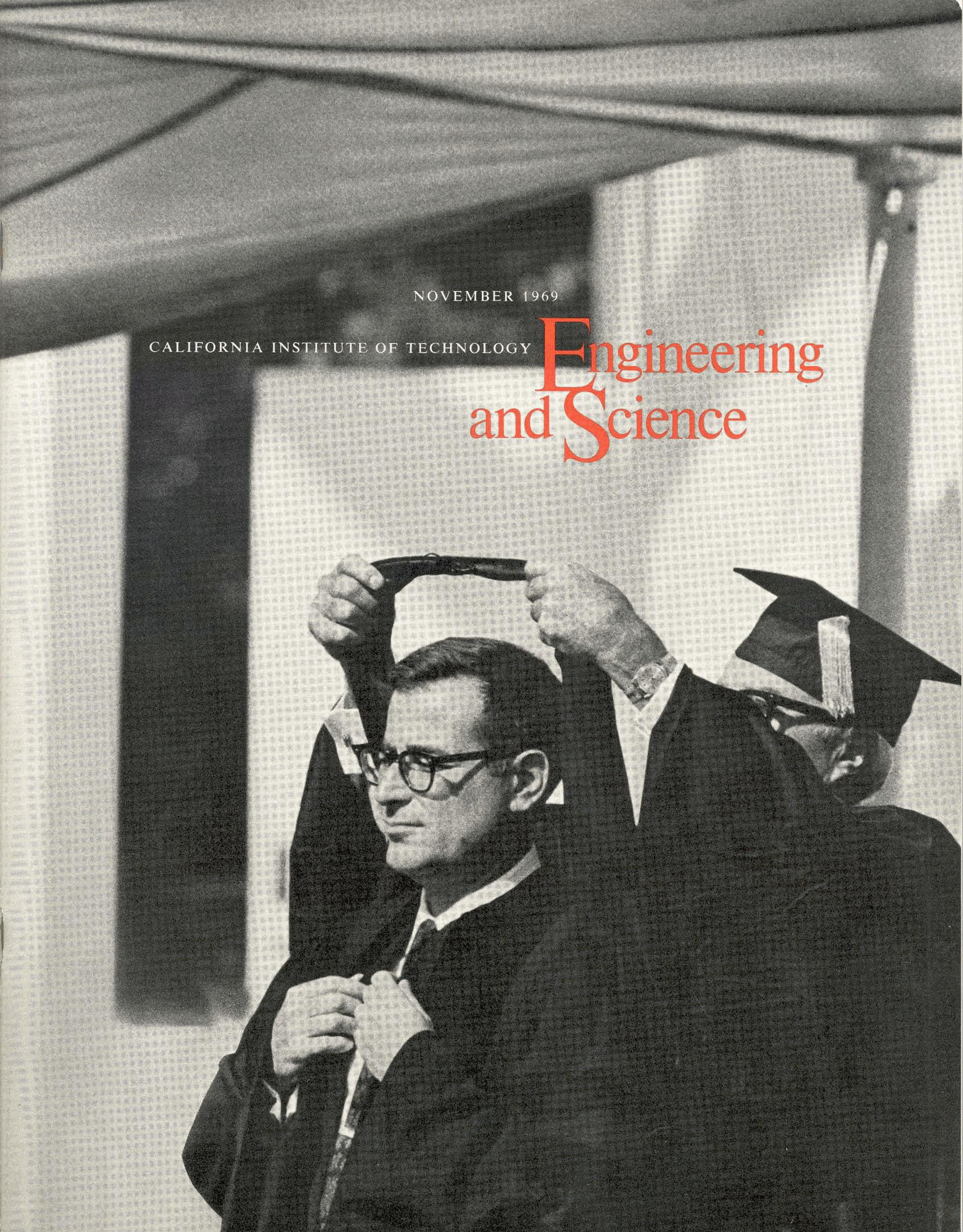
NOVEMBER 1969

CALIFORNIA INSTITUTE OF TECHNOLOGY

Engineering and Science



