on the polymerization reaction (in which small units are linked together in long chains), Grubbs and his group, including graduate students Jorge Soto and Michael Steigerwald, have generated a large family of possibilities. They have been able to eliminate one sizable section of these and are now concentrating on narrowing the field still further. One way of doing this is to exploit the differences between reactions. For instance, in the remaining group, one set of possible polymerization mechanisms involves hydrogen migration in the intermediate steps, and a small but significant set does not. Current experiments (measuring isotope effects in the polymerization of ethylene) to distinguish whether hydrogen migration actually does take place in the true catalytic reaction seem to indicate that it does not, allowing Grubbs to zero in another step closer to his target.

One of his goals has already been reached — isolation of an intermediate in the olefin metathesis reaction, one of the most important processes in organometallic chemistry, which, with the assistance of a transition metal as a catalyst, interconverts olefins. This process is now a key step in the production of detergent and perfume intermediates as well as a new class of plastics. Olefins are hydrocarbons with one carbon-carbon double bond, which is cleaved and reformed in the catalytic reaction. For example, propylene, a C_3 olefin, is converted to ethylene, a C_2 olefin, and 2-butene, a C_4 olefin. Going through all the steps (over several years) of narrowing down the modeled possibilities of all the mechanisms, Grubbs last year isolated and defined the structure of one of the proposed intermediates in a carefully selected (not a model) catalytic system. He found that the olefin metathesis reaction has two intermediates that interconvert. He has demonstrated that his intermediate, in which titanium links up three carbon fragments in an unusual arrangement of atoms, does proceed through the steps of bond breaking and reformation necessary to the catalytic reaction. Working with Grubbs on this project were graduate students Kevin Ott, John BOSCO Lee, Dan Straus, and Suzzy Ho.

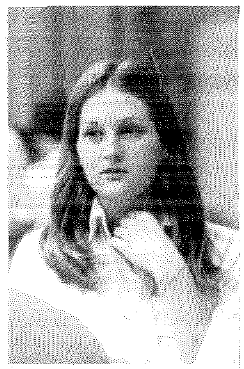
Another current project concerns developing a catalytic scheme to convert carbon monoxide from coal into useful organic materials. Graduate students Ken Doxsee and Tom Coolbaugh are involved in this project. And, as it has always been with catalysis, Grubbs finds that balancing all the intermediate equilibria still involves a considerable amount of luck. □
–J.D.



This computer drawing illustrates the structure of an intermediate, isolated by Robert Grubbs, in a titanium catalyzed olefin metathesis reaction. The key structural feature is the four-membered ring at right defined by the titanium atom (TI) and the carbon atoms, C1, C3, and C2.

The 1982 Student-Faculty Conference

by Sue VandeWoude



Sue VandeWoude is a senior in chemistry who was elected ASCIT president last fall. It was under her leadership that the conference was planned. At the right, attentive participants evaluate a statement by David Sundelson, Mellon postdoctoral instructor in literature.

THE 1982 Student-Faculty Conference was held at JPL on February 19, an Institute academic holiday. Approximately 125 students and faculty attended, among whom were Caltech President with Mrs. Marvin Goldberger, Provost Jack Roberts, several division and faculty committee chairmen, Interhouse Committee officers, and a number of students of the California Institute of Technology. All were gathered to discuss "Improving the Quality of Undergraduate Education at Caltech."

Dr. Arden Albee, chief scientist at JPL, welcomed the group, and Dr. David Wales, dean of students, began the meeting by introducing members of the Core Courses and Curriculum panel, who led off the presentations of the day. Humanities and Social Sciences, and Feedback, Advisers, and TAs were the other two panel topics discussed during the morning session. Each panel of faculty and students gave a 30-minute presentation of its topic, which was followed by another 30 minutes of open discussion. Freshman labs and chemistry, sophomore math, and freshman humanities were mentioned as courses needing reorganization; the need for an introductory computer-programming class and a wider variety of humanities courses was cited; improvements in the Teaching Quality Feedback Report, and ombudsmen and upperclass advising systems were suggested. Comments were enlightening, inspiring, entertaining, and debatable, but the overall attitude that prevailed seemed to be one of cooperation.

