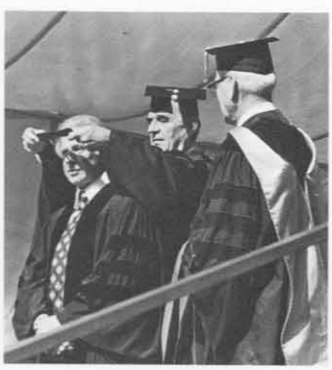
Engineering & Science

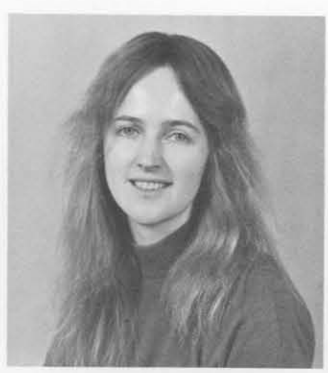
California Institute of Technology | November-December 1978

In This Issue

A New Era Begins
On the cover—Marvin L. Goldberger, newly installed president of the California Institute of Technology, delivers his inaugural address. The inauguration was a gala occasion that included more than 5,000 guests assembling on a sunlit Beckman Mall on the morning of October 27. And there were other—though smaller—festivities before and after as well. "Caltech: Harnessing Science and Technology with Wisdom," which begins on page 7, is Goldberger's statement about some of his hopes and plans for Caltech's future. More pictures of the participants and the parties appear on pages 2 to 6.



Rodman W. Pepys
When *E&S* learned last summer that a contingent of Caltech trustees and faculty would be accompanying President Marvin Goldberger on a trip to China, we knew we wanted to publish a story of the trip. It was our good fortune that Rodman W. Paul, Edward S. Harkness Professor of History and acting chairman of the division of the humanities and social sciences, was to be a member of that group—and that he was willing to keep a diary for the duration. Paul has a number of qualifications for telling such a story. One is that he is a prolific and distinguished writer of history, although his special field is not the Orient but the American West. But neither he nor we could have predicted that diary-keeping would prove so fascinating that it would turn into a two-part article. "Caltech Goes to China: Entries from a Diary" on page 24 is Part I; Part II is slated to appear in an early issue.



Looking Up
Even though Gillian Knapp started life in Liverpool, England, she considers herself a Scot. She was reared in Edinburgh and took her BS in physics at the university there in 1966. Then she came to the United States to study astronomy at the University of Maryland—a school she chose partly because of its proximity to this nation's capital. She was awarded her PhD in astronomy in 1971.

Optical astronomy had been an interest of Knapp's since she was a child, but she found that, on the eastern seaboard, viewing was something between not particularly good and impossible. She was, however, able to turn to radio astronomy and extra-galactic research, and she has found it a very happy substitute.

After a short stint of teaching at Maryland, while her husband finished work for his degree. Knapp took a job as a research fellow at Caltech in 1974. In 1976 she was promoted to senior research fellow and made a staff member of the Owens Valley Radio Observatory. Now she spends a quarter to a third of her time at Owens Valley and puts in an occasional session at Palomar. Between the two, she considers herself privileged to work with the best equipment in the world. Last May Knapp gave a Watson Lecture about some of that work. "Interstellar Molecules" on page 16 is adapted from that talk.

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Photographer—Richard Kee

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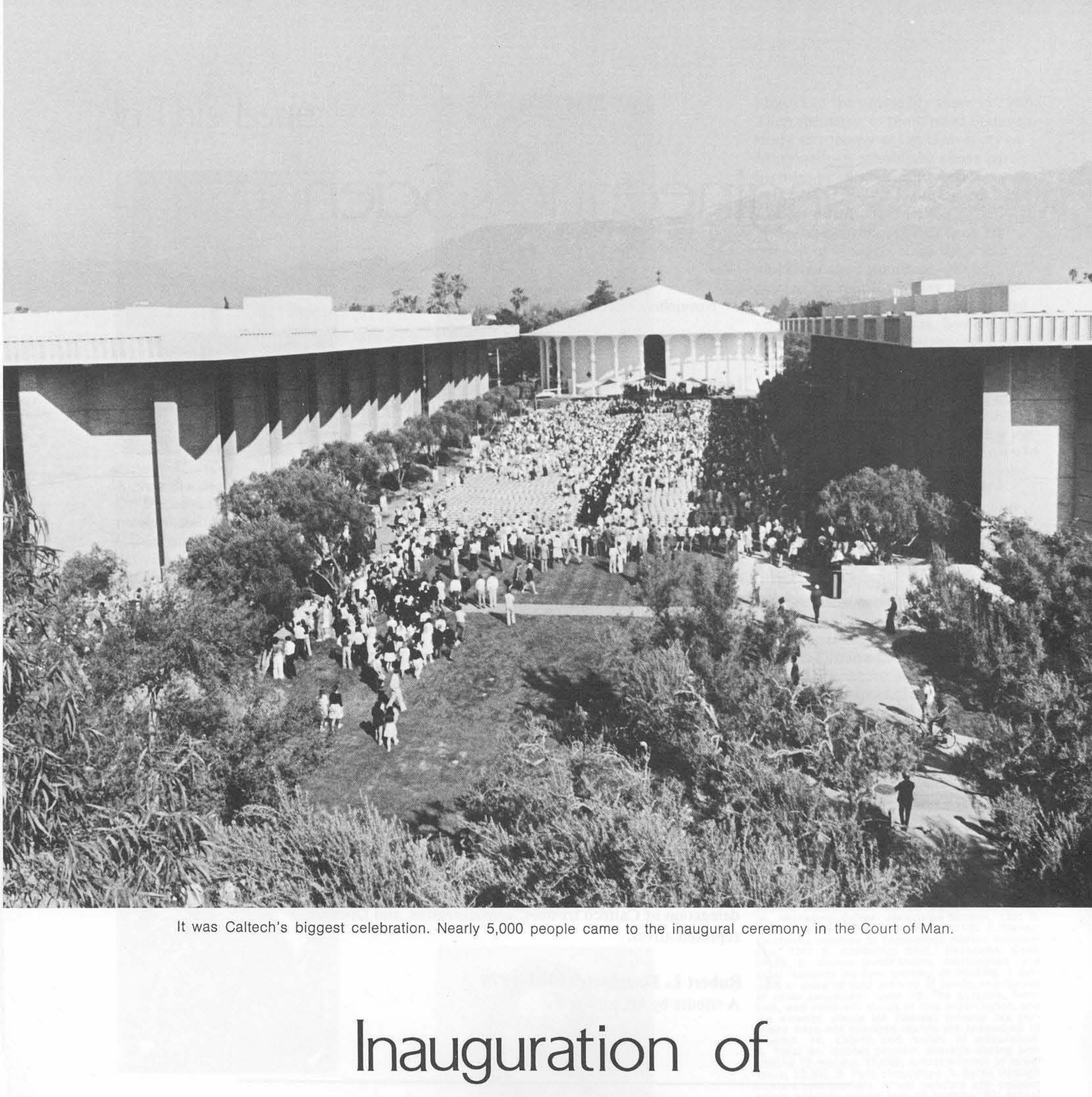
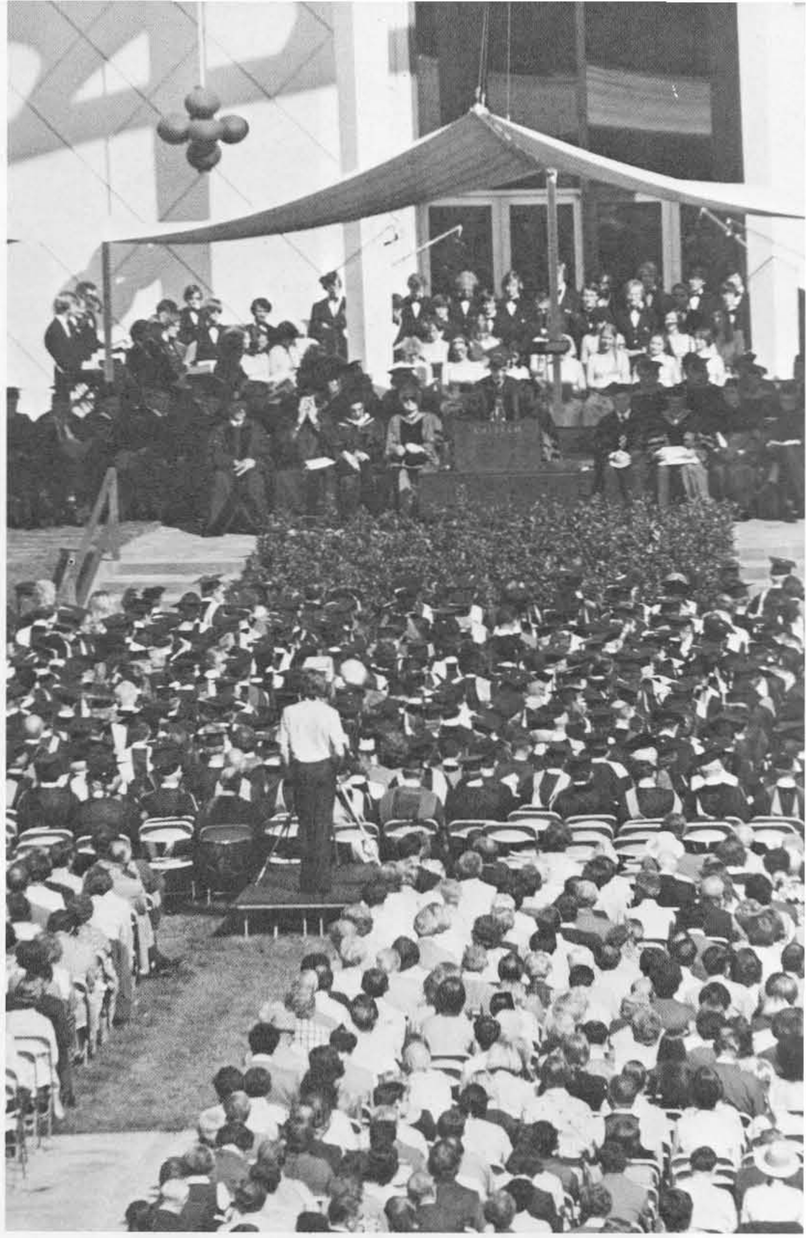


It was Caltech's biggest celebration. Nearly 5,000 people came to the inaugural ceremony in the Court of Man.

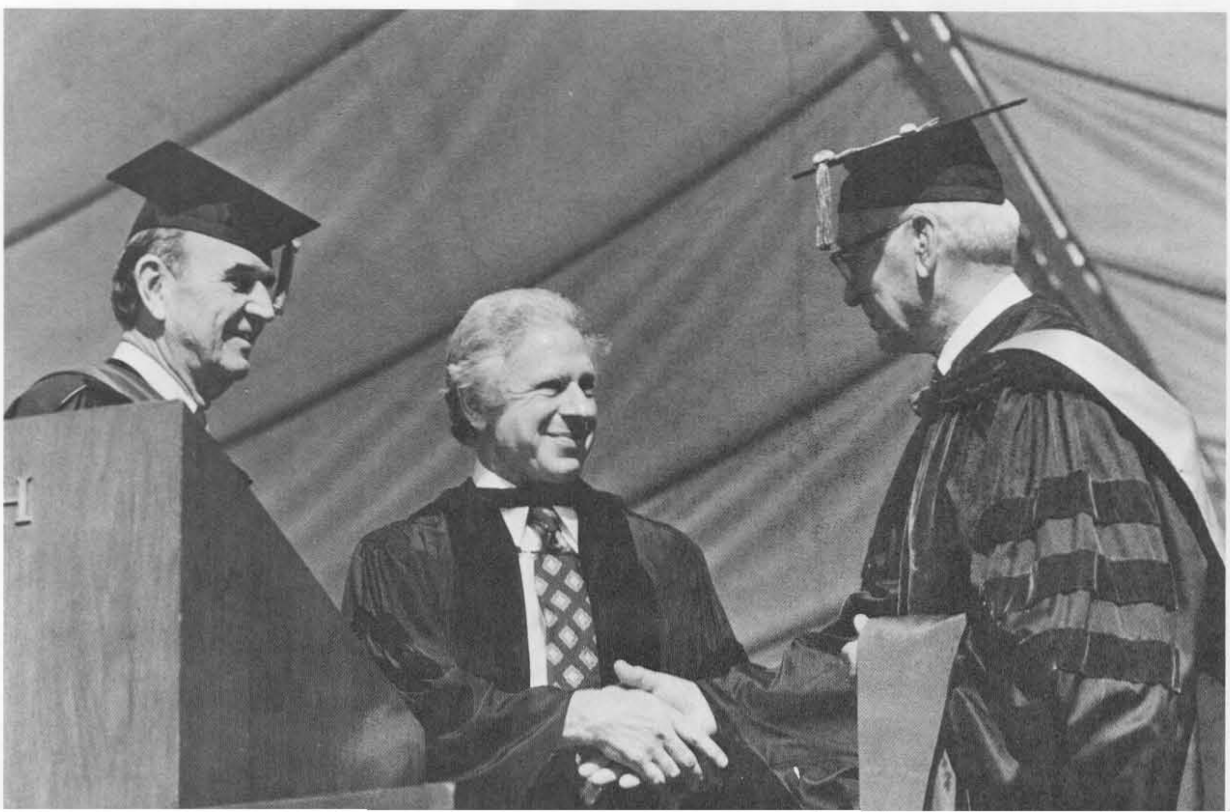
Inauguration of the President

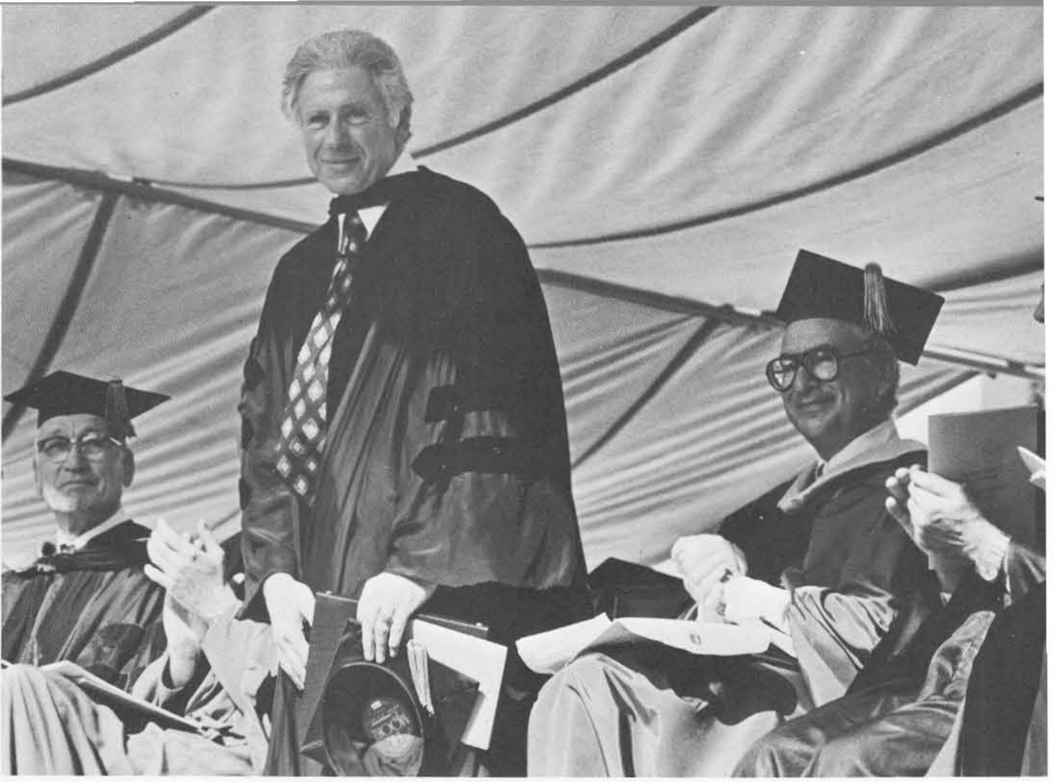
October 27, 1978

Some pictorial highlights from the inauguration of Marvin L. Goldberger as Caltech's fourth chief executive



The new president gets his first congratulations from R. Stanton Avery, chairman of the board of trustees (left), and Arnold O. Beckman, emeritus chairman.