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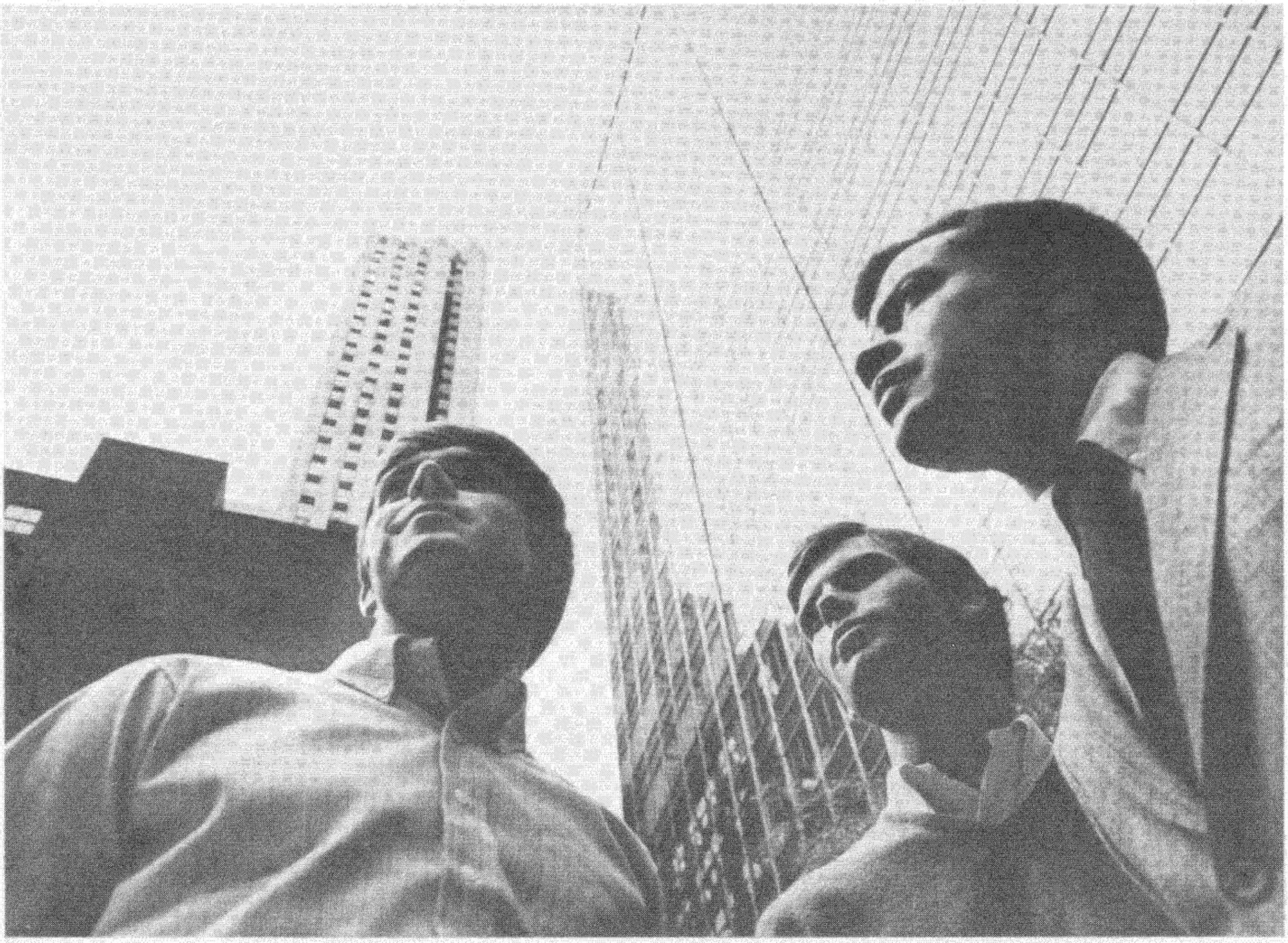