Chairman of the afternoon session was Dr. Jim Morgan, vice president for student affairs. Presentations and discussion centered on the honor system, student body size, and undergraduate research. Of particular concern was the need to educate grad students and new faculty about the honor system, and evaluation of student usage of master keys, expansion of student housing, and endowment of the Summer Undergraduate Research Fellowship (SURF) program.

As expected, the tone and topics of the conference were quite different from the Faculty-Student Conference of 1980. There were several reasons for this. At the last conference, faculty became aware of the major problems with undergraduate education at Caltech. Since the first conference, many improvements have been made in student-related interests. People at Caltech are more aware of the problems students and faculty face, and concentration on improvement of weak spots in undergraduate education has continued.

The panel format also differed from the conference two years ago, and helped bring faculty and students together before the conference in order to prepare their presentations. The organization of the conference also involved both students and faculty members. ASCIT members, the Caltech Y, the coordinator of student activities, the deans, and the vice president for student affairs as well as the chairman of the faculty — all helped to coordinate various aspects of the meeting.

In the past two years, interaction between faculty and students seems to have improved tremendously. In general, faculty seem more responsive and attentive while students seem more willing to communicate. This was evidenced by the praise students gave to options with improved teaching and feedback methods, and the faculty's agreement with many student-proposed suggestions.

Ed Lambert, vice president of ASCIT, gave closing remarks on behalf of the students. He stressed the importance of communication in improving Caltech education. Dr. Morgan also offered a summary of the day's events, emphasizing that a discussion is a starting point for action.

The conference was extremely worthwhile. It was an educational, informal discussion between student and faculty leaders, which is probably the most effective device to implement useful changes in undergrad education. The deans, a student from each panel, and Dr. Fred Anson, chairman of the faculty, met one week after the conference to delegate recommendations arising from the conference to appropriate committees for action. The effect of the conference is already being felt in several areas; freshman chemistry is to be restructured next year, and endowment of the SURF program is being seriously discussed.

Faculty and students at Caltech should continue to take advantage of the opportunity to have regular conferences to avoid the "education gap" that exists between these groups at many prestigious institutions. The conferences will take a commitment on the part of both, but are well worth the effort. Indeed, these meetings can continue to assess and improve the quality of undergraduate education at Caltech for future generations of Caltech students. □

Books—by, about, or of interest to Caltech people

MOLECULAR ELECTRONIC STRUCTURES
An Introduction
by C. J. Ballhausen and Harry B. Gray

The Benjamin/Cummings Publishing Company, Inc. $14.00

An introduction to molecular electronic structural theory, this book is aimed at students who have reasonable familiarity with differential and integral calculus and are beginning a study of the physical description of chemical systems. It concentrates on the description of ground state electronic structures, that is, the principles of chemical bonding in molecules. Suggested reading and problems are included in each chapter. C. J. Ballhausen is professor of chemistry at the University of Copenhagen. Harry Gray is Beckman Professor of Chemistry and chairman of the division of chemistry and chemical engineering at Caltech. The book was largely written during the six-month period when Ballhausen was a Sherman Fairchild Scholar at the Institute.

FREUD'S UNFINISHED JOURNEY
Conventional and Critical Perspectives in Psychoanalytic Theory
by Louis Breger

Routledge and Kegan Paul $15.00

A critical examination of psychoanalytic theory, this book attempts to clarify major conflicts within psychoanalysis and between various analytic and neoanalytic schools. Louis Breger, who is associate professor of psychology at Caltech, holds that Freud began with a 19th-century world view that was masculine, committed to scientific objectivity, and politically and socially conventional. The development of psychoanalysis involved the creation of a new socially critical world view that is both masculine and feminine and that values intuition and the unconscious along with objectivity. This transition from the old to the new perspective is, however, incomplete. Psychoanalytic theory is best understood as a fluctuating mixture of assumptions and values — hence the "unfinished journey." This is Breger's fourth book on psychoanalytically related subjects, written not only for members of the mental health profession, but also for the layman who is interested in therapy, human development, and psychological theory.