Applause for President Goldberger from Arnold O. Beckman, chairman of the board of trustees emeritus; Murray Gell-Mann, Nobel Laureate; and Alumni President John Fee . . .

. . . and from his wife, Mildred, and two sons, Joel and Samuel . . .

. . . and—in their own special way, of course—from the students, who lowered this banner during the ceremony.

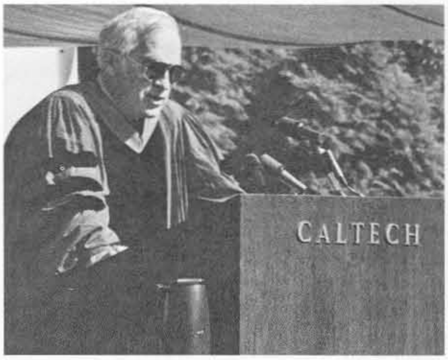
Linus Pauling, professor of chemistry emeritus and Nobel Laureate, elicits a reaction from three spectators, who are still too young to understand why grown men dress up this way.

More than 500 guests attended a dinner on the night before the inauguration, and the Goldbergers managed to greet most of them.

Tables for more than 850 luncheon guests filled every corner of the Athenaeum. Governor William Scranton and Mrs. Scranton, who is a member of the Caltech board of trustees, work their way through the west patio.

A smiling, newly installed President Goldberger strides down the Olive Walk toward the post-inaugural luncheon.

The Averys, the Goldbergers, the Gell-Manns, and Fred Anson, who was chairman of the presidential search committee, lunch at the end of a job well—and happily—done.

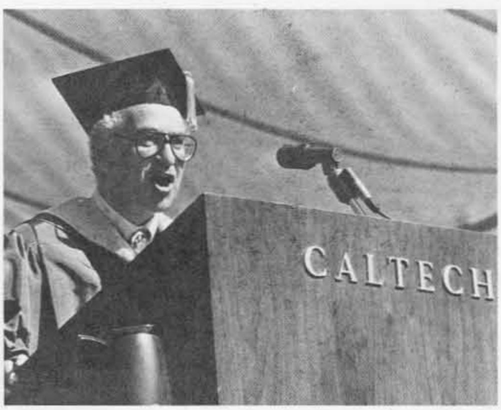


James J. Morgan, *Professor of Environmental Engineering Science; Chairman of the Faculty*

The faculty presidential search committee had a strong sense that the new challenges and opportunities at this point in Caltech's history called for a president who was an intellectual leader, with an excellent reputation as a scholar . . . who would manage the Institute with judgment in selecting people, reasonable accessibility to the faculty, and a willingness to listen . . . who had a genuine interest in students and teaching and a feeling for academic life. We are happy indeed to have found the president who embodies all of these qualities. Dr. Goldberger—Murph—the faculty welcomes you to Caltech.

Raymond G. Beausoleil, Jr., *President of the Associated Students*

In spite of the enormity of the responsibilities conferred upon him today, Dr. Goldberger has remained both amiable and approachable. He has promised that, whenever possible, his office will remain open to all, and he is not unwilling to talk over lunch at Chandler Dining Hall. As a representative of the undergraduates I have emphasized our reactions to his accomplishments. It should become apparent that he is equally responsive to the needs of the entire Caltech community.



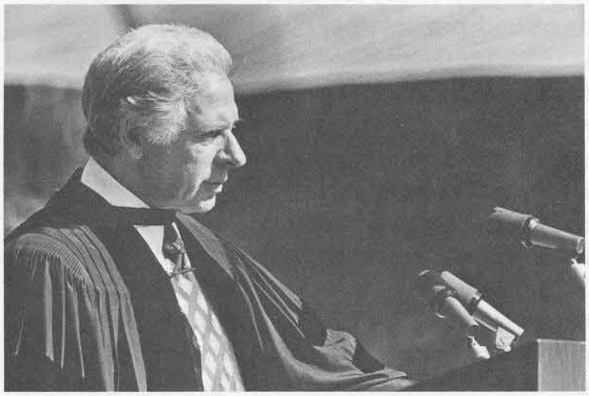
Murray Gell-Mann, *Robert Andrews Millikan Professor of Theoretical Physics; Nobel Laureate, Physics 1969*

You all know that he has made enormously important contributions to the theory of fundamental physics . . . but his interests and achievements have been extended to many other fields. He was, for example, a member of President Johnson's Science Advisory Committee, chairman of some of its panels. It has always been natural to make Murph chairman or president. He is an obvious person for a leader—first of all because he enjoys it so much. For another thing, he does a splendid job without being obnoxious—except occasionally to people who really deserve it.

Leonard I. Beerman, *Rabbi, Leo Baeck Temple, West Los Angeles*

Bless this Institute and bless its president; guide and guard them. Grant unto him a wise heart, and grant unto him also a generous portion of humor—much needed in Pasadena, and in other parts of this very somber world in which we have been fated to live. And give to him, and to all who serve with him in the quest for knowledge and wisdom, the courage to be humble and the muscle to be compassionate, so that whatever their minds and hearts seek to do, they may do with all their might.

Caltech: Harnessing Science and Technology with Wisdom



by Marvin L. Goldberger

Thanks to all of you for coming here to be part of this occasion. Some of you are my family, some of you are my oldest friends, some of you are my newest friends, some of you represent institutions I've had the privilege of being associated with in the past, but all of you are friends of Caltech—one of the greatest centers of research and education in the world. All of us here are proud that you have taken time to be with us today.

As most of you know, I have not been here very long—only since the first of July. In these past four months I've had a lot of catching up to do. Unlike many of my wiser (or luckier) colleagues, I had never had any professional connection with Caltech. Of course I have known many people on the faculty and had for over 25 years known and admired the two previous presidents—Lee DuBridge and Harold Brown. But everyone who works in scientific research soon learns about the California Institute of Technology through following the contributions to one's own field that are made here, through meeting all the outstanding people who have Caltech associations—the former undergraduate or graduate students, and the postdocs, whom one encounters in leading institutions all over the world.

In January of this year I came, at the invitation of the search committee, with my wife for a two and one-half day exposure to the whole Caltech constituency: faculty, staff, administration, students, and trustees. This was at least as difficult as a PhD exam, and I frequently wondered how well I was answering their questions. At the same time, the whole experience was tremendously exciting, simply because I was actually being considered as a serious candidate for the presidency of this institution. Furthermore, the social events we attended gave both my wife and me the feeling of being welcomed by new friends, rather than being looked over critically. After March 6, 1978, at 2:37 p.m. eastern time, when I received a telephone call from Stan Avery telling me I had in fact been chosen for the presidency, we visited Pasadena several times before moving out for good. As you can see, the elapsed time has been short, but we already feel very much at home in the Caltech community and even in the larger community of which Caltech is an important part.

Since that day in March I have been faced with the reality of being the fourth chief executive officer at Caltech. I have been trying hard to learn how the Institute works, and how it came to be what everyone knows it is—namely, the best at everything it does. I have been pondering some of the questions addressed to me last January about what I would do if I got the job. I've done some reading and lots of talking to all the different kinds of people who have a stake in Caltech. I've been sorting out some of the ideas on education and research acquired in 35 years of experience. I've been worrying about recent national trends and the attitudes in Washington and elsewhere toward support of research. I'd like to share some of these reflections with you.

It seemed reasonable to begin reading about Caltech by going to Robert Millikan's autobiography. In an early address he gives a definition of the Institute that is still very much to the point: "The Institute is a university in the sense that it has a graduate school in which profound scholarship and the highest order of creative work are found.

"It is a college in the sense that it confers a bachelor's degree and aims to cultivate intensively the humanities through devoting special attention to English, including literature, history, and economics.

"It is a technical school in the sense that it is attempting to give the men *(and now we add, obviously and most emphatically, women)* who go out from its walls with such a cultural background and so thorough a training in the fundamentals upon which all engineering rests as will enable them to take an outstanding place in the progress of industry and science."

He went on to say that the Huntington Library, and particularly the Mt. Wilson Observatory, were of special importance: "These three things—fundamental and creative science, applications of science, and cultural background make this a unique research and educational enterprise." Aside from some obvious omissions such as JPL and the full panoply of the Hale Observatories, this 1921 definition of Caltech sounds remarkably fresh and accurate.

How do we change, staying vital and at the forefront of research and education, without much growth?

A number of noteworthy things have happened since Dr. Millikan made these remarks, and he played an important role in many of them. One of these was the establishment of a division of biology in 1928 under the leadership of Thomas Hunt Morgan. We shall celebrate the 50th anniversary of this occasion next month with an international symposium. Another was the building in collaboration with the Carnegie Institution of Washington of the great 200-inch telescope at Palomar. The Jet Propulsion Laboratory dates from 1936, when a small group led by Theodore von Kármán developed an interest in the basic principles of rocket propulsion. JPL became affiliated with NASA in 1958 and has played and will continue to play a central role in the nation's space program.

More recently, beginning about 1968 a strong group in the social sciences has developed here which includes economics and political science, and both of these activities have vigorous graduate programs. Finally, I should mention the Environmental Quality Laboratory (EQL), which was established in 1971 to carry out multidisciplinary policy studies of important environmental problems.

So much for the past. What now for the future? I once received a letter from a colleague recommending a particular postdoc which ended with the following statement: "Dr. I. is small of stature, but he has a fighting heart." Caltech is small in size, certainly not in stature, and it has and will continue to have a fighting heart. This is fortunate because the competition for the very best people is fierce and, as in other arenas, the strong take from the weak, but the smart take from the strong. I agree strongly with James Conant that the way to wreck a university is to make good appointments. Good appointments are not good enough; it must be only the very best that we care about.

One of the great virtues of Caltech is its smallness. I don't envisage any substantial growth in the near future. At our present size, we can avoid the inertia of larger institutions, and we can move quickly when we decide what we want to do. Nevertheless, if there is a good idea in research or in education, our stature gives such innovations great influence.

The basic problem we face is the following: How do we change, staying vital and at the forefront of research and education, without much growth? Sir Lawrence Bragg at Cambridge sometime during his long career enunciated two important principles that are worth recalling in this connection: First, don't try to re-create the glories of the past, and second, don't follow the crowd. We must be sure that the argument that begins with the statement, "Caltech has always been strong in . . . ," doesn't force us to neglect new initiatives in order to preserve ancient traditions. As for following the crowd, we obviously cannot neglect certain popular demands when we have educational obligations to meet. But in the research area, it is often unprofitable to make radical shifts just to accommodate what may be transient swings. More important, I don't want to be in the position of playing catch-up if it can be avoided. I'd prefer that others be trying to catch us.

In the course of changing without growing we must occasionally be daring. We have to be prepared to seize opportunities to strike out in new directions, to bring people or programs to Caltech that will make real qualitative changes. This may call for an occasional discrete jump in the size of a particular staff and for special funds. I'm eager to respond to such initiatives from the faculty, and I cannot promise to forbear doing some needling if they are not forthcoming.

In a more modest vein, I'd like to mention a few conventional areas that I see as immediate targets for improvement and perhaps even a little change. The first of these has to do with undergraduate education. Our undergraduates are phenomenal. Historically, they have been phenomenally successful, using any criteria of success. Since I haven't been here very long, it's not clear that all the impressions I've gathered are entirely accurate, but I feel there is enough truth to what I've heard to express some concerns. In spite of the initiation of the pass-fail option for the freshman year, we lose too many students. No institution can hope to graduate its entire freshman class, but Caltech ought to be able to hold most of the students it selects with such care. There are many reasons for the losses. Let me draw attention to the one that concerns me the most, which is also the one we can do something significant about immediately.

The material in the undergraduate curriculum is necessarily difficult, but it is also frequently boring and the students become disillusioned and impatient. In an institution like this, where the faculty are engaged in important and absorbing research and scholarship, it is often tempting to avoid giving undergraduate teaching the attention it requires to instill a sense of excitement in the students. I want to urge the senior, most distinguished, faculty to undertake this task, but I warn you, it is much more difficult than graduate teaching. I'm sure that our faculty, some of whom I'm told have never taught undergraduates, can cope with the difficulties. Because our students are so exceptional, they deserve the best we have to offer.