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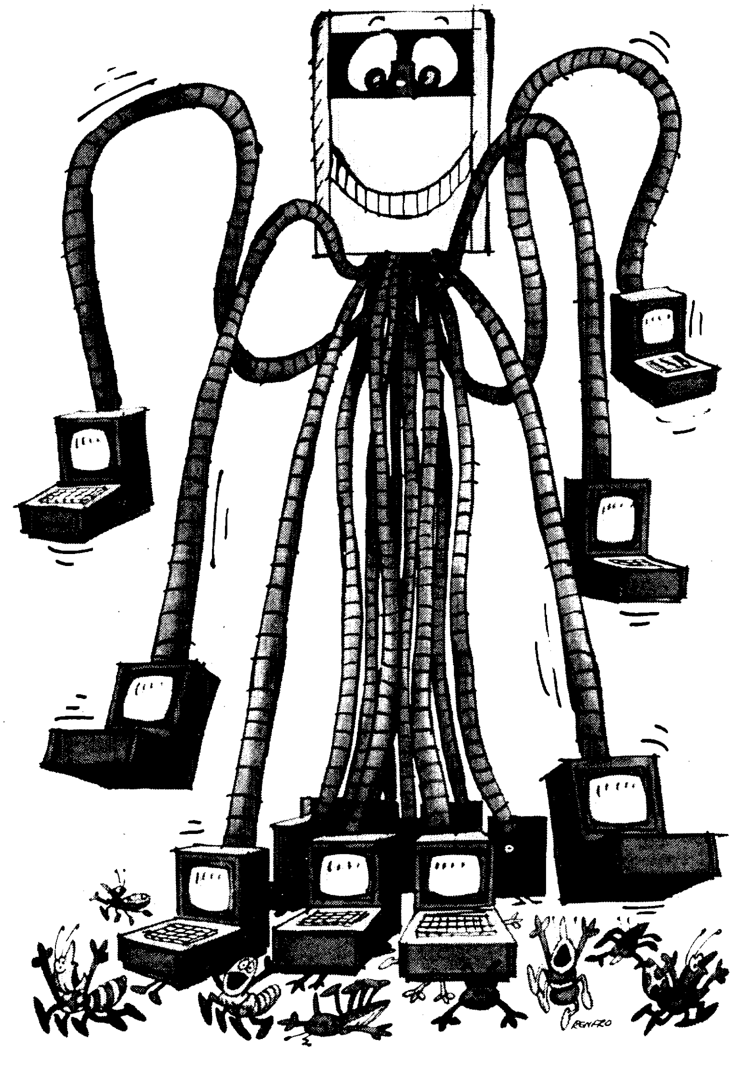