ADVANCES IN SWITCHED-MODE POWER CONVERSION
by R. D. Middlebrook and Slobodan Ćuk

TESLAco. $45.00

This two-volume book, say the authors, constitutes an intermediate step along the way to a text. It is an assembly of papers that have been published by the Caltech Power Electronics Group, for the most part in conference proceedings. Since they were difficult to obtain in that form and since the discipline is an expanding one, the authors decided to publish the papers as a group and to add an introductory chapter, of a tutorial nature, that establishes the fundamental principles of switched-mode power conversion. Robert Middlebrook is professor and Slobodan Ćuk is assistant professor of electrical engineering at Caltech.

SIGNALS
The Telephone and Beyond
by John R. Pierce

W. H. Freeman and Company . . . $15.95
$7.95 paper

A slim volume that introduces us to the men who pioneered the telephone and traces the technological evolution of the network, this book also looks beyond technology, discussing the economics, government regulations, and legislation that will ultimately dictate the future of telephone communication. John Pierce is professor of engineering, emeritus, at Caltech and a three-degree (BS '33, MS '34, PhD '36) alumnus who had a distinguished career at Bell Laboratories before returning to his alma mater in 1971.

FOUNDATION ANALYSIS
by Ronald F. Scott

Prentice-Hall, Inc. $29.95

Design may be the most complicated process an engineer is called upon to perform, but in its conventional sense, it consists of guesses made in between parts of the analysis of an engineering problem. Exact analysis is often impossible, and the designer's ingenuity lies in the choice of an analytical method that most reasonably approximates real life but still permits a solution to be obtained. This process can always be aided by careful choice of simplified hand calculation at an early stage in the design operation. It is to this area that Ronald Scott, professor of civil engineering at Caltech, directs this book. He presents a number of hand or elementary computer calculation routines that have been useful to him in consulting practice and in teaching. The book is for practicing engineers and for educators and students of foundation engineering, for whom he offers problems and exercises with each chapter.

PREDICTION AND PROOF:
Theory and Observation in Astronomy
edited by James Cornell and Alan Lightman

The MIT Press. $17.50

This book is based on a series of public lectures sponsored by the Harvard-Smithsonian Center for Astrophysics and the Boston Museum of Science. Its contributors describe for the general reader the most recent advances in man's understanding of the cosmos and attempt to clarify the nature of the mutual interaction between theory and observation, concept and experiment, prediction and proof. Alan Lightman, Caltech MS '73 and PhD '74, is on the faculty at Harvard, where his work focuses on black holes and problems of gravitational collapse.

EARTHLIKE PLANETS
Surfaces of Mercury, Venus, Earth, Moon, Mars
by Bruce Murray, Michael C. Malin, and Ronald Greeley

W. H. Freeman and Company $14.95

Under the impact of close-up and direct observations of actual surface phenomena, all of our traditional explanations of the nature and history of the planets of the inner solar system are crumbling. Written for college undergraduates and other serious nonspecialists, this book tries to outline the intellectual revolution concerning these planets, especially their surface features, processes, and histories. The book is suggested for use as a supplementary text in college geology and astronomy courses and also for courses covering topics in physical geology, geomorphology, planetary astronomy, volcanology, and planetary science. General references are included at the end of each chapter for those who wish to explore further. Bruce Murray is professor of planetary science at Caltech and director of the Jet Propulsion Laboratory; Michael Malin and Ronald Greeley are both professors at Arizona State University.

GENES, CELLS, AND BEHAVIOR
A View of Biology Fifty Years Later
edited by Norman H. Horowitz and Edward Hutchings Jr.