It's worth remembering what we are trying to achieve with our undergraduate programs. Some significant fraction of our students will go on to graduate school. Some, particularly in the applied sciences, will go to work in industry. Some will go into law or medicine or politics. The latter is an area where we desperately need technically trained people. As part of the educational experience of all of these different groups, I want to suggest that the faculty consider a requirement of independent study leading to a senior thesis for all students so that they can experience the reality of research and the exhilaration of accomplishment that goes with it.

While I'm on the subject of education, I must say that while our graduate programs are extremely successful, there is no room for complacency. There are some areas in which, to my positive knowledge, we are not attracting the very best graduate students, and we must understand the reasons for this and take corrective steps.

"Science is at best knowledge;
it is not wisdom. Wisdom is
knowledge tempered with judgment."

I anticipate significant change in some other areas of our educational and research endeavors in the near future. In his definition of Caltech, Dr. Millikan stressed the importance of the humanities. This is a concept that I feel very strongly about. Lord Ritchie Calder has said, "Science is at best knowledge; it is not wisdom. Wisdom is knowledge tempered with judgment." The study of the humanities can help us immeasurably in our quest for wisdom. There are those at Caltech who believe there should be a major restructuring of the relationship between science and the humanities. I shall work hard with them in the coming months to understand these views. In the meantime I plan to move swiftly to replace the losses we've suffered in recent years in this area. I've promised the new chairman of the Humanities and Social Sciences Division a significant number of senior appointments in the humanities including the currently vacant Dreyfuss Professorship. We will work to put together a group that has the typical Caltech uniqueness and distinction. We shall try to capitalize on our great local asset, the Huntington Library, to help us attract scholars of distinction.

We have another great local asset which has not, in my opinion, been exploited by Caltech as effectively as it might be. This is the Jet Propulsion Laboratory. JPL is part of Caltech. It is, of course, far larger than the campus. It has special roles, missions, and obligations to its sponsor, the National Aeronautics and Space Administration. The NASA/JPL association has been an enormously fruitful one for the nation, and we look forward to many more years of collaboration on exciting programs. What I would like to see, however, is an even closer relationship between the campus and JPL than we have now. A substantial number of professors and students are already involved with various aspects of JPL work, but I look forward to our seriously taking advantage of the extraordinary educational opportunity JPL provides us with. To have available a real live laboratory doing technical research, development, and systems implementation at the very limits of technology gives us an incredible advantage over any other educational institution in the country. I shall urge the faculty to look into means by which a solid work-study program—call it what you will—can be instituted for students of applied science, both undergraduate and graduate. I hope we shall also take steps to encourage and increase joint campus/JPL research activities, particularly in the field of energy.

Finally, before leaving this subject of new initiatives, I want to mention that we are about to begin construction on the Braun Cell Biology and Chemistry Laboratories. This will give added impetus to our major programs in biology, immunology, and the neurosciences. We shall also very soon see the start of the Thomas J. Watson, Sr., Laboratories for Applied Physics, which will enable us to broaden research activities in this important area. We are initiating a major effort in the physics department aimed at the detection of gravitational radiation. We have a vigorous and growing program in computer sciences. We are embarking on a major new program in resource geology, an area in which we already have considerable strength, but one to which we are giving new emphasis. This year, as a result of generous support by our trustees, we have also established the Robert P. Sharp Professorship in Geology.

This all sounds very upbeat, as it is, and I have every confidence that we will succeed in all of these programs. There are, however, some clouds on the horizon of which we must be aware. Consider the outlook for continuing federal support of research, upon which we count very heavily, just as all the nation's principal research universities do.

For many years after World War II, basic research in the physical sciences was heavily supported by the Department of Defense and the Atomic Energy Commission. In spite of the disclaimers on the part of the scientists that no new super weapons, like the atomic bomb, were likely to result from the research, many of the defense agencies still secretly believed such weapons might emerge. Right up to very recent times the Congress held those beliefs.

A few years ago the following interchange took place between Senator Pastore and Dr. Robert Wilson, the director of the Fermi National Accelerator Laboratory, at a hearing in connection with that laboratory's 500-billion-electron-volt proton accelerator:

> *Senator Pastore*: "Is there anything connected with the hopes of the accelerator that in any way involves the security of the country?"
>
> *Dr. Wilson*: "No, sir; I do not believe so."
>
> *Senator Pastore*: "Nothing at all?"
>
> *Dr. Wilson*: "Nothing at all."
>
> *Senator Pastore*: "It has no value in that respect?"

And then Dr. Wilson said something which I feel expresses the fundamental aspects of basic research better than anything I've ever heard before or since.

> *Dr. Wilson*: "It has only to do with the respect with which we regard one another, the dignity of man, our love of culture. It has to do with those things. It has to do with are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. It has nothing to do directly with defending our country except to help make it worth defending."

Basic research sponsored by the mission-oriented agencies, both defense and non-defense, has dropped off enormously, although there are some hopeful signs of new initiatives being taken by the Department of Defense to once again support research in the universities. Unfortunately congressional pressure in recent times has forced agencies like NASA and the Department of Defense to drop scientific programs. Of even greater significance and importance is the question of principle involved here, that mission-oriented agencies should be concerned only with applications and not with basic research. This is an incredibly short-sighted view.

Let me give one example of the kind of thing that can and did happen because of such short-sightedness. For many years the Advanced Research Project Agency (ARPA) in the Department of Defense supported major programs in materials research in universities. Now, just at a time when materials play such a critical role, in solar energy, nuclear energy, controlled fusion, fluidized-bed coal combustion, to name just a few areas, the programs no longer exist.

One of the frontier areas of science is high-energy physics. The annual operating budget for the whole effort in the United States is about $200 million. The work is carried out at three major national laboratories: Brookhaven, Fermilab, and the Stanford Linear Accelerator. The people who do the work have been trained in the universities and are mostly members of university faculties. The program has been phenomenally successful by any measure; the field is dominated by United States scientists; there are important contributions to technology, such as superconducting magnets, high-powered microwave tubes, advances in electronics and computer utilization; and Nobel Prizes have been won. But shrinking support is beginning to slow the program significantly. The European laboratories in Geneva, known as CERN, and in Hamburg, called DESY, are growing rapidly both in facilities and research support. At the present time, Western Europe is spending almost twice as much as the United States.

Now, in all honesty, I must admit that the world will not come to an end if some important discoveries in high-energy physics are made in Europe. But I dislike relinquishing supremacy in a fundamental field, and I resent policies that inevitably mean we are going to come in second.

An atmosphere of tight spending in scientific research has many unfortunate consequences and dangers. First, good people are discouraged from entering the fields. Second, only the most powerful and best established people get to work with the limited funds, and thus the careers of young people are blocked. Third, federal agencies tend to support their investments in national facilities to the detriment of the universities; this sets up a chain reaction leading to a decline in the quality of research, which in turn leads to a decline in the training of a new generation of scientists. Fourth, cutbacks in the funding of new instrumentation are particularly dangerous to big science, little science, and to industry; obsolescence of equipment means a decrease in cost effectiveness; training students on such dying equipment makes them less useful to industry; innovation is stifled and what used to be our hallmark—our ability to respond to technological challenges from abroad—is threatened. For example, our computer industry is going to be sorely tried in the near future to stay ahead of Japan. Finally, fifth, in an atmosphere of tight funding there is a tendency to do what is safe and to steer away from the true frontier areas where we can make real quantum jumps in our understanding.

Now what can be done to fight this trend? For too long the scientific community and the universities have adopted the attitude that what they were doing was so obviously good that no arguments had to be presented and that the money would just roll in. This is evidently no longer true, and it is not going to be true in the future. Nothing is accomplished by sitting back and wringing our hands about the failure of Congress to appreciate and support research, even in the face of a very strong effort on the part of the Carter administration to increase significantly research funds. Nor can the professional societies or the National Academy of Sciences be counted on to plead the case. We as individual scientists and as university administrators have to take the initiative. We have a great product to sell. We must write articles, give interviews, volunteer to testify before Congress, enlist the help of technologically based industries, enter into arrangements with the media to bring to the people the truly exciting case we have to present about science and education. The future of our country and even that of the world depends on our ability to harness science and technology with wisdom for the common good and to continue to push forward the frontiers of knowledge.

We at Caltech have our work cut out for ourselves. We must continue to rely heavily on federal support for research, and we must help create the atmosphere that will earn it. We must seek innovative methods for interactions with industry and support from it for both basic and applied research. We must win support for our programs in the humanities by both deepening and, perhaps at some future time and in some daring fashion, broadening them. We must continue to be the leaders in all of our areas of scientific research. Research carried out in conjunction with teaching forms the cornerstone of the American educational system—in my opinion, the best in the world. We must train students who will be the new and wise leaders in industry, in public affairs, in the universities, and in extending the forefront of knowledge.

This is a heavy responsibility for one small jewel-like institution. But we stand on the heritage of Robert Millikan, Lee DuBridge, and Harold Brown. I'm honored and proud to have the opportunity to follow in their footsteps and to build upon the solid foundation of greatness laid by them. I'll do my very best, and with the help of the whole Caltech family, I think we can reach our goals. □

The Trip of a Lifetime

How to endow a professorship—and have the time of your life

The idea was born in the fertile minds of Lee Silver and Gene Shoemaker, and it first found vocal expression in the Houston airport one day in 1975 when, in a grounded plane, they were being pacified with cocktails and snacks while a crew of mechanics struggled to make the plane operable.

Silver and Shoemaker, who were both involved in NASA's lunar program, were on their way back from Houston to Caltech, where they are professors of geology. Ultimately, talk got around to the geology division in general and how to raise money for it in particular—and that's when the idea surfaced. Back at Caltech, they took the plan to Barclay Kamb, the division chairman, who was enthralled but a little skeptical. He called in one of the division sages, Bob Sharp, professor of geology, and tried it on him. Sharp's immediate reaction was that he wished he had been smart enough to think it up himself. Kamb then took the proposition to the Caltech development staff and several members of the administration, who admitted it was certainly unusual but worth a try.

The idea was to raise $1,000,000 for an endowed professorship in geology by sponsoring a special deluxe raft expedition through the Grand Canyon—a trip to be guided by four of the best geologists in the country—Silver, Shoemaker, Kamb, and Sharp. Their special reason for launching this venture was to change the situation in which the geology division, unlike the other divisions at Caltech, did not have a single endowed chair on its professorial roster.

To achieve this goal, donors would be asked to contribute $50,000 (or $75,000 per couple) and, in return, the geology division would offer them the trip through Grand Canyon as a gesture of thanks. The trip would provide a unique opportunity to learn about the earth's history as read by geologists from the rocks themselves. And it would all be combined with the excitement and beauty of the river and canyon.

With a flair that would do credit to Madison Avenue, the venture was christened "The Trip of a

Lifetime." Kamb and Sharp went to work recruiting donors, with particular help from Stanton Avery, chairman of Caltech's board of trustees, William Corcoran, vice president for Institute relations, and the development staff. Sue Walker and Gene Wilson of Development helped Sharp prepare brochures ("Although we can't take you to the Moon, we offer the next best thing . . . "), prospectuses, and other materials, which went out to a number of potential donors.

The response was strong and enthusiastic, and one of the first to sign up, with his wife, was Stanton Avery. "I was going to Europe this summer," said another trustee, "but this is such a unique philanthropic approach that I'm canceling that trip and going on the canyon run with you guys." In good time there was a clutch of prospective passengers.

The first trip, from May 16 to 22, 1976, raised more than half of the needed $1,000,000. It took two more trips to reach the goal—a second run September 25 to October 2, 1977, and a third August 20 to 26, 1978.

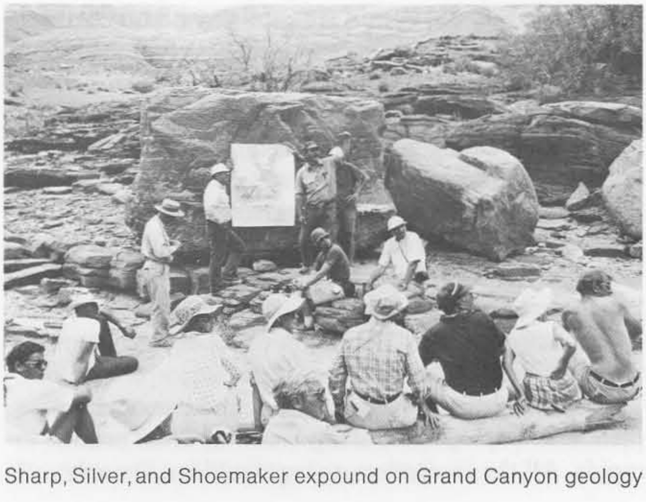
The four geologists—Silver, Shoemaker, Kamb, and Sharp—went on all three trips, except that Sharp missed the second when he came down with a spectacular cold. He did manage, however, to fly to the assembly point in Las Vegas and see that everything was in order for the trip. Then, as the party started out, he climbed on a plane and flew home ("one of the bitterest experiences of my life").

The physical organization of the trips was provided by Western River Expeditions of Salt Lake City. They furnished boats, equipment, and crew, so that the Caltech geologists did not need to be concerned with the mechanics of running the river itself and could concentrate on entertaining their passengers with the natural history and geology of the Grand Canyon.

Their contributions were not all academic, however. They also added to the physical comforts of their guests by supplying such luxuries as Coleman lanterns, cots, air mattresses, and a well-stocked bar. It was Silver and Sharp who made all the arrangements and did the hard work of handling the logistics.

On the river, Sharp's special role in the group grew naturally out of his long experience with Grand Canyon geology, dating back to his participation in the Caltech-Carnegie expedition of 1937, which was the first modern scientific expedition through the canyon since the work of John Wesley Powell and his associates in the last century. On the 1937 expedition Sharp made a classic, widely cited study of the ancient erosion surfaces that mark the two great unconformities in the geological record of Grand Canyon. These features are among the highlights of Grand Canyon geology, and he was particularly eager to point them out and explain them to the river-trip participants. Bob's historical perspective was an important ingredient in the intellectual fare of the trips, and he added to it by bringing along a library of books on the history and geology of the canyon, which was made available each afternoon in camp, after the day's run was over.