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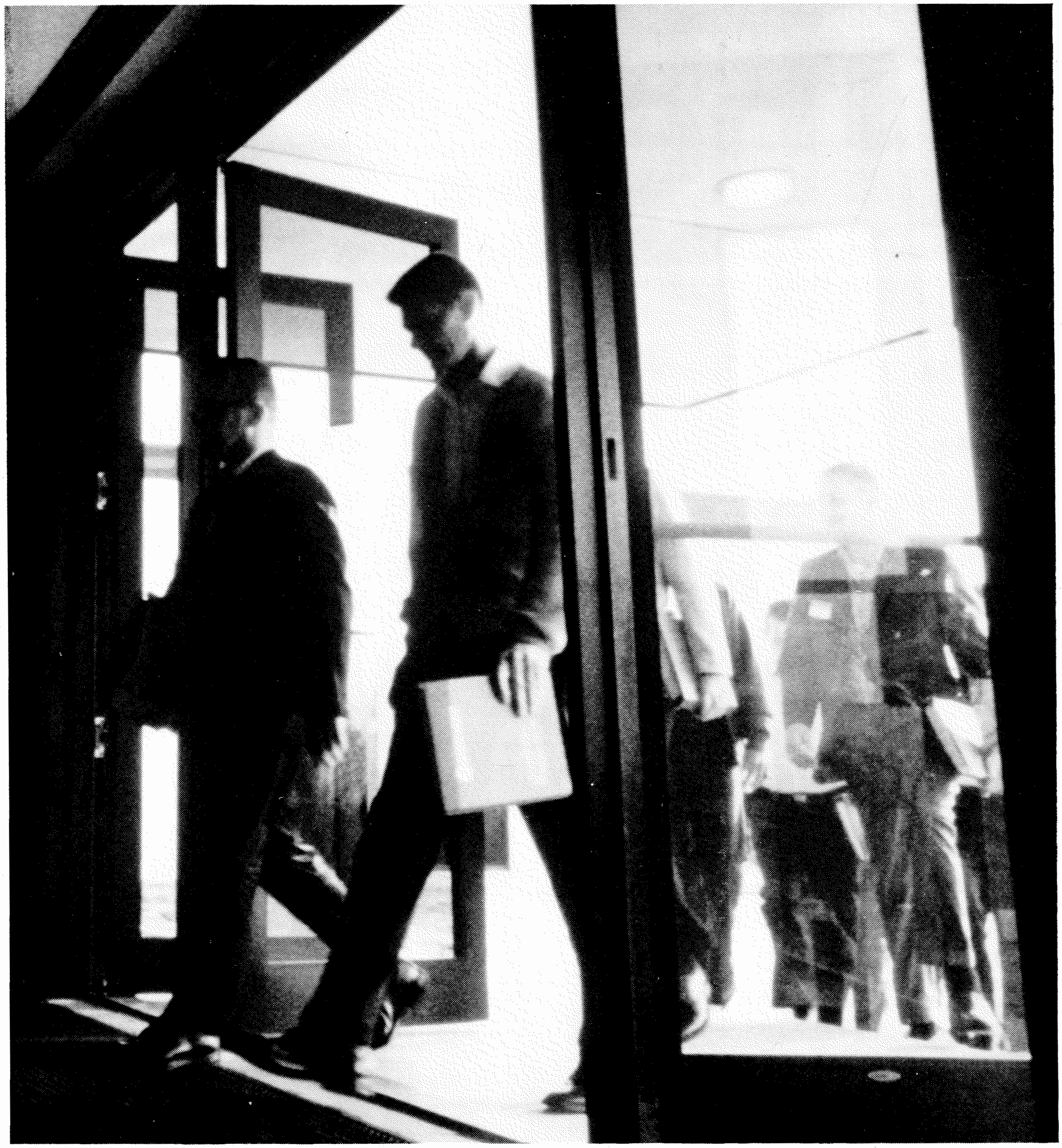

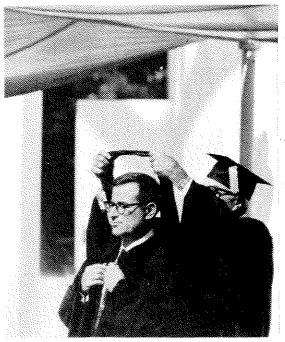

In this issue

Inauguration

On the cover, trustee Norman Chandler places Robert A. Millikan's doctoral hood on Harold Brown as he is formally inaugurated as Caltech president on October 30. More pictures of the day begin on page 18.

Brown's Address

On pages 19 to 28, the new president explains his concept of a university, and specifically Caltech, and delineates his hopes and plans for the Institute's future.

Nobel Prizes

Caltech's two newest Nobel Laureates, feted on pages 8 to 17, follow 11 other Caltech faculty or alumni who have won 12 Prizes since 1923. Their predecessors are Robert Millikan, 1923; Carl Anderson, 1936; William Shockley, 1956; Donald Glaser, 1960; Rudolf Mössbauer, 1961; Charles Townes, 1964; and Richard Feynman, 1965—all in physics. In medicine and physiology—Thomas Hunt Morgan, 1933, and George Beadle, 1958. In chemistry—Edwin McMillan, 1951; and Linus Pauling, 1954. Pauling also received the Nobel Peace Prize in 1962.