W. H. Freeman and Company . . . $12.95

These 17 papers plus 5 introductory statements were originally presented in a symposium held at Caltech in November 1978 on the occasion of the 50th anniversary of the founding of the division of biology. All speakers at the symposium were alumni or former members of the division faculty, who had been invited to discuss their current research. In five sessions they covered Biology of Cancer; Phage; Evolution, Genes, and Molecules; Biology of Cells; and Neurons and Behavior. Norman Horowitz, professor of biology, was formerly chairman of that division. Edward Hutchings, lecturer in journalism, was for many years editor of *E&S*.

AQUATIC CHEMISTRY
An Introduction Emphasizing Chemical Equilibrium in Natural Waters
2nd Edition
by Werner Stumm and James J. Morgan

John Wiley and Sons $27.50

In the ten years since the first edition of *Aquatic Chemistry* was published, the field has grown and matured considerably in terms of data, unifying concepts, techniques and applications. A new edition, say the authors, is now in order, but their aim remains the same: to present a quantitative treatment of the variables that determine the composition of natural waters by drawing on basic chemical principles. Chemical equilibrium continues to be the central theme, but steady-state and dynamic models using mass-balance approaches and kinetic information have been given more attention. The book emphasizes a teaching approach and is designed to assist the reader in applying general principles and methodologies to systems of particular interest. Werner Stumm is a professor and head of the laboratory for water resources and water pollution control at the Swiss Federal Institute of Technology in Zurich. He was a Fairchild Distinguished Scholar at Caltech in 1977-78. James Morgan is professor of environmental engineering science and vice president for student affairs at Caltech.

FRONTIERS IN IMMUNOGENETICS
edited by William H. Hildemann

Elsevier/North Holland $45.00

An international symposium for immunogenetics was held in June of 1980 in honor of Ray D. Owen, Caltech professor of biology, on the occasion of his 65th birthday. This book contains the proceedings of that conference. The 16 articles by former students and colleagues are divided into four sections: Allogenic Polymorphism and Immunophylogeny; Genetics of Immune Responsiveness; Immunodifferentiation and Development; and Immunogenes and Disease. Hildemann is a Caltech alumnus (PhD '56) now at the UC School of Medicine, Center for Health Sciences, in Los Angeles.

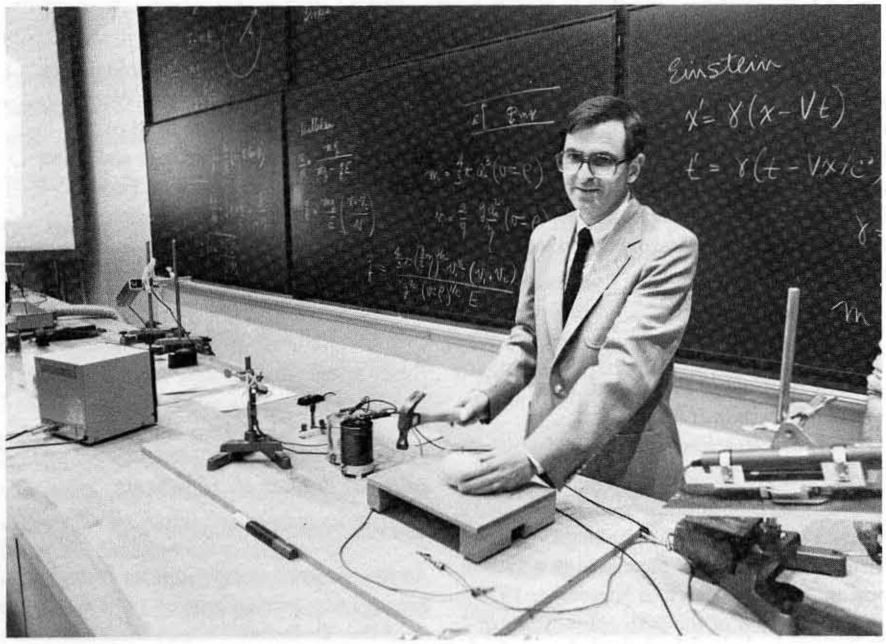
THE RISE OF ROBERT MILLIKAN
Portrait of a Life in American Science
by Robert H. Kargon