Among the four guides, Gene Shoemaker has the greatest experience in river-running through the Grand Canyon, having made the trip numerous times to do geological field work. A confirmed "river rat," he could regale the participants indefinitely with canyon lore. In 1968, on the occasion of the John Wesley Powell centennial, he led a historic three-month trip down the river from Wyoming to Lake Mead for the purpose of recovering Powell's original camera positions and thus documenting photographically the changes that had taken place in the canyon in the 100 years since Powell's expeditions. Gene's current research includes stratigraphic studies, by a new paleomagnetic method, of the Triassic and late Precambrian sedimentary rocks of the Grand Canyon region, and also studies of the late Tertiary and Quaternary history of the Colorado River and the cutting of the Grand Canyon. In addition, he has prodigiously detailed knowledge of the general geology of the canyon in all its aspects, which he shared enthusiastically with the river-trip participants.



Sharp, Silver, and Shoemaker expound on Grand Canyon geology

The Trip of a Lifetime

Travel on the river is alternately on millpond . . .

Lee Silver's special connection with Grand Canyon arose in the course of his studies of the geochronology and uranium-lead geochemistry of crystalline basement rocks in the southwest. Over the past two decades he has run the river many times to collect important basement samples from the Granite Gorge of the canyon. So he was the group's expert on the Older Precambrian rocks, and he expounded eagerly on the complexities of events that tortured these rocks one to two billion years ago. In addition, he performed expertly as bartender of the expeditions.

Barclay Kamb was the only one of the four guides who had not run the river before, and therefore functioned more as a general factotum than a scientific or historical expert. However, some years ago he had worked in the Navajo Indian Reservation east of Grand Canyon, studying the Quaternary geology in connection with the archaeology of this region, and this experience was of value in connection with archaeological sites (pueblo ruins and artifacts) that the groups encountered. Kamb also entertained with accordion and harmonica playing, and made photographic records of the trips, including helping his son Barky make movies of the first and final trips.

Each trip lasted a full week, starting with a get-together in Page, Arizona. The boats were put in at Lee's Ferry, and at the end of the run passengers were helicoptered out at Lava Falls. This 180-mile stretch is about two-thirds of the length of the Grand Canyon, the most spectacular part.

There are many sandy beaches and bars making pleasant camping spots along the river, often next to rapids. All the campsites are kept spotless; the only thing campers leave behind them is footprints. For example, the parties carried their own portable johns, complete with small shelter tents.

A normal day on the river isn't particularly a rush-rush affair. People wake between 6 and 7. The crew has coffee ready, and soon produces a sturdy breakfast —cantaloupe, grapefruit, French toast, sausage, scrambled eggs. Then everyone helps break camp and load the rafts.

During the day, aside from a stop for lunch, which is usually something simple like fruit and sandwiches, there are often as many as half a dozen stops at different points of interest. There might be a walk up a side canyon for a quarter or half a mile. Or a stop at the mouth of the Little Colorado to go upstream a few hundred yards for a swim in the turquoise blue water. The water in the main stream is far too cold to swim in; it comes from the depths of Lake Powell—winter water that has sunk to the bottom there. Its temperature is in the low 50's. There are stops to look at fossils, Indian ruins, and an abandoned asbestos mine. Sometimes there is a major excursion taking half a day or more—up Tapeats Creek to Thunder River and the falls, for example, a round trip of about five miles. Of course, not everyone went on all of the longer trips.

Travel on the river is alternately on millpond and rapids—which are actually caused by little "Boulder Dams" built into the river by debris from the side canyons. The water above each rapid is ponded. When the boats hit the rapid, the passengers have to grab onto the tie-down ropes, because it is often a wild ride, careening down through huge churning waves.

. . . and rapids

In the excitement there is much whooping and screaming, and whenever someone gets drenched, it is cause for considerable mirth. Some even look for extra excitement by sitting forward on the rafts, where the water sprays up thick and fast. There are a great many small rapids on the river, and going through these is simply fun; but the big rapids ("sockdolagers" was what the old Powell expedition called them—and they still are) are really exciting. In fact, if the rafts weren't so large, the rough water would be terrifying. (This may be the place to note that there was always a doctor aboard on the trips, though he never had occasion to deal with more than minor afflictions.)

There were about 15 people to a raft on the Caltech trips, with a crew of two boatmen. The powered neoprene rafts—practically unsinkable and unflippable—were made of five big pontoons, laced together and made so as to bend at two places fore and aft. Supplies were carried in big waterproof boxes lashed securely to the raft frame.

Everybody helped unload the rafts when they stopped for the evening. While the crew cooked dinner (steak, seafood, or some other delectable entree with fresh vegetables and a salad), the geologists set up the bar. Kamb would play the accordion or Sharp would get out his library, and of course there was plenty of talk—but not very far into the night. For nearly everyone, bedtime came early.

There were few formal lectures, but the four geologists were busy expounding at every opportunity on the geology to be seen along the way. The geologists themselves are so completely under the spell of the Grand Canyon and the dynamic river that they can't help but communicate that feeling to their guests. It is strangely awesome to discover that in one trip down the river you traverse nearly two billion years of geological time. And in some places you can literally straddle a billion years by putting one foot on one side of a rock contact and the other foot on the other side. They have a saying that no one is ever quite the same once he's experienced the Grand Canyon run.

Even the professional boatmen were appreciative of the expertise of the Caltech geologists. While waiting at Lava Falls to be helicoptered out at the end of one trip, Sharp overheard a conversation between two boatmen from another group. One pointed to a boatman with the Caltech group. "That lucky guy," he said, "just came down the river with *four* geologists!"

Sharp was eventually baffled by his colleagues

Bob and Jean Sharp on the river

because, while he needled them repeatedly about what they were going to name the endowed professorship they were all working for, they seemed remarkably unconcerned. It was only on the third trip down the river, this past summer, that the other three geologists finally let out the secret they had been cherishing since the trips began. In fact, it was President Goldberger who broke the news. He was an invited guest on this trip, as were the geologists' wives—Gerry Silver, Carolyn Shoemaker, Linda Kamb, and Jean Sharp.

On the third night out the party was settled in a nice campsite near Unkar Creek, and after supper Barclay Kamb called the group together. "Murph Goldberger," he told them, "has something to say." Beaming, Goldberger announced that this operation was now a guaranteed success. The money had all been raised. The endowed professorship was going to be named for Bob Sharp. And the first occupant of the chair would be—Bob Sharp.

Sharp was rendered temporarily speechless ("you could have knocked me over with a feather"). Now he can say, "It was a beautiful place to do it. Right on the river. Beautiful evening. In camp. With some of the people who were involved. And a *satellite* went over." Murph Goldberger made a public announcement of the professorship in his inaugural address.

If there is one thing that distinguished this unique fund-raising effort, it was that it was fun all the way through. Everybody involved in it had a good time—not just the people who took the trips, but also the people who worked to make the trips possible. And, of course, the man who holds the new Robert P. Sharp Professorship of Geology most of all. □

Interstellar Molecules

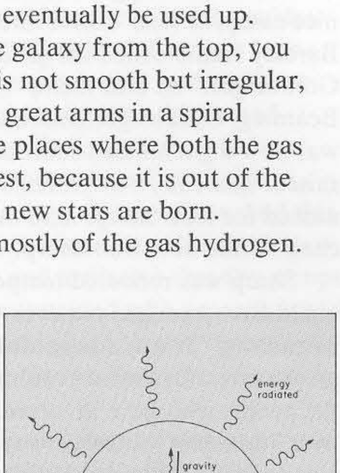
by Gillian Knapp

When you look into the sky at night, you see our galaxy as a band of light crossed by dark patches. New stars are born in dark patches like these, which are not holes in the galaxy but huge clouds of gas and dust that block out the starlight behind them.

Our galaxy contains about 100 billion stars arranged like a flat wheel turning slowly about once every 100 million years or so. The stars in the galaxy vary greatly in size, in age, and in the intensity of the light they give off, but the light from each star will eventually go out because stars burn by their own internal energy, which will eventually be used up.

If you could look at the galaxy from the top, you would see that the surface is not smooth but irregular, with the light emitted from great arms in a spiral pattern. These arms are the places where both the gas and new stars are the densest, because it is out of the clouds of gas and dust that new stars are born.

The universe consists mostly of the gas hydrogen. We think, in fact, that when the universe first formed, it contained only two elements, hydrogen and helium. We also know that the dark patches out of which the stars are born are made of dust grains that contain atoms much heavier than hydrogen and helium, and we think those atoms were produced during the deaths of stars.



A schematic cross-section of a typical star shows the balance between the force of gravity and the radiation pressure within the star, plus a second kind of balance—that between the production of energy in the core and the loss of energy from the surface.

A star is a large spherical cloud of gas maintaining itself in a two-way equilibrium. It's in balance between the inward force of gravity, which tends to try to pull it together and contract it into a point, and the outward pressure of radiation produced in its center by the nuclear reactions that turn one element into another—nuclear fusion. In the case of a star like the Sun, the fusion is of hydrogen atoms into helium atoms. In some other stars helium atoms fuse into carbon atoms. That's the first kind of balance—the balance that keeps the star the size it is.

There's also a second kind of balance. The star is shining, and energy is radiated from its surface which must be in continuous balance with the energy produced in its heart. Therefore, the star is continuously losing energy, and so it can't last forever. The length of time it will last has an inverse dependence on its size. The bigger the star, the faster it will use up its energy.

When the star has lost all the energy it can produce in its center and is no longer radiating energy, gravity takes over and starts to crush the center of the star. If the star is massive enough, the pressure gets very high in the center and more and more complex reactions take place. Eventually the reactions go so fast that the process simply runs away, and the star blows away its outer envelope.

In the smallest stars, the nuclear reactions are fairly slow, and the explosion that blows off the outside envelope is not a very violent one. The explosion in the center of a somewhat more massive star is more violent and more material is blown out. The most violent stellar explosion of all is called a supernova. In such an explosion, a single star can suddenly become brighter than a whole galaxy. As time passes, the gas blown away from the exploding star gradually diffuses through space.

This expanding material does not contain just the hydrogen and helium that made up the star originally. It also contains heavier, more complicated atomic nuclei produced in the nuclear reactions in the center of the star, and in particular that were produced in the runaway nuclear reactions that immediately preceded the final explosion. Among the materials thrown out into the galaxy by the explosion of a large star are atoms of carbon, oxygen, sulfur, calcium, nitrogen, uranium—all of the atoms heavier than hydrogen and helium. These atoms fly out into space and gradually enrich—or contaminate—the hydrogen or helium gas that is already there. So the dust clouds from which stars are born depend on the deaths of an earlier generation of stars, and all the heavy elements of which this earth and its inhabitants are made were produced in such cataclysmic explosions earlier in the life of the galaxy.

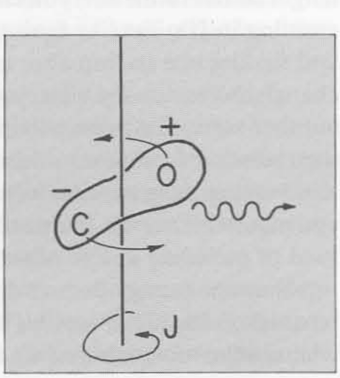
We know that the very hot stars we observe are new because the hotter a star is the quicker it radiates its energy. Such hot stars can live only a few million years or so, so we know that they have to have been formed fairly recently (in a cosmic sense). Some of these stars are surrounded by clouds of dust, which scatters the light from the star in the same way that cigarette smoke scatters light and so looks bluish and hazy. Some stars are surrounded by gas whose characteristic red glow shows that the gas is hydrogen heated by the hot star to a very high temperature—about 10,000 degrees Centigrade. So, when we see those newborn stars surrounded by gas and dust, it seems very likely that they must have formed out of a cloud of gas. This is circumstantial evidence that stars are formed in the large dust clouds.

How does it happen? By the time we see a large region of glowing gas surrounding a star, it is obviously too late to watch the birth happen, because the star is already formed. What goes on in a dark cloud that causes the stars to form? Until recently it was impossible to answer this question for the very simple reason that you can't see through the dark clouds. The dust in them completely stops starlight from passing through.

Recently, however, two new avenues of astronomical research have opened up. We have been able to observe infrared radiation and radio-frequency radiation from interstellar molecules. Both of these forms of radiation can pass completely through dust clouds because their wavelengths are much larger than the dust grains themselves. The dust clouds contain a large variety of molecules in gaseous form, and by studying their radiation we can determine what is going on inside the dark clouds and hope to build a sort of scenario of the processes that lead to the formation of stars.

These great dark clouds are very large indeed. They contain from about a thousand to a million times as much material as our own Sun, which weighs a billion billion billion tons. The clouds are also very extensive—perhaps two or three light years in diameter—and of extremely low density. The number of molecules of oxygen and nitrogen and so on in a cubic inch of air at sea level on the surface of the earth is about 100 billion billion. Inside that same volume in these dark clouds out in space, the number of molecules and atoms is only about 10,000. So, although astronomers often call these objects "dense"—because they are much denser than the rest of the gas in the galaxy—they are nevertheless a much better vacuum than anything we can get on the surface of the earth. They are tremendously rarefied, but because they are so enormous there's a huge amount of material in them.

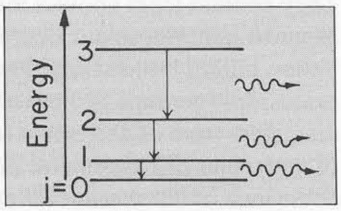
What do observations of interstellar molecules tell us, and how can we use that information to find out what is going on in the cloud? A typical interstellar molecule, one of the most abundant, is carbon monoxide, which consists of an atom of carbon and one of oxygen, bonded together by a cloud of electrons around



The CO molecule can rotate at various energy levels—that is, with various values of angular momentum (J). A decrease in J (a loss of energy) results in radiation.

them. Because the carbon atom is different from the oxygen atom, the electrons are distributed asymmetrically; that is, there are more electrons on one side of the molecule than on the other. So it just acts like a small magnet, with the plus charge on one side and the negative charge on the other. Such a molecule, by rotating like a dumbbell, can interact with the electromagnetic field and cause radiation that we see as light or as radio or infrared waves, depending on the energy and wavelength of the radiation.

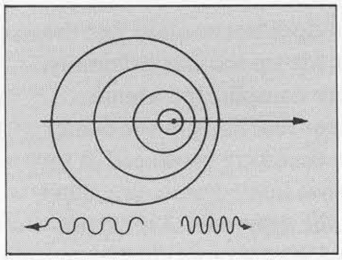
The molecules rotate, but things that small are allowed to rotate only at specific speeds (their rotation is quantized), and that means only with specific energies. This is rather like saying, if you're going up or



The transition from one value of J to another has a specific energy difference, depending on what the molecule is like and how fast it is rotating. Some of the transitions in the rotational energy levels of CO are shown above.