Prize Article

Kip Thorne, author of "The Death of a Star" beginning on page 30, is a Caltech alumnus ('62) who got his PhD at Princeton University in 1965. He came back to Caltech in 1966, and is now associate professor of theoretical physics. His article, which first appeared in *Science Year,* is the 1969 winner of a $1,000 prize from the American Institute of Physics-United States Steel Foundation for the year's best science writing in physics and astronomy.

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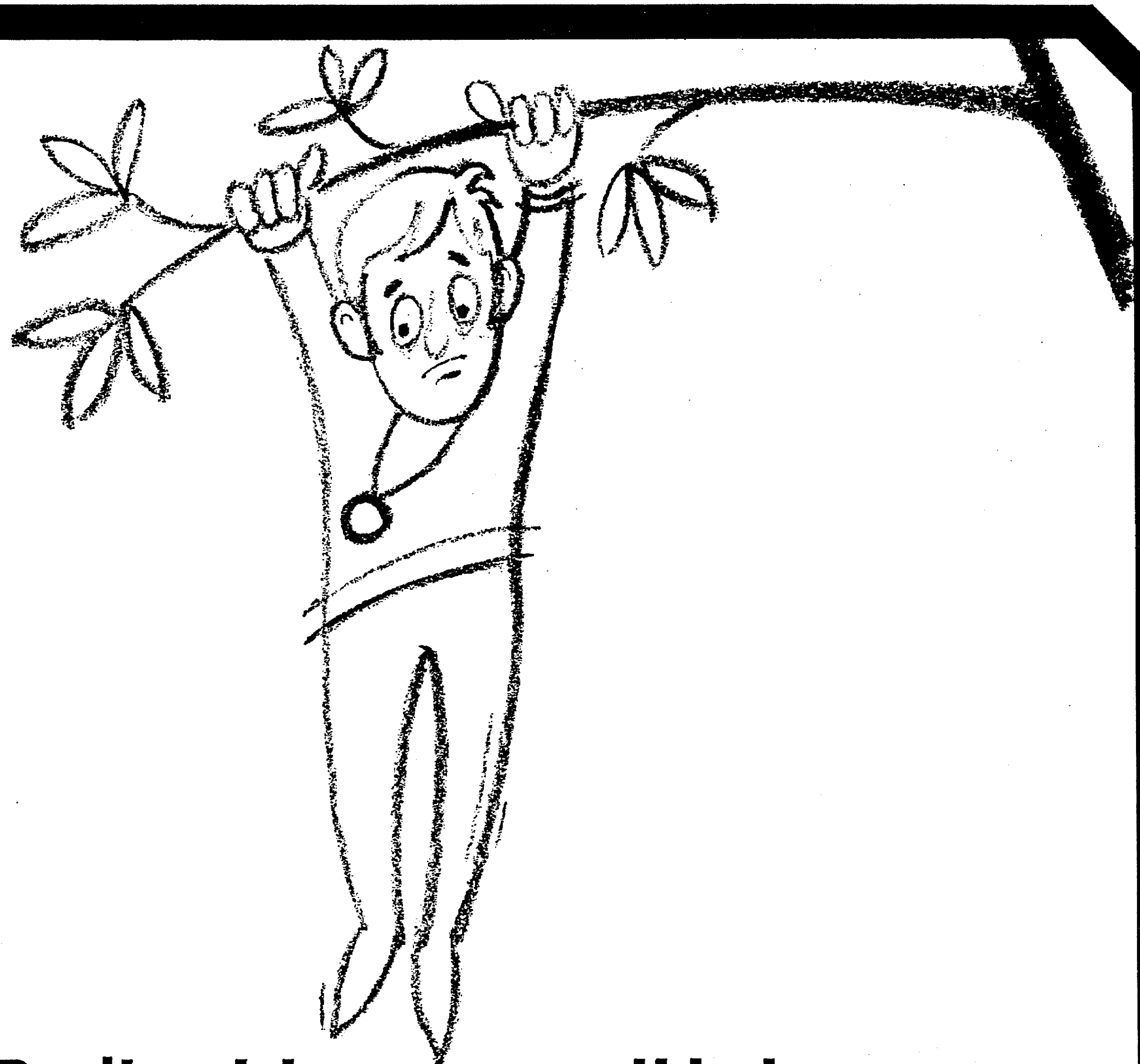