Cornell University Press $22.50

Robert Kargon, Willis K. Shepard Professor of the History of Science at The Johns Hopkins University, discusses Robert Millikan's character, achievements, and scientific style as a means of illuminating the changes that have taken place in science in this century. By describing Millikan in his roles as teacher, researcher, administrator, entrepreneur, and public figure, Kargon demonstrates how science grew in complexity and became an integral part of our culture. Millikan emerges in this account as a many-faceted and often controversial man and one with his own doubts and uncertainties. He also emerges as a major force in the development of American science. The book is slated for publication in May.

Random Walk

Sharing the Wealth



A top-notch teacher, physicist David Goodstein, with some of the tools of his trade.

CALTECH students — bright, probing, and wise in the ways of academe — are quite likely the most challenging gang of intellectual toughs any science teacher could ever face. Imagine, then, a teacher who could elicit such comments about his freshman physics course as: "Some of the lectures brought tears to my eyes. The rest were merely incredible." "Great lecturer: enthusiastic, clear, entertaining . . ." "Several students commented he was the best lecturer they ever had."

The object of this praise (gleaned from the student-published *Teaching Quality Feedback Report*) is David Goodstein, professor of physics and applied physics, who is considered by students and faculty alike as something of a natural resource — perhaps the pedagogical equivalent of the Alaskan North Slope oil fields.

Now Caltech seems about to share its wealth. Goodstein and his colleagues are now embarking on an ambitious effort to produce a physics telecourse that will combine the visual pizzazz of television with the academic rigor of high quality college-level teaching. The first section of the course is entitled "The Mechanical Universe," and in 26 half-hour programs Goodstein will cover the basics of classical mechanics, including such topics as the laws of motion and force. As a dividend, the group plans to put on a one-hour televison special for prime-time distribution. Producing the $2-million series will take about two years, and it is to be followed by courses entitled "The Electrical World" and "Relativity/Space and Time." Together the three projects will complete the sequence of an entire year of standard introductory college physics.

The high promise of "The Mechanical Universe" has already been recognized in educational circles; it was one of only six projects (of 227 submitted) recently awarded development funds from the Corporation for Public Broadcasting/Annenberg School of Communications. The Caltech telecourse received a grant of $1 million, contingent upon completion of a pilot program and the commitment of another $1 million in matching funds from other sources.

The series will be no mere succession of talking heads. Location shooting and special effects such as the computer graphics artistry of JPL's James Blinn, renowned for his stunning depictions of the Voyager planetary flybys, will be included. Blinn is already hard at work figuring out how to bring to animated life the basic equations governing classical mechanics, as well as scenes illustrating physical laws applied to such realms as space travel. There will also be discussions of how the laws of conservation of angular momentum help scientists understand hurricanes, fire storms, and the shape of galaxies and the solar system. Basic laws will be applied to space navigation, to black holes, and to understanding how sound can break a wine glass and why the Tacoma Narrows Bridge collapsed.

The lessons in physics will be interwoven with insights into the history and spirit of science. For example, Goodstein will host a guided tour through the laboratory notebooks of Robert A. Millikan, to reveal how data are treated — and sometimes mistreated — in science.

The course will have sound academic underpinnings, covering, for example, a solid introduction to the mathematics — including calculus — needed to understand classical mechanics. It will not be assumed, however, that students have had calculus beforehand.

Goodstein expects the telecourse to prove valuable to students and teachers in high schools, community colleges, universities, and companies with continuing education programs. Staffing the course are executive producer Sally Beaty of the Corporation for Community College Television; project manager Don Delson, producer Peter F. Buffa, and associate producer/writer Glenn Kammen. And Steven Frautschi, professor of theoretical physics, will be in charge of writing a textbook that Caltech's own students will be able to use.