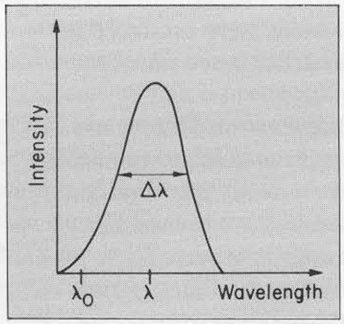
down some steps, that you can stand on one step and then the next, but there isn't any place to stand in between. There is a specific gap between one step and the next. The energy of rotation of the molecules follows these steps, and the molecules' rotation can step up and down and lose a very specific amount of energy—depending on what the molecule itself is like and how fast it is rotating. A molecule that has two heavier atoms will rotate more slowly for a given amount of energy than one with two lighter atoms, for instance. Since each molecule rotates with characteristic speed and drops down these characteristic steps, each time it does so out comes radiation of a particular wavelength emitted only by this molecule. By measuring the wavelength of the radiation, you can tell which molecule is emitting it. It's just like tuning through a radio band and finding one station after another. Each time you change the frequency a bit, you hear the radiation from another station. At one particular frequency you "hear" the radiation from one molecule; change the frequency and you get the radiation from another molecule. So you can tell from the frequency of the radiation what kind of molecule you're observing.

Now the energy doesn't come in at a very sharp frequency. Ideally, it would, but in space—as everywhere—the molecules inside the clouds are moving around because of the internal heat of the clouds. The clouds, in addition, might be rotating as a whole, as well as expanding or collapsing. The radiation from any object that is moving is changed slightly in wavelength. Waves in the direction of motion of a moving molecule get squeezed together, and so the wavelength gets shorter. If the molecule is moving away, the waves get spread out, and the wavelength is longer. From that small shift in the wavelengths at which the molecules



The radiation from a moving object shows the Doppler shift. It appears to have a slightly shorter wavelength if the motion of the object is toward the observer (right) and a longer wavelength if the motion is away from the observer (left).

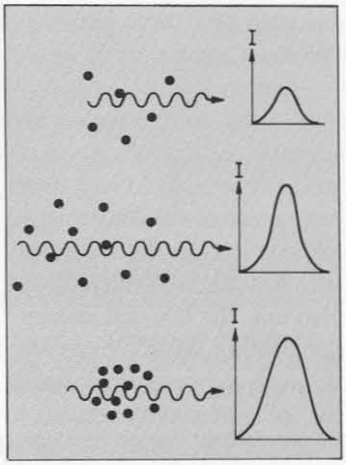
radiate, you can tell at what speed the molecule is going. Since you have enormous numbers of molecules in the cloud and they're all rushing around at their own individual speeds, the radiation from the cloud will not occur at a sharp wavelength, but will be spread out over a small range of wavelengths.



The resulting emission can be expressed as intensity versus wavelength. The shift in wavelength (λ_0 to λ) measures the speed of approach or recession of the cloud. The wavelength spread ($\Delta\lambda$) measures the internal motions of the cloud.

From this you can tell two things about the cloud of gas that is emitting the radiation. First, if the emission is at a wavelength a little different from the proper central wavelength, you can tell that the cloud as a whole is moving away from or toward you at a certain speed. Second, the emission doesn't occur at a sharp wavelength, but at a spread of wavelengths, so you can measure the internal motions in that cloud. If the cloud is collapsing, for example, you can tell how fast from the spread of the radiation. If it is falling together very fast, the radiation is spread over a wide range in wavelength.

If there are a lot of atoms in a cloud, but the density is low, then the radiation from them simply



The intensity (I) of the emission of radiation from a cloud measures the total number of molecules in the cloud. The smaller the number of molecules, the weaker the signal (top). You cannot tell whether those molecules are in a low-density gas that is spread out (center) or in a high-density, very condensed gas cloud (bottom).

adds up. If there are only a small number of molecules, you observe only a weak signal. If there are more molecules, you observe a stronger signal. You can't tell whether the molecules are in a low-density gas that is spread out or whether they are in a high-density, very condensed gas cloud. You can only measure the total number of molecules. On the other hand, the gas can be so dense that, as one molecule radiates, the molecules in front of it absorb the radiation. In that case, all you ever see is the front face of the cloud, so a few molecules produce the same intensity as a lot of molecules, and all you can tell is the surface temperature of the cloud. If the cloud is at a higher temperature, the intensity of the radiation from the molecules at the front is higher.

We can, then, get all this information out of observations of molecules in a gas cloud in space: We can tell what molecules are present and how many there are of each; we can tell what the temperature of the cloud is, and we can measure the total density of the cloud. By making these observations at various points in a cloud, we can study the variations in temperature and density across the cloud. Finally, we can study the velocity field in the cloud—how fast its various parts are moving. Because the radiation is not absorbed by dust, we can see right into the cloud.

It happens that most of the interstellar molecules that we have studied to date radiate at wavelengths that vary between a few centimeters and about a millimeter or so. Caltech is fortunate in having a beautiful new radio telescope built by Robert Leighton at the Owens Valley Radio Observatory (see page 22). The telescope consists of a movable mount that holds a very large mirror, just like the mirror of an optical telescope. The diameter of the telescope is ten meters, and it is made out of hexagonal plates. The big mirror collects radio radiation, which is reflected up to a second, smaller mirror, and is then reflected back into a housing that contains receiving equipment operating at the appropriate frequency. This equipment receives the radiation and amplifies it; then the signal goes into a control room, where it is analyzed and recorded.

The wavelengths at which interstellar molecules radiate are usually very short, and the telescope surface has to be accurate to much better than the wavelength of the radiation that falls on it. Otherwise, it's like ground glass. You can't see a clear image through a piece of ground glass because the surface of it is rough, and the light waves are scattered as they pass through. The wavelength of the radio waves from some interstellar molecules is about a millimeter, so the surface of the telescope that is observing them needs to be accurate to much better than a millimeter all over. That means that the shape of the telescope, which is ideally a parabola, must not deviate by more than a tenth of a millimeter all over—either in total shape or in terms of local irregularities in the surface. The new telescope at Owens Valley has been machined to be accurate to much better than this tolerance and is, in fact, by far the most accurate in the world.

A very large number of interstellar molecules have been discovered—over 40 species. They are made up of common atoms—hydrogen, oxygen, carbon, nitrogen, and sulfur—combined into molecules like formaldehyde, various kinds of alcohols, water, and carbon monoxide. On earth, because the density of the atmosphere is so great, the natural state of hydrogen, or oxygen or nitrogen, is the molecular, but this is not necessarily true out in space. The density of materials there is so low that most of it is in single atomic form. It is only when the gas condenses and collapses together into a dense cloud that there are sufficient numbers of atoms close enough to each other for these molecules to form.

Furthermore, out in space there's a lot of high-energy starlight that easily destroys molecules by simply breaking their bonds open. It is only inside these dense dark clouds that molecules can get together and be protected by the dust from light from the nearby stars—thus allowing the molecules to persist.

In such clouds most of the hydrogen is in the form of hydrogen molecules. It's a particularly unfortunate property of the hydrogen molecule, however, that it doesn't emit any radiation via rotational transitions. This is because both atoms of the hydrogen molecule are the same, and therefore the cloud of electrons around them is evenly distributed, so that we can't study hydrogen molecules by these techniques.

The most common molecule that we can study is carbon monoxide. Another molecule that has been seen in a couple of clouds in space is ethyl alcohol, and it can be used to illustrate the enormity of those dark clouds and of the space in which they are found. The total amount of alcohol in those clouds—if distilled down into bottles—would amount to ten billion billion billion fifths of alcohol at 100 degrees proof. By comparison, the cloud from which our Sun formed contained 100 billion billion fifths of alcohol.

Of course, getting your hands on that alcohol wouldn't be easy. The densities are so low in space that there is only about one molecule of alcohol every cubic meter or so. This means that if the star ship *Enterprise* had a scoop out in front of it with a surface area of one square mile and was sweeping through such a cloud at the speed of light, it would take it a million years to gather enough alcohol for one drink.

The heaviest molecule observed to date is HC_9N, which consists of a long string of carbon atoms with an H on one end and an N on the other. It appears that carbon atoms like to form these long chains. The water molecule is one of the commonest molecules found in space. To date no truly life-forming molecules have been observed, such as amino acids or glycine, nor have any ring molecules been found. We have searched for some of them, and they don't appear to be there, but the frequencies of some of the others have not been measured well enough for us to look for them.

Of interest to earthbound chemists is the fact that molecules like N_2H^+ and HCO^+, which are singly ionized—a very difficult thing to have happen on earth—exist in abundance in space. On earth, densities are so high that while certain simple molecules can form, they immediately combine into more complicated molecules. So some molecules simply can't persist long enough on earth to be studied, but they can persist a long time in space because the densities are so low.

We can also make a study of molecules that contain isotopes. The common carbon monoxide molecule, for example, consists of $^{12}C^{16}O$, but you can also observe radiation from $^{13}C^{16}O$. Comparing relative abundances of these isotopes in space with those that you see on earth, we find that the material out in space has been enriched with more heavy elements and more isotopes through the process of stellar evolution.

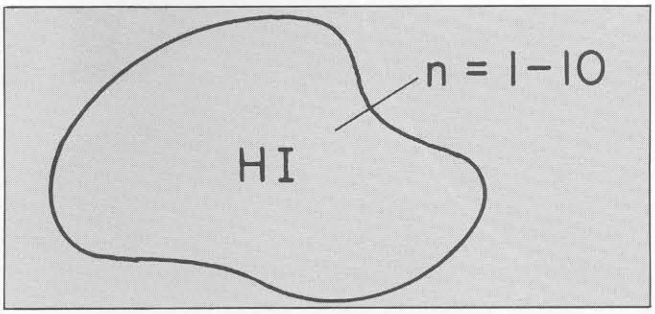
Observations of a great many molecular spectral lines, then, lead to the construction of the following scenario for the formation of stars: A cloud of dust and gas in space is held together by the force of gravity, each molecule pulling on every other molecule and holding the cloud together. It will not automatically shrink down to a small object, however, because it is also hot; the internal energy keeps the cloud from contracting. Most clouds are pretty well in balance between the outward force of their internal energy and the force of gravity tending to pull them together. In order for stars to form, something has to happen to disturb that equilibrium.

To begin with, perhaps there is a cloud of interstellar gas of such low density that the material in it is mostly in the form of atoms. Then something comes along and gives it an extra squeeze. Such pressure could come from several things that we know about in space. One is the shock waves from the tremendous explosions that take place when stars die. So the death of one star may actually start the processes that result in the birth of other stars.

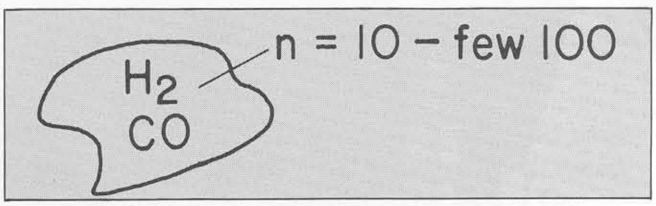
Another possible way for these high pressures to occur in our galaxy is from the non-even distribution of material. The density is higher in the spiral arms of galaxies than it is outside the arms. So if a cloud drifts into such a region, the pressure would be higher and it might get compressed.

However it happens, as the cloud gets compressed, its density increases, and the material in it starts to form into simple molecules like hydrogen and carbon monoxide. These molecules can radiate energy because they are heated up by collisions with other atoms in the cloud. Thus the cloud loses energy, its temperature drops, and it collapses. When smaller pieces of it are collapsed to much higher densities, the radiation of molecules such as hydrogen cyanide, formaldehyde, and so on can be detected. Then a little piece of this higher density material, pretty well in spherical shape, starts to get extremely hot in the center. Eventually it becomes so hot and dense that nuclear reactions can start. Out pours the radiation, which then balances the force of gravity, and a star is formed.

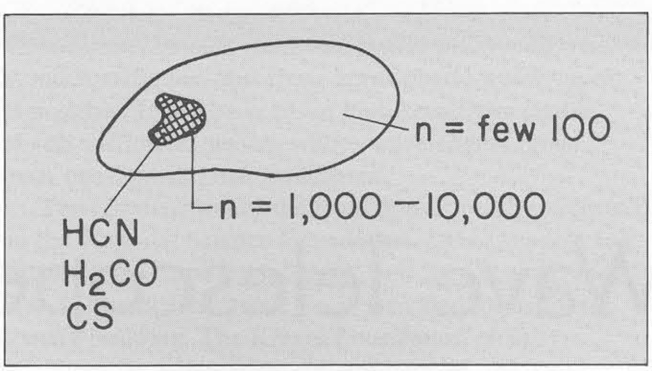
The final stage in this story of the birth of a star is that if the star is very hot and energetic, it will blow away the dark cloud of gas and dust remaining around it.



1. The formation of a star begins when a cloud of dust and gas in space starts to collapse. At that point the density (n) of atoms within the cloud is not more than about ten per cubic centimeter.



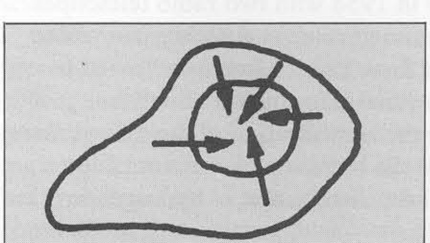
2. As the cloud collapses, the density of atoms becomes a few hundred per cubic centimeter, and simple molecules like H_2 and CO are formed.



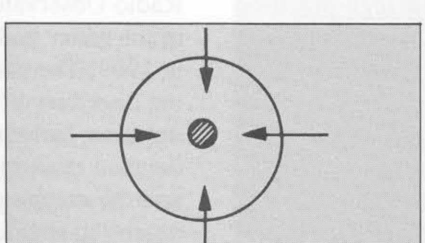
3. Eventually regions of up to 10,000 atoms and molecules per cubic centimeter begin to appear here and there in the low-density cloud. These higher density regions can be detected via their emissions from molecules such as HCN, H_2CO, and CS.