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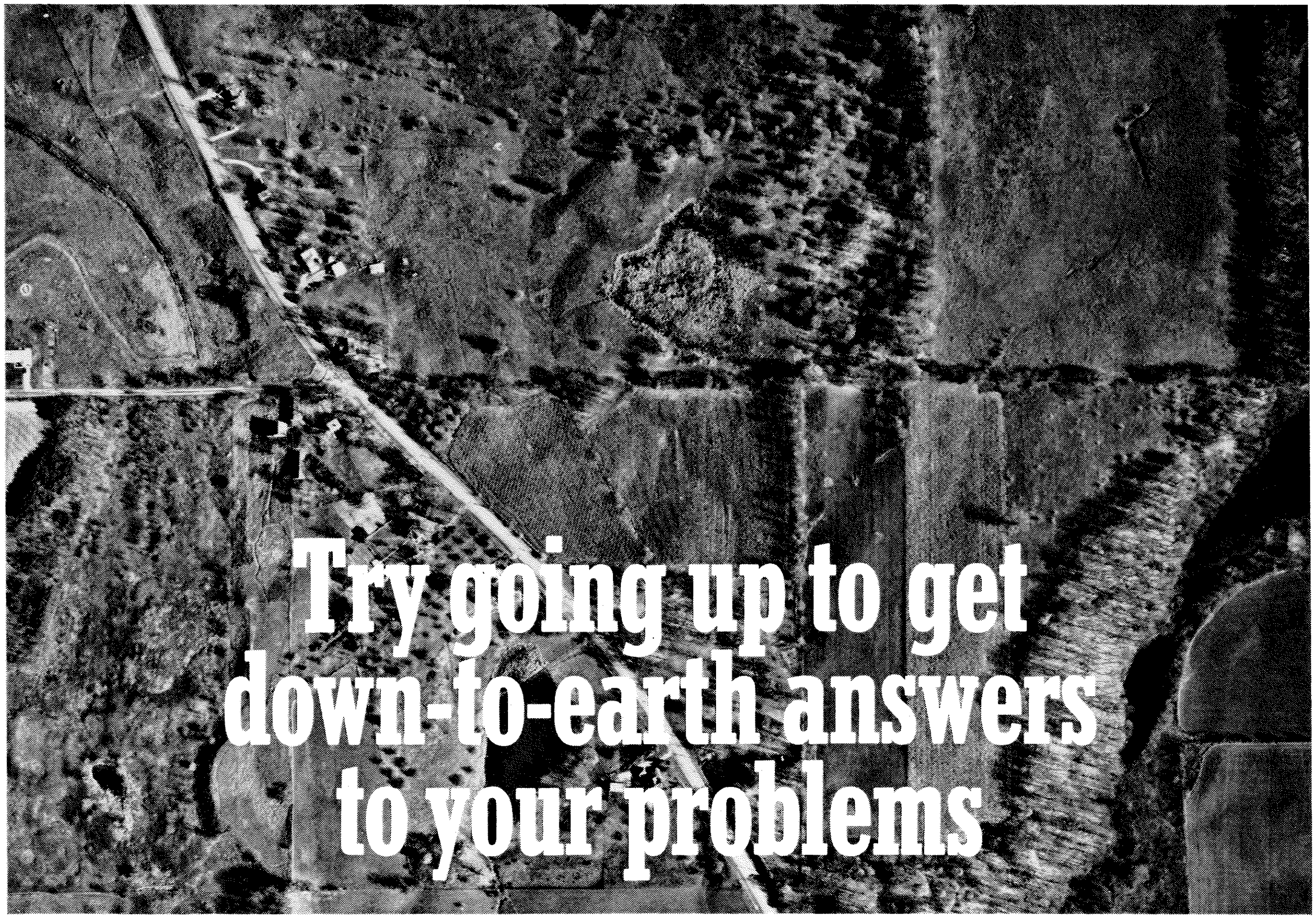