The national advisory committee for the project includes famed movie producer and Caltech alumnus Frank Capra; the honorable Shirley Hufstedler, Caltech trustee and former Secretary of Education; Frank Oppenheimer, director of the Exploratorium in San Francisco and also an alumnus; and other prominent figures in science communication and education. □
– Dennis Meredith

The Thomas J. Watson, Sr., Laboratories of Applied Physics, newly completed and dedicated on May 5.

Ready to Go

THE DEDICATION of the newly completed Thomas J. Watson, Sr., Laboratories of Applied Physics took place on May 5 with Caltech President Marvin Goldberger presiding. Among the speakers were Stanton Avery, chairman of the Institute's board of trustees; Roy Gould, chairman of the division of engineering and applied science and Ramo Professor of Engineering; Simon Ramo, chairman of the engineering division's visiting committee and a trustee of the Institute; Lee DuBridge, Caltech's president emeritus; and Thomas J. Watson, Jr., also a trustee and a major donor for the building, which is named in honor of his father who was founder of IBM.

The first six Caltech faculty members to occupy Watson Labs will be Gould; Amnon Yariv, Myers Professor of Electrical Engineering and professor of applied physics; Noel Corngold and Thomas McGill, professors, and Paul Bellan, assistant professor of applied physics; and William Bridges, professor of electrical engineering and applied physics. They have begun the process of settling into their new labs for carrying on their research in applied physics, with emphasis on opto-electronics, electronic materials, and plasma physics. Eventually, two more research groups will be added. With supporting clerical and technical personnel, the total population of Watson Labs will probably be approximately 70 people.

Several sophisticated facilities will aid the researchers' work in applied physics. Among them are an ultra-high vacuum surface analysis instrument for the analysis of opto-electronic materials, picosecond pulse and tunable single-frequency dye lasers for studies of the interaction of light and materials, and two tokamaks for fusion energy research.

This building is quite different from most others on campus, being composed of four sections built around an inner open courtyard planted with trees and shrubs and featuring a garden pool and fountain. Three of the sections are two stories high, and the fourth is just one. What you see is what there is in this case — the building is unique among major structures on campus in having no basement, let alone a subbasement. Most of the space is devoted to labs and offices, but there are also two conference rooms and a classroom.

ALUMNI FLIGHTS ABROAD

This program of tours, originally planned for alumni of Harvard, Yale, Princeton, and M.I.T., is now open to alumni of California Institute of Technology as well as certain other distinguished colleges and universities. Begun in 1965 and now in its sixteenth year, it is designed for educated and intelligent travelers and planned for persons who might normally prefer to travel independently, visiting distant lands and regions where it is advantageous to travel as a group.

The program offers a wide choice of journeys to some of the most interesting and unusual parts of the world, including Japan and the Far East; Central Asia, from the Khyber Pass to the Taj Mahal and the Himalayas of Nepal; the surprising world of South India; the islands of the East, from Java and Sumatra to Borneo and Ceylon; the treasures of ancient Egypt, the world of antiquity in Greece and Asia Minor; East Africa and Islands of the Seychelles; New Guinea; the South Pacific; the Galapagos and South America; and more.

REALMS OF ANTIQUITY: A newly-expanded program of itineraries, ranging from 15 to 35 days, offers an even wider range of the archaeological treasures of classical antiquity in Greece, Asia Minor and the Aegean, as well as the ancient Greek cities on the island of Sicily, the ruins of Carthage and Roman cities of North Africa, and a comprehensive and authoritative survey of the civilization of ancient Egypt, along the Nile Valley from Cairo and Meidum as far as Abu Simbel near the border of the Sudan. This is one of the most complete and far-ranging programs ever offered to the civilizations and cities of the ancient world, including sites such as Aphrodisias, Didyma, Aspendos, Miletus and the Hittite citadel of Hattusas, as well as Athens, Troy, Mycenae, Pergamum, Crete and a host of other cities and islands of classical antiquity. The programs in Egypt offer an unusually comprehensive and perceptive view of the civilization of ancient Egypt and the antiquities of the Nile Valley, and include as well a visit to the collection of Egyptian antiquities in the British Museum in London, with the Rosetta Stone.