In summary, we have believed for a long time that new stars were contiuously being born in the dark clouds in our galaxy, but we didn't know how it was happening because we couldn't see into the depths of these clouds. This has been changed with the opening up of new regions of the electromagnetic spectrum in the short radio wavelengths and the infrared wavelengths. In the frequencies and intensities of those waves we can see the gradual increases in density and the gradual collapsing of material in the processes that precede the formation of a star.

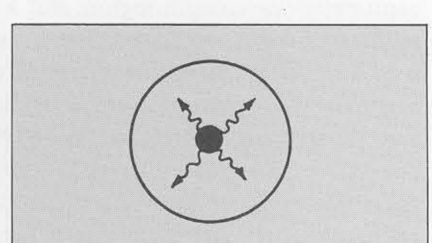
These regions are studied in the radiation of some fairly exotic molecules, which are very interesting in their own right from the chemical point of view. Among other things, they illustrate the ease of forming complicated molecules containing carbon, and show us that the materials of the dark cloud out of which our Sun formed contained a lot of heavy elements, and also contained complex molecules (most of which would be destroyed as the Sun was born). So the seeds for forming complicated organic molecules were already there in the dark cloud. Such molecules formed not only in our solar system, of course, but must do so in the gas from which other planetary systems were born. Perhaps such molecules contain the seeds of life everywhere in the universe. □



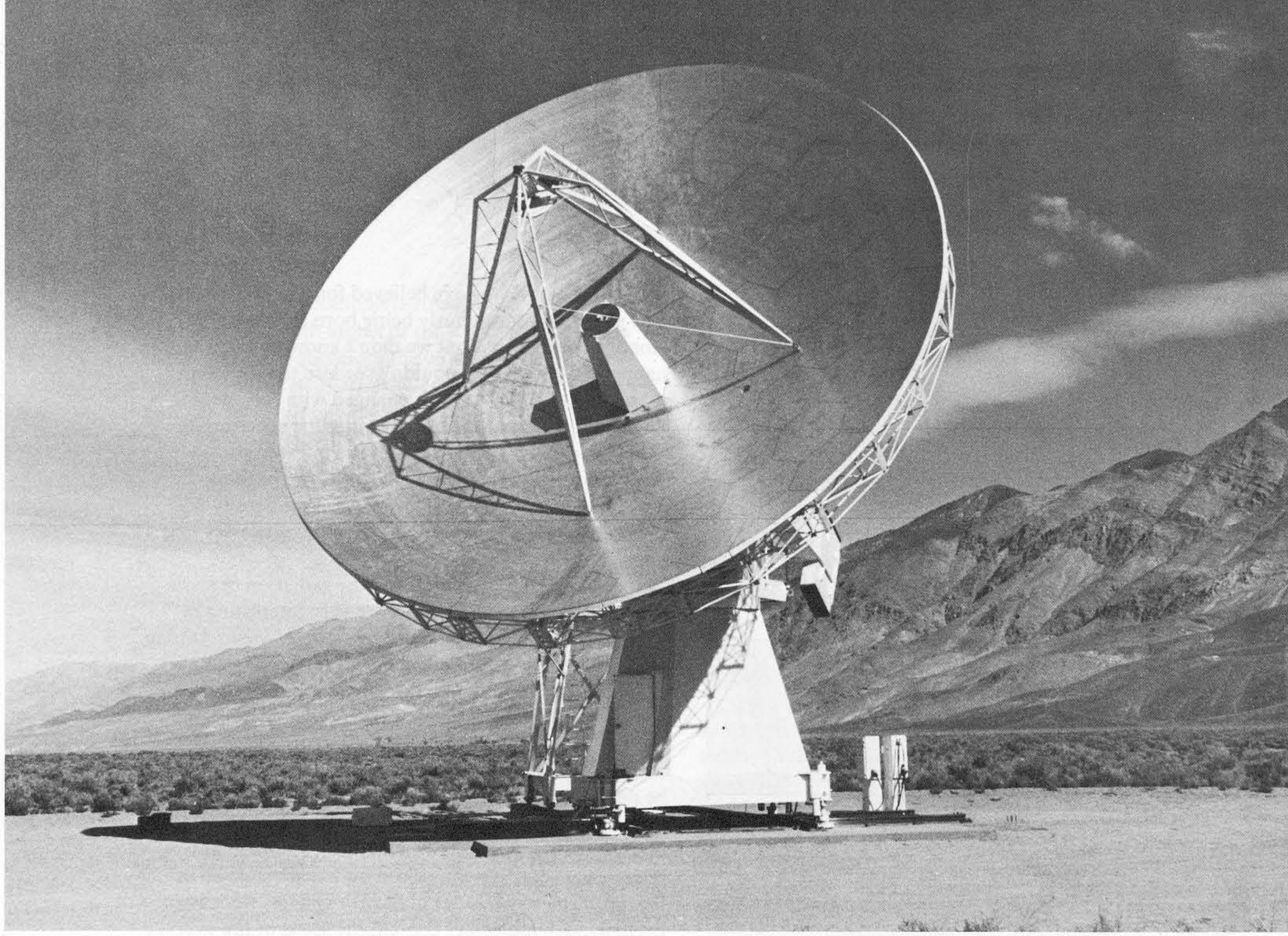
4. Some of the higher density regions contract into small spheres, becoming "protostars."



5. Because of gravitational collapse, the center of such a protostar heats up, becoming more dense.



6. When the center becomes hot and dense enough, nuclear reactions start. A star is born.



The Millimeter-Wave Telescope

Most work in radio astronomy is carried out in the centimeter-wavelength region. But a new high-precision millimeter-wave radio telescope at the Owens Valley Radio Observatory has now opened up a whole new region of the spectrum to study by astronomers.

The new radio telescope, which has been in operation since November 1977, has already reached the highest resolution ever achieved with a single-dish radio telescope, and it has also achieved several times better sensitivity than any other device for examining millimeter-wavelength radio waves from space.

A pioneer in the relatively new field of radio astronomy, Caltech began operating its Owens Valley Radio Observatory in 1958 with two radio telescopes in the meter and decimeter range. Another was added in 1969. The use of these radio telescopes has led to the discovery of essential information about the universe, including the identification of the first quasars, detailed mapping of the radiation belt around Jupiter, and the mapping of the distribution of hydrogen in nearby galaxies.

Studies of millimeter wavelengths and below should now give astronomers new information about molecules in other gigantic nebulae in outer space where stars condense from gas and dust. Some nebulae are almost certainly sites where new stars are being formed today, and studies at these very short wavelengths will be important in understanding how stars are born.

Until recently astronomers have been nearly "blind" at wavelengths of one millimeter and less, because the technology needed to build the necessary receivers and high-accuracy radio antennas had not been developed. The original Caltech instrument was constructed using high-precision techniques developed by Robert B. Leighton, professor of physics, and his colleagues—Alan Moffet, director of the Owens Valley Radio Observatory and professor of radio astronomy; Gerry Neugebauer, professor of physics; and Duane O. Muhleman, professor of planetary science.

Two more millimeter-wave telescopes will be installed at Owens Valley in the next few years, and the three telescopes, mounted on railroad tracks allowing them to be moved perhaps as much as 1,000 meters apart, will constitute an interferometric array. The millimeter-wavelength array should be capable of resolution up to 100 times higher than that of a single large telescope.

A fourth telescope, with slightly greater precision, will be installed on a mountaintop, to place it above as much radiation-absorbing atmospheric water vapor as possible. It will be used for high-sensitivity studies of sub-millimeter waves, whose wavelengths range from one-tenth to one millimeter.

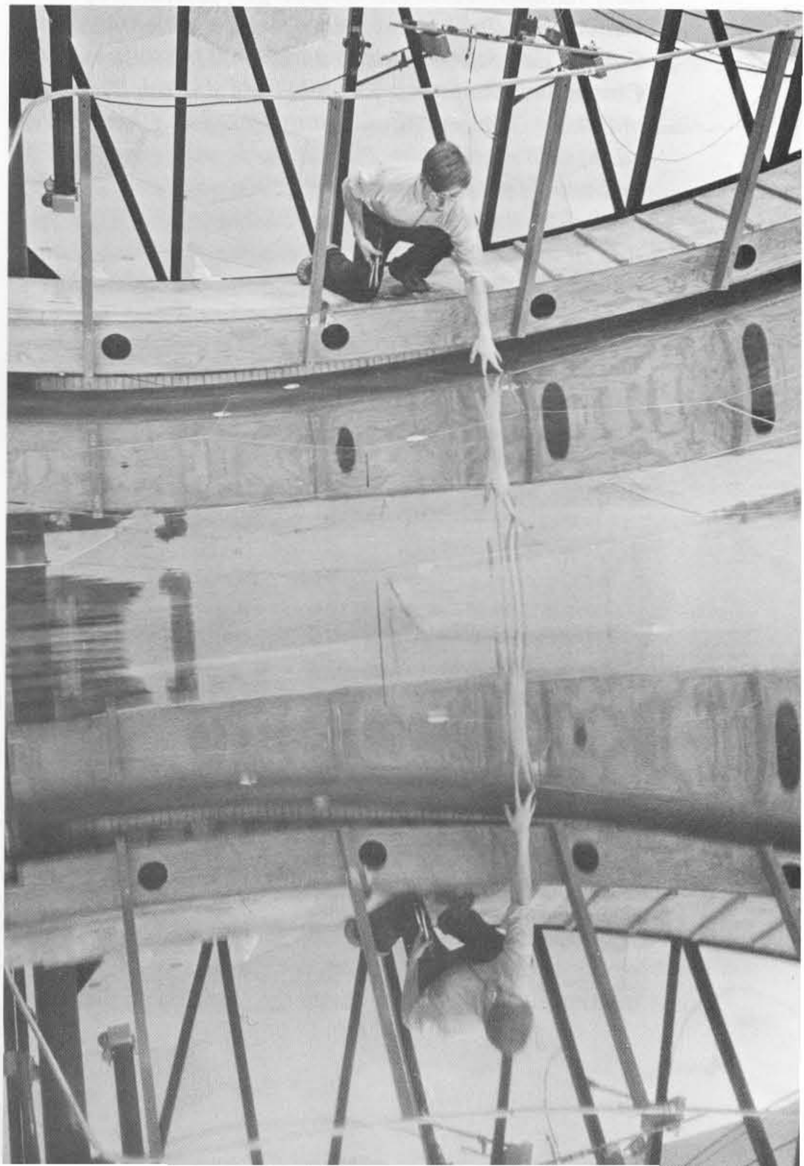
The construction of the telescopes is being supported by the National Science Foundation. Other support for initial design came from NASA, and the Oscar G. and Elsa S. Mayer Charitable Trust provided funds for the control building. The Kresge Foundation of Troy, Michigan, is supporting construction of the sub-millimeter mountaintop telescope. The telescopes will be operated as nationally available scientific facilities, with as much as half the observing time allotted to visiting scientists.

The instruments are being constructed using high-precision techniques developed by Leighton and his colleagues. Each 10-meter (34-foot) radio dish is constructed with a framework of steel tubing, supporting a reflector surface composed of interlocked hexagonal panels. Each panel is an aluminum honeycomb about three inches thick—which affords both strength and light weight—covered with thin aluminum sheets.

After assembly of the steel framework, and mounting of the honeycomb panels, the entire dish is rotated on a turntable, like a gigantic lazy Susan, and the honeycomb surface is shaved to the precise shape required, using a fine, spinning saw blade. Then the aluminum sheets are glued in place, using a vacuum process to mold them onto the honeycomb. The sheets may then be chemically etched to even finer tolerance.

In order for a telescope to be useful for focusing at millimeter wavelengths and below with little distortion, its surface must be a parabolic curve accurate to better than two-thousandths of an inch or less. The new dishes have surface accuracies of about one-thousandth of an inch, and the sub-millimeter-wave telescope will have an accuracy of less than one-thousandth of an inch. □

Checking the mirror of the prototype telescope after final preparation in the old 200-inch optical shop.



Caltech Goes to China

Entries from a Diary

by Rodman W. Paul

Last summer Marvin L. Goldberger, president of Caltech, received an invitation to bring a ten-man Caltech delegation to visit educational institutions in China, with the primary host being Tsinghua University in Peking. The invitation was extended by Chou Pei-yuan, who received his PhD at the Institute in 1928 and who is president of Peking University and acting chairman of the Scientific and Technological Association of the Chinese People's Republic. Such an exciting offer was accepted happily, and these people set out from LAX on September 6:

Marvin L. Goldberger, *President of Caltech*
R. Stanton Avery, *Chairman of the Board of Trustees*
Arnold O. Beckman, *Chairman Emeritus of the Board of Trustees*
Bruce C. Murray, *Director of the Jet Propulsion Laboratory*
Seymour Benzer, *James G. Boswell Professor of Neuroscience, representing the Division of Biology*
Robert F. Christy, *Vice President and Provost, representing the Division of Chemistry and Chemical Engineering*
Robert H. Cannon, Jr., *Chairman of the Division of Engineering and Applied Science*
Barclay Kamb, *Chairman of the Division of Geological and Planetary Sciences*
Rodman W. Paul, *Acting Chairman of the Division of the Humanities and Social Sciences*
Rochus E. Vogt, *Chairman of the Division of Physics, Mathematics and Astronomy*

September 6: Departure day at last. It's only a few weeks since Murph Goldberger startled us by announcing that he was going to invite the Division chairmen along with trustees Stan Avery and Arnold Beckman to go with him to the People's Republic of China, but it's been a scramble to tidy up the Division's business and my own, read through half a dozen good histories of China, get "shots" at the Health Center, and buy more camera film than I ever owned before. Clothing has been no problem, since Murph, who has led two previous expeditions to China, tells us that for visitors to egalitarian socialist China correct uniform is simply sport shirts and washable slacks. (Mildred Goldberger warns against loud-colored shirts because they would contrast too much with the universal black or gray Mao suits of our hosts.) We're told to bring one business suit apiece to wear at the half-dozen formal banquets that we are likely to be tendered.

As usual, the plane was late in taking off from LAX, but now we're midway on as comfortable a flight as anyone could ask for. Murph turns out to be not only a poker player but a winner.

Now approaching Tokyo, where we change planes for Hong Kong. It's intriguing to realize that, although we took off from LAX after 1:30 p.m. and have flown westward for ten hours and a half, we are only just now seeing a golden red sunset over Mt. Fuji.