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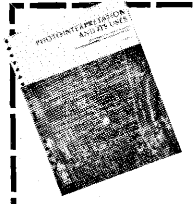

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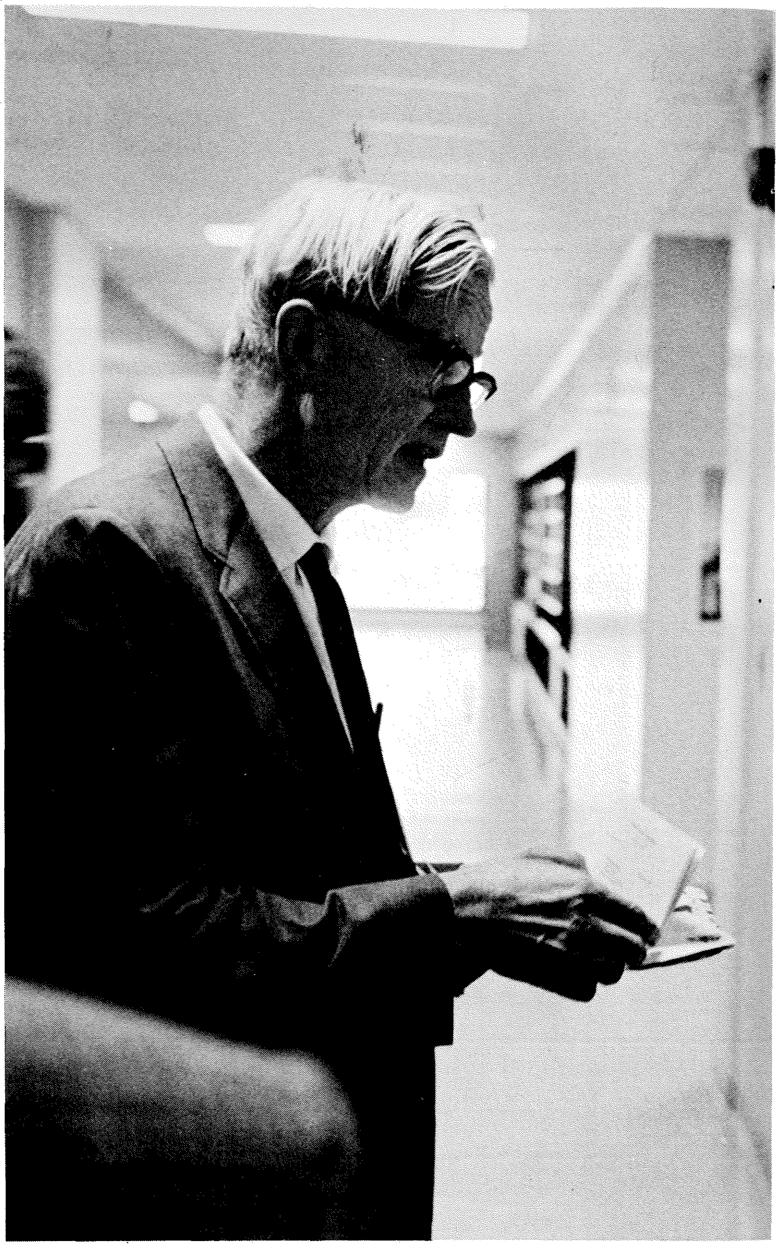
Delbrück: Conscience, Goad, and Sage