SOUTH AMERICA and THE GALAPAGOS: A choice of itineraries of from 12 to 29 days, including a cruise among the islands of the Galapagos, the jungle of the Amazon, the Nazca Lines and the desert of southern Peru, the ancient civilizations of the Andes from Machu Picchu to Tiahuanaco near Lake Titicaca, the great colonial cities of the conquistadores, the futuristic city of Brasilia, Iguassu Falls, the snow-capped peaks of the Andes and other sights of unusual interest.

EAST AFRICA—KENYA, TANZANIA AND THE SEYCHELLES: A distinctive program of 5 outstanding safaris, ranging in length from 16 to 32 days, to the great wilderness areas of Kenya and Tanzania and to the beautiful islands of the Seychelles. The safari programs are carefully planned and comprehensive and are led by experts on East African wildlife, offering an exceptional opportunity to see and photograph the wildlife of Africa.

THE SOUTH PACIFIC and NEW GUINEA: A primitive and beautiful land unfolds in the 22-day EXPEDITION TO NEW GUINEA, a rare glimpse into a vanishing world of Stone Age tribes and customs. Includes the famous Highlands of New Guinea, with Sing Sings and tribal cultures and customs, and an exploration of the remote tribal villages of the Sepik and Karawari Rivers and the vast Sepik Plain, as well as the North Coast at Madang and Wewak and the beautiful volcanic island of New Britain with the Baining Fire Dancers. To the south, the island continent of Australia and the islands of New Zealand are covered by the SOUTH PACIFIC, 28 days, unfolding a world of Maori villages, boiling geysers, fiords and snow-capped mountains, ski plane flights over glacier snows, jet boat rides, sheep ranches, penguins, the Australian "outback," historic convict settlements from the days of Charles Dickens, and the Great Barrier Reef. Optional visits can also be made to other islands of the southern Pacific, such as Fiji and Tahiti.

CENTRAL ASIA and THE HIMALAYAS: An expanded program of three itineraries, from 24 to 29 days, explores north and central India and the romantic world of the Moghul Empire, the interesting and surprising world of south India, the remote mountain kingdom of Nepal, and the untamed Northwest Frontier at Peshawar and the Punjab in Pakistan. Includes the Khyber Pass, towering Moghul forts, intricately sculptured temples, lavish palaces, historic gardens, the teeming banks of the Ganges, holy cities and picturesque villages, and the splendor of the Taj Mahal, as well as tropical lagoons and canals, ancient Portuguese churches, the snow-capped peaks of the Himalayas along the roof of the world, and hotels which once were palaces of maharajas.

THE FAR EAST: Itineraries which offer a penetrating insight into the lands and islands of the East. THE ORIENT, 30 days, surveys the treasures of ancient and modern Japan, with Kyoto, Nara, Ise-Shima, Kamakura, Nikko, the Fuji-Hakone National Park, and Tokyo. Also included are the important cities of Southeast Asia, from Singapore and Hong Kong to the temples of Bangkok and the island of Bali. A different and unusual perspective is offered in BEYOND THE JAVA SEA, 34 days, a journey through the tropics of the Far East from Manila and the island fortress of Corregidor to headhunter villages in the jungle of Borneo, the ancient civilizations of Ceylon, Batak tribal villages in Sumatra, the tropical island of Penang, and ancient temples in Java and Bali.

Prices range from $2,350 to $4,500 from U.S. points of departure. Air travel is on regularly scheduled flights of major airlines, utilizing reduced fares which save up to $600.00 and more over normal fares. Fully descriptive brochures are available, giving itineraries in detail and listing departure dates, hotels, individual tour rates and other information. For full details contact:

ALUMNI FLIGHTS ABROAD
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