September 8, Hong Kong: Murph has given us this one day in Hong Kong to rest up before we enter the People's Republic, but it's too exciting here to loll about. This is an intensely alive place. It must be the most crowded city in the world. The streets and stores are filled with lively, cheerful-looking crowds that are constantly in motion. There seem to be vast numbers filling menial jobs, presumably because the labor market is flooded with both Hong Kong's own local poor and with thousands of refugees from the mainland. The tall buildings that are going up everywhere suggest how scarce, and hence expensive, land has become. Out in the harbor there is still another population that lives afloat. The junks that are home for so many are motorized now, to my regret, for I dearly wanted to see Chinese junks with their great rectangular sails tacking through this mass of international shipping.

For dinner we took a funicular tram part way up Victoria Peak, then hiked the rest of the way to a restaurant from which we had a superb view over the city and harbor. Barclay Kamb climbed further up the hill than anyone else, to prove that he really is a geologist. Robbie Vogt's suitcase never arrived last night; when recovered by the airline many hours later, it had been robbed of an expensive telephoto lens.

September 9: Left early by train for Canton, which my Chinese-printed guidebook calls Guangzhou. We traveled up to the Chinese border in a hot, crowded, rather dirty capitalist train; at the border we walked across the bridge into Chinese territory and climbed into an air-conditioned, comfortable, spotlessly clean socialist train where they served us green tea. In this first confrontation, capitalism loses.

Now we are moving smoothly through miles of hot, steamy tropical country, where the canals and embanked streams are heavy with mud. Every inch of land is in use, most of it in rice, but there are patches of American corn and numerous small fields with other crops. Tree-planting projects everywhere. The long-leafed pine I can understand, but why the eucalyptus? Water buffalo, presumably a prized possession, are being grazed, with one person assigned to watch each buffalo. Robbie Vogt is prepared to retire as chairman of Physics, Mathematics and Astronomy to become a water-buffalo tender. We encouraged him in this idea, assuring him that water buffalo would be much easier to deal with than the Caltech faculty.

The hard-working peasants that we see out the window don't look like newspaper pictures of smiling characters in Mao suits. They are often shirtless, wear big straw hats, miscellaneous pants, and look hot and sweaty like any other humans in this climate. Men and women work side by side in the rice fields, up to their knees in water, and bent over for hours at a time. Other peasants move along the dirt roads carrying on their shoulders a heavy load that is nicely balanced in two parcels suspended from either end of a bamboo pole—a technique for weight-carrying that the Chinese have practiced for centuries. But modernity is there too, because a few farm trucks and some dark green trucks of the People's Liberation Army go roaring past, kicking dust into the faces of the pedestrians, while bicycles are omnipresent and used for carrying all sorts of loads in addition to the rider.

September 10, Canton: When we reached Canton yesterday evening, we were met by a large delegation representing the local and national ministries of education and Sun Yat-sen University, which we are to visit. The Chinese are punctilious hosts. We are learning that they are always on hand to greet you when you arrive; and after everyone has shaken hands with everyone else, starting with the heads of the visiting delegation and the institution about to be visited, then you are always taken into a reception room to have green tea. You sit in overstuffed armchairs that are protected by antimacassars, but no business is done at that time, because your hosts' primary concern is to let the visitors rest after their journey. There is here a charming old-fashioned concern for guests that we rarely display in our bustling society.

We are quartered in a characterless, run-down hotel that is in process of reconstruction. Robbie claims that it reminds him of a German army barracks, but I've told him that it's luxurious compared to the United States Navy's training quarters that I once knew. The night was exceedingly hot and humid, but I slept hard

Murph Goldberger and Madame Wang, a physicist, who was technical host to the group during most of the trip.

until early morning, when the electric fan ran wild and started to chew up the room. Jerking out the base plug stopped the carnage, but I couldn't get back to sleep, and so sat in the window watching the little run-down cottages behind the hotel where the day's routine was just beginning. Each family brought out a bucket of water and a wash basin and squatted down to wash face and arms and brush their teeth. They spit into an open gutter and dumped their wash water there, while chickens ran around them as if in a barnyard. Apparently life in the city is not all that different from the peasant existence that we saw yesterday from the train windows. Clearly, for most people this is a poor country.

In sharp contrast, in the evening the officials of the ministry of education took us to dinner at a famous restaurant, which served an excellent and exotic meal. Faced by sheer need to survive, I did surprisingly well with the chopsticks. The banquet lasted through two and three-quarters hours of steady eating and featured eight main courses plus numerous special vegetable servings. This is quite aside from small items equivalent to hors d'oeuvres that we had before the meal, and a soup that tasted like Floating Island that ended the feast. (In China soup is served at the end, not the beginning, of dinner.) Besides, two-thirds of the way through we had a specialty, which consisted of a kind of chicken soup filled with much solid matter.

To get ready for this splendid repast I had taken a walk before supper, and had come upon a long, low building from which came such a noise of high-pitched voices that I assumed a political meeting must be taking place. Instead, it was a civilian mess hall where perhaps 200 working men sat in rows on benches, packed solid against each other, hot and sweaty, as they downed bowls of rice and a kind of thin stew. Truly, there are several levels of economic existence in this city.

The same contrast characterizes transportation. Most people travel on foot, or on the thousands of bicycles that are constantly whizzing down each main street, or on the overcrowded shiny new buses. At times it's impossible to cross the street because the bicycle traffic is so heavy. But we, as allegedly distinguished visitors, are taken everywhere in a fleet of state-owned cars that crash through the foot and bicycle traffic with a furious blowing of horns. Protocol dictates that Murph must ride in the lead car, and he was fated to ride alone until he labored through an explanation of Stan Avery's distinguished status as chairman of the Board of Trustees. No more than two of us are ever permitted to ride in a single car, apparently for fear that we might be crowded or uncomfortable. Or perhaps it's just protocol again.

At times it is impossible to cross the street because the bicycle traffic is so heavy.

We have been placed under the care of Wu Kuo Hua, a member of the Foreign Language Teaching Group at Tsinghua University. Tsinghua is to be our principal institutional host in China, responsible for our living and travel arrangements and for paying our bills. By a somewhat unfortunate phrase, Tsinghua was described to us as "the MIT of China." It is located in Peking and is the scientific sister to Peking University, which has a much more general curriculum that spans the arts as well as the sciences. Mr. Wu, as we have learned to call him, is our interpreter, but he is also responsible for our daily plans. He is a good-natured and patient young man who seems destined to have a nervous breakdown if we don't quit making special requests to visit places not on our itinerary. We are learning that, in a highly organized, centrally administered government like socialist China's, any deviation from a formally prepared schedule causes administrative consternation and an almost audible sound of gears grinding as officials try to redirect what seems to be massive machinery.

A visit to what is now called Sun Yat-sen University was a nostalgic experience for Stan Avery, who studied there during a year that he spent as a student in China during 1929-30. The place is run down, but in a poor country, perhaps it's a question of regarding other things as more immediately important than paint and gardening.

September 11, Peking: We arrived last night after a flight of more than 1,100 miles from Canton. Geographically as well as in population this is a huge country, about the size of the United States. Our flight took us from the humid tropics of southern China up to the much drier plains that surround Peking, which used to be called "the northern capital." Expressed differently, we went from rice country to wheat country. En route we swept over the two great rivers that drain eastern China, the Yangtze and the Yellow, and over many more miles of mountains than of fertile plains or valleys. I can well understand why my handbook says only 11 percent of China is under cultivation.

Robbie Vogt is destined to be our hard-luck traveler. In addition to having the airline lose his suitcase, his pajamas have failed to come back from the hotel laundry, and now he, an insomniac, has been assigned to room with me, a snorer. He says it's a conspiracy. He points out that he was the last one to be served at dinner and that he can't get any more of the only brand of Chinese beer that he likes.

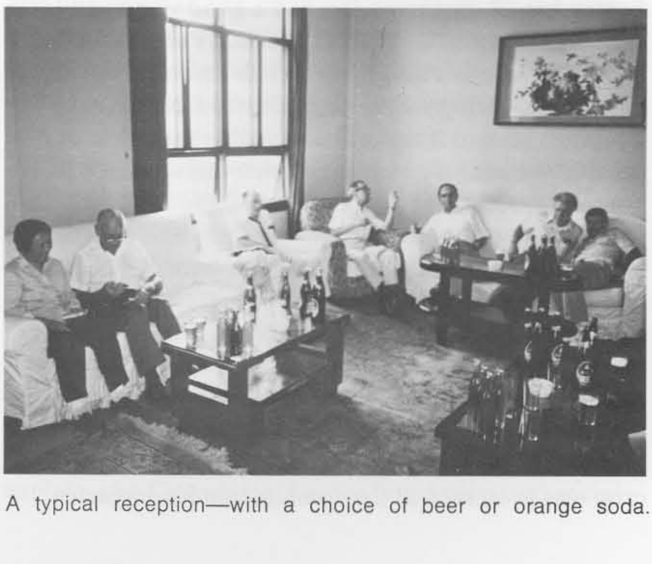
If you thought Canton was crowded, you ought to see Peking. Even though the main streets have been widened into broad boulevards, they are jammed during rush hours with more people than I ever saw before. The handbook says that 95 percent of China's 900,000,000 people live in the cities and villages of eastern China, while the arid and mountainous western regions go almost empty. There is an almost oppressive sense of being always engulfed in masses of people. In transportation, as in so many aspects of this revolutionary society, the new competes with the old: Big, modern double-length buses (hinged in the middle) carry overloads the way San Francisco cable cars do; but they are surrounded by thousands of bicyclists and pedestrians, while off in the gutter ancient horse-drawn wagons, handcarts, and pedicarts struggle stolidly along. At intervals the moving crowd scatters precipitately to make way for horn-blowing official cars like ours or the omnipresent military trucks of the P.L.A.

The newer public buildings that we passed en route to our first day at Tsinghua University were all done in the massive rectangular style that Stalin imposed on Soviet Russia. It's a pity that the Chinese have given up their traditional architecture so easily.

At Tsinghua we went through the usual procedure of being taken into a reception room for tea, but very soon we were at work. The host institution led off with careful presentations that described the nature of their university, its uncomfortable recent history, and its pressing needs during the immediate future. Our delegation then responded, with Murph giving a clear and succinct introductory statement, while Bob Christy and others took up selected aspects of Caltech.

It is becoming very clear why Caltech was asked to bring a delegation to China. The Chinese universities have just emerged from a disastrous period of ten years of neglect and persecution. First, during the 1960's, they suffered the Cultural Revolution, during which the universities were closed and the professors were sent off to rural areas to learn farming. (Reflection: This must have been almost as hard on the farmers as on the professors.) Then in the 1970's they were hit by the prejudices of the Gang of Four, headed by Chairman Mao's wife. Being profoundly anti-elitist, the Gang of Four were also anti-intellectual. When the universities were permitted to reopen on a limited scale, with only a small percentage of their former enrollments, they were sent students and new junior faculty who had been chosen on the basis of political worthiness rather than on tested or demonstrated intellectual ability. This autumn, for the first time in a decade, the universities are going to receive students who have been required to take entrance examinations.

The new "pragmatic" government that has gotten rid of the Gang of Four is sharply aware that their country has lost at least ten years of teaching and research, and in practice the loss must amount to a full generation, because before the Cultural Revolution, China suffered years of imposed Russification, during which the universities tried unhappily to copy the



A typical reception—with a choice of beer or orange soda.

Caltech Goes to China

The Imperial Palace at Peking

Russian system that separates teaching from research. Before that the country was torn up by the civil war and the war with Japan.

As part of the turn to pragmatism, older scholars who took higher degrees years ago at American, European, and Japanese universities have been "rehabilitated" and are now in positions of authority. The key person in opening negotiations with Caltech, for example, was Chou Pei-yuan, who took his PhD at Caltech in 1928 (same year as Arnold Beckman). Chou is president of Peking University and vice chairman of the Chinese Academy of Sciences. These older scholars are eager to send both students and faculty to well-known places like Caltech, so that China's obsolete science can be brought up to date.

September 12, Peking: We had a good visit to an agricultural commune outside Peking, except that we had no chance to visit homes or talk casually with individuals. Being sensible people, the Chinese have doubtless seen to it that our experience should be at a notably successful commune, which this certainly is. It houses 18,000 families, for a total of about 80,000 people. The commune is so nearly self-sustaining that it provides practically all services for humans, animals, and machines. It feeds itself and exports its surplus to Peking. The commune raises cows, pigs, ducks, grain, rice, and vegetables. Really, it is a kind of well-organized agricultural factory run by the workers in accordance with a basic ideological scheme that has been altered to adjust to realities. Their most attractive crop was to be seen at the combination kindergarten and day care center. There the children looked healthy, happy, chubby, and altogether charming. They did a Tibetan folk dance for the "American friends," as we are termed. (Paying tribute to the culture of ethnic minorities is a big thing in China just now, hence the Tibetan touch.) Since both parents work, these little children get three meals a day at the school and can stay overnight if necessary.

September 13, Peking: A very good working session at Peking University today. Here, too, the lag caused by the Cultural Revolution and the Gang of Four has been very serious. It is an attractive old campus that incorporates the former Yenching Institute, which was designed by the American architect Henry Killam Murphy, who must have felt a well-deserved respect for traditional Chinese architecture. But the library, which claims 3,000,000 volumes, got stuck with the Dewey Decimal system years ago, just as we did at Caltech. I have a mental picture of some determined missionary shoving that disastrous cataloging system down their throats 50 years ago along with Western medicine, Christianity, and firearms. The intricate, almost arcane, nature of the Chinese language and the fact that it has no alphabet must give librarians some unusual problems.

By now the varying individual personalities of our delegation are beginning to reveal themselves. Barclay Kamb is our wanderer. He believes firmly that "a geologist can't get lost," and never hesitates to go roving off, despite the obvious fact that none of us can either read the street signs or ask directions. His Polaroid camera is a sensation, especially with children.

Barclay's Polaroid camera is a sensation wherever he goes.

Barclay's technique is to indicate by gestures that he wants to take someone's picture, then he develops the photograph while the intrigued subject waits and a crowd gathers. Then, with a flourish, Barclay presents the picture to his delighted victim. By that time everyone else wants to have his picture taken, and Barclay has done more good than 12 ambassadors.

Seymour Benzer is a wanderer of a different kind. He is eager to find restaurants that serve such delicacies as sautéed cobra, braised salamander, three-snake soup, and dog meat. Stan Avery had an apparently limitless supply of red self-adhesive stickers that say "smile" in Chinese and show a beaming face drawn with a few pen strokes. By now there are people all over eastern China who have red stickers on their coat lapel or shirt front. Bob Cannon keeps eagerly practicing the list of questions and salutations that a Taiwanese graduate student prepared for him back at Caltech (key question: "Where is the bathroom?"). Murph Goldberger is learning some valuable lessons that a new president should know. For example, after we had discovered the blessed fact that at any hotel we could order a "Western" breakfast of omelet, toast, and sometimes sausage, Murph, who is enthusiastic about Chinese food, proposed that we eat Chinese breakfasts. He was unanimously voted down. You can't press a faculty too far.

Nothing adequately prepares you for the sight of the Great Wall.

September 14, Peking: This was a great day. We have all been clamoring to see the Great Wall, and early this morning we were driven two hours northwest from Peking to climb and hike along a section of the wall that has been rebuilt for miles as an attraction for the tourist trade of both Chinese and foreigners. To me, as a historian, one of the encouraging signs has been to note that the modern Chinese, children of the most drastic revolution any nation has experienced, queue up in long lines to gain admittance to historic buildings and sites. Crowds of them were on the wall today, or having picnics at the base of this particular section. Despite a lifetime of seeing pictures of the Great Wall, nothing adequately prepares you for the sight of this immense structure snaking its impressive way into the distance, up mountain slopes and down again, as far as the eye can see—for 1,400 miles, we were told.

On the way home we visited the Ming Dynasty tombs at Dingling. Here, again, the Chinese government, although run by apostles of revolution, is carefully preserving this great historical treasure for its own people even more than for the lucrative foreign trade. I couldn't discover whether these monuments to harsh and unequal rule had been vandalized during the past 30 years, like Cromwell's Puritans scarring the great cathedrals, or whether the visible damage and graffiti were simply the normal work of ancient grave robbers and modern teen-agers.

In the evening we were taken to see the Peking Ballet stage a trilogy of highly stylized traditional Chinese fairy tales, quite free of political propaganda. I judge that one would not have been able to see this three or four years ago, for the Gang of Four demanded politically "relevant" drama. Another sign of China's return to sanity.

September 15, Peking: This was a fun day, however academic. I was sent out to Peking University to explain why Caltech teaches the humanities and social sciences. Despite the handicap of working through an interpreter (one learns to feed him only a few sentences at a time), this became a very lively session that filled the three hours before lunch, and the historians in this mixed audience of faculty and administrators asked me to return after lunch "to teach a sample class just as you would at Caltech." Any of my students at Caltech during the past 30 years would have recognized the performance that resulted, because I became absorbed in what I was doing, talked with my hands as I always do, worked from a map, and moved restlessly about while fielding questions that seemed to come from all over the crowded room. Many of the listeners understood a lot of English, and every time the poor interpreter stumbled, because he was an English teacher who knew no history, four or five of them would jump on him in furious bursts of Chinese. The pathetic part of this very active day was the discovery of how severely these members of my profession felt their isolation from the great international world of historical thinking. We kept at it for over three hours.

September 16, Peking: An extraordinary event. Mysteriously we were told that after dinner we should all go to our rooms, change into a dark suit, clean shirt, and tie, and wait for a possible call. When the call came, it was for us to enter a convoy of automobiles and be driven to the Great Hall of the People. This is an honor comparable to being summoned to an audience at the Kremlin or the Vatican. Through the darkness we swept down to Tian'anmen Square, swung past the front of this huge building that can seat 10,000 members of the Communist Party, and were admitted from the rear into a very high-ceilinged reception room. There, it developed, our host was to be one of the vice premiers of China, Wang Chen, one of the survivors of the Long March, a man greatly honored in the Party and in governmental circles. He seemed to be in his late seventies. His present post is Vice Premier for Industry and Technology.

We sat in the now familiar stuffed armchairs with antimacassars and were served green tea (of a special blend, we were told). The president and vice president of Tsinghua University and the other higher officials with whom we had been dealing all week were present. We felt a sense of tension. This meeting meant that the week had indeed gone as well as we had guessed, and now Caltech was about to be propositioned. The vice premier returned to the theme we have heard so often: The Cultural Revolution and the Gang of Four have left China far behind in science, technology, and related industry; the men trained at Caltech have done well and are now restored to authority. Would Caltech form a partnership with Tsinghua University to train faculty, postdocs, doctoral candidates, and eventually undergraduates?

Murph replied clearly, warmly, but carefully, lest he overcommit us. He is very good at this delicate business of diplomatic negotiations for scholarly objectives. He, Bob Christy, and Stan Avery have spent hours beating out a basic policy with the Chinese, while the rest of us have had specialized assignments or have gone walking about this intriguing city. Now Murph firmly stated Caltech's reservations, based on what we have learned from this "on-site" inspection. First, Caltech is a small place and is determined to remain so; hence we could not handle a flood of Chinese scholars. Second, it would be pointless to send to Caltech any save the very brightest. Third, a working knowledge of English is essential and must be acquired before arrival.

Our host, this aging survivor of the original group that has created modern China, replied with a speech that must have been outlined to him by his staff on the basis of the week's negotiations. It was an acceptance, point for point, of what has been tentatively proposed, including Bob Christy's suggestion that since it takes six years to train a doctoral candidate and the Chinese are in a hurry, the process could be speeded up by first sending present faculty and postdocs for relatively brief periods of intensive study (one to two years). They could then return to China at once to begin educating younger men and women who could form the next wave of scholars to be sent for study in the West.

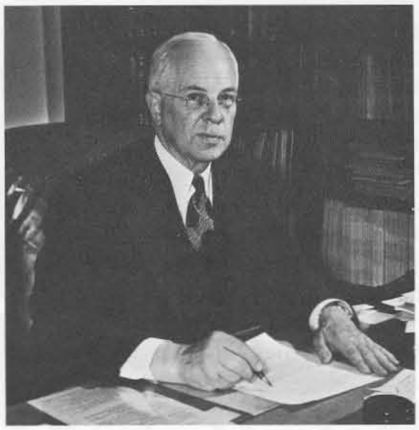
So there was agreement on both sides, and suddenly this solemn, fascinating experience was over, amidst a veritable downpour of expressions of mutual esteem and hopes for everlasting friendship. The main purpose of our visit to China has been successfully completed.

Murph and Bruce Murray are to fly back to California tomorrow morning, after we make a visit at 8 a.m. to view the late Chairman Mao's body as it lies in state (in a glass case) in the huge new mausoleum that the Chinese erected in record time. So ends the first half of our visit. □

Part II will appear in our next issue.

Robert L. Daugherty

1885 - 1978



Robert L. Daugherty's association with Caltech extended over 74 years —beginning in 1904 when he enrolled as a student in Throop Polytechnic Institute, and including 37 years as professor of mechanical engineering and 22 years as professor emeritus. He died on August 20, 1978, just 19 days short of his 93rd birthday.

He was born on September 14, 1885, in Indianapolis, Indiana, and later his family moved to Pasadena where he attended, and graduated from, Pasadena High School. He received an AB degree from Stanford University in 1909 and served as instructor during the academic year 1909-10. He was then appointed to the staff of Cornell University, where he served for five years. In 1916 he became professor of hydraulic engineering at Rensselaer Polytechnic Institute and in 1919 joined the Caltech faculty (still Throop Polytechnic Institute at that time) as professor of mechanical and hydraulic engineering.

In these 47 years of teaching Professor Daugherty inspired several generations of engineers both in his classes and through his writing. He was the author of 29 technical papers and 3 books. His very successful textbook *Hydraulics* was first printed in 1916 and, in an updated form, is still in print. Many thousands of students have found this book an excellent introduction to the subject, and Professor Daugherty explained its success by pointing out that when he arrived at Cornell University, he was assigned to teach five sections of hydraulics. After two years of this intensive teaching he knew every question a student could ask about hydraulics, and he wrote his book so as to answer all of those questions.

Professor Daugherty was a man of great energy and hard work, and this was evident throughout his career. He went to Cornell with the rank of instructor, expecting to work for an advanced degree. However, during his first year, he was promoted to assistant professor, which made him ineligible to receive an advanced degree from Cornell. As a special favor, Stanford University permitted him to register as a graduate student for two years and waived the residence requirement. He reported to Stanford upon his research and submitted a thesis for which he was awarded the ME degree. His thesis was published by the McGraw-Hill Book Company in 1913 under the title *Hydraulic Turbines*, and this established him as a leading expert in the field. His second book, *Centrifugal Pumps*, was published in 1915. Publication of *Hydraulics* in 1916 meant that within seven years of graduating from college Daugherty had published 3 books and 8 technical papers.

In his long association with Caltech, Professor Daugherty accumulated a vast fund of anecdotes that he enjoyed recounting. One of these stories dealt with the inauguration of the Athenaeum. When the building was completed in 1930, a formal inaugural banquet was held. Professor Daugherty showed up at the affair in his tuxedo and was met by an agitated Dr. Millikan, who said, "It is too cold for the ladies in their formal dresses, and no one knows how to start the furnace. Can you do something about it?" So Professor Daugherty went down in the basement and tried to figure out how the furnace could be started. By the time he succeeded, adjusted the temperatures, and returned upstairs, the food had been served and the banquet completed—so his participation in the inauguration of the Athenaeum consisted of serving as a full-dress stoker in the basement.

Professor Daugherty took his teaching very seriously and much enjoyed his contacts with the students. William Holladay, '24, tells how Professor Daugherty handled his class following a tonsillectomy. Daugherty never willingly missed a class, so even though he was unable to speak after his operation, he came to class, stood at the blackboard, and had the students ask him questions. Then he wrote the answers on the board.

In addition to his academic life he pursued an active professional career, serving as consultant on many important engineering projects, most of which involved in some way pumps or turbines. In the 1930's, together with his colleagues Theodore von Kármán and Robert Knapp, he served as consultant on the design of the precedent-setting water pumps for the Colorado River Aqueduct. At that time, this was the largest pumping project in the world, and it has since played an important role in the development of southern California. Later he served as consultant on the design of the 65,000 hp pumps for the Grand Coulee Dam and Irrigation Project on the Columbia River, which in the 1940's became the biggest pumping project in the world.

The consulting that gave Daugherty the greatest personal satisfaction was his solution of the ventilation problem on the Moffat Tunnel of the Denver and Rio Grande Railroad. The tunnel was at that time the longest in the world used by steam locomotives. Professor Daugherty was called in when it was found that the ventilation system could not clear the tunnel of smoke and exhaust gases. When he analyzed the situation, he perceived that a train passing through the tunnel could be thought of as a large loose-fitting piston pushing air ahead of it. He could also see that if the ventilation system were to be operated so as to take advantage of the piston effect instead of opposing it, the problem could be solved. This consulting project led to the publication of a paper, "Piston Effect of Trains in Tunnels" (*Trans. Amer. Soc. of Mech. Engr.*, Vol. 64, 1942), and in a discussion of the paper the chief engineer of the railroad stated that not only did the solution provide adequate ventilation but accomplished it at a 35 percent reduction in operating cost.

In 1946, following World War II, the first evidences of southern California smog appeared, and Professor Daugherty immediately became interested in the problem. In 1948 he was appointed chairman of the advisory committee to the hearing board of the Los Angeles County Air Pollution Control District. After his retirement from Caltech in 1956, at the age of 70, he served for 17 years as a full-time member of this board, and it was largely due to his good advice that the problem of industrial contribution to the smog was solved in an efficient and cooperative way.

On the occasion of his 90th birthday party, which was celebrated at the Athenaeum in 1975, he mentioned in the course of the conversation that he had not yet requested his annuity payments to begin—after all, the salary he received for serving on the hearing board was greater than the salary he had had as professor at Caltech and he did not need the money. What the Teachers Insurance and Annuity Association made of an annuitant who had not yet started collecting pension payments at the age of 90 can be imagined.

In recognition of his many professional achievements he was made a Fellow of the American Society of Mechanical Engineers. He always took great satisfaction in his membership in professional societies, particularly ASME, the American Society for Engineering Education, Society of Sigma Xi, and Society of Tau Beta Pi.

Another side of Professor Daugherty's career involved the development of the city of Pasadena. He served on the city's Board of Directors from 1927 to 1931, and he was Mayor from 1929 to 1931. These were particularly difficult years for city governments and were especially difficult for Pasadena. The new City Hall had been constructed on Garfield Avenue, and the new Central Library building had been constructed at the north end of that street. To complete the project an auditorium building was to be built at the south end. Although it was in the midst of the depression years, Professor Daugherty worked out a successful financing plan, and the resulting Pasadena Civic Auditorium became the nucleus for many future developments in the downtown area. He received a number of citations for his contributions to the city of Pasadena; the most recent was presented in the spring of 1978 by the Pasadena Beautiful Foundation.

One of the stories Professor Daugherty told about some of his duties as mayor had to do with a throw-away newspaper that started up in Pasadena during his term of office. This paper tended to publish the more libelous news items, and Professor Daugherty noticed that though many of those dealing with the city government were erroneous, they were nevertheless generating unhappiness among the citizenry. So he went to the newspaper office to discuss the problem. The editor explained that all the news items were typed up on slips of paper and put on a spindle on his desk; when he needed filler for the paper, he took the items off the spindle. He then claimed that he did not have time to check these items for accuracy or truthfulness. Said Daugherty, "If you don't object, I will check them for you." From then on, every Monday morning, Professor Daugherty stopped in at the editor's office, went through the slips on the spindle, and threw those that he did not approve of in the wastebasket. He considered this a great contribution to harmonious city government.

Professor Daugherty married Marguerite Rayner in 1932. Together over the years they maintained a special interest in Caltech students and other members of the Caltech community. They were hosts at many parties, and they attended almost all Caltech functions. On Alumni Day each year he was always the first on hand to greet those who came to campus—not only those he had known during his tenure as a faculty member, but also younger alumni—on behalf of Caltech, the Alumni Association, and the Gnome Club. He was at the 1978 Alumni Day on May 13, attending the seminars and, at the end of the day, joining the 1953 class reunion in Millikan Board Room.

His friends all agree that Robert Daugherty was an unusual man. He was a "gentleman of the old school," an exceptional writer of textbooks, an innovative and productive engineer, an unusually effective leader in our community, and an inspiration to many generations of students. Few institutions have had the good fortune to claim the allegiance and active support of such a man over a span of so many years. □

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