While looking for a paradox he never discovered, he helped found molecular biology and inspired hundreds of colleagues to emulate his own high standards of scholarship



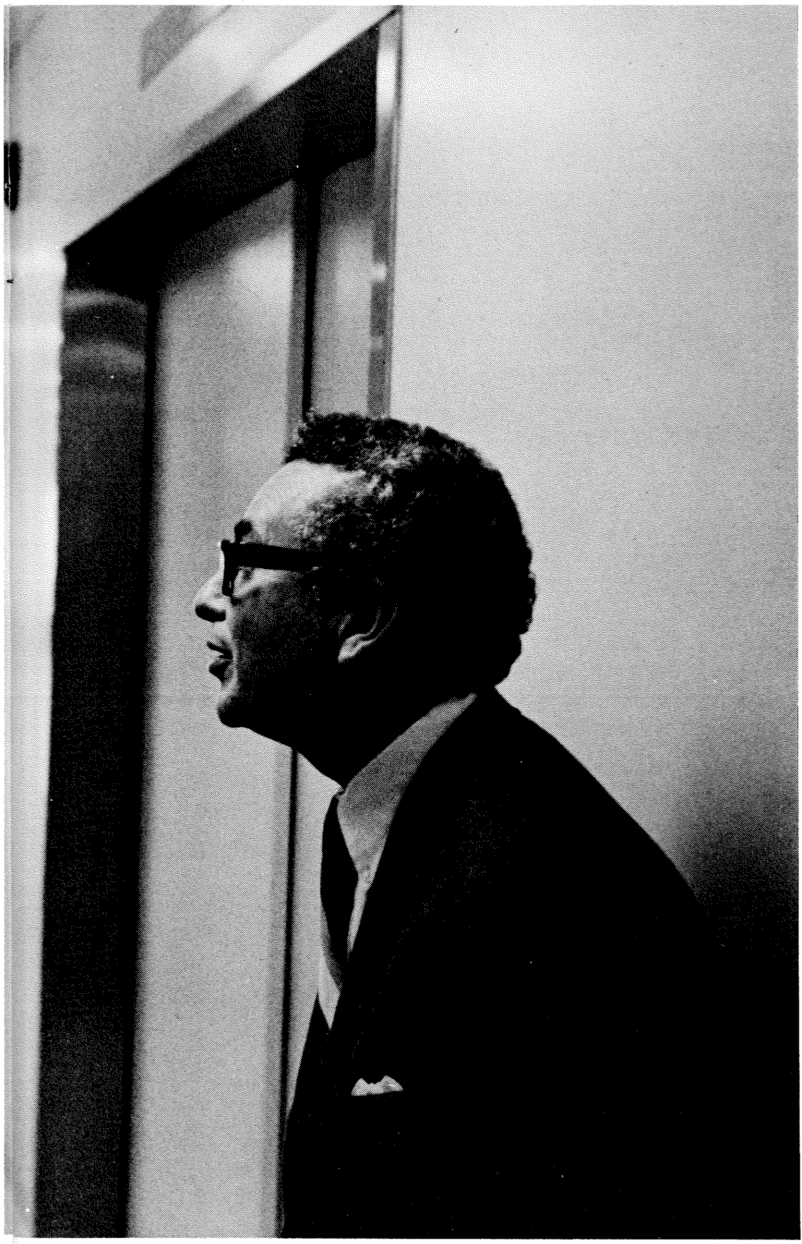
For 30 years the question "What will Max think of it?" has guided biologists as they home in on the secrets in the DNA molecule. Max Delbrück's presence at Caltech for most of that time has been instrumental in maintaining the Institute's prominence in biology, which began when Thomas Hunt Morgan came to Pasadena in 1928. Now Delbrück, like Morgan, has won the Nobel Prize in medicine and physiology, along with his long-time friends and collaborators Alfred Hershey of the Carnegie Institution and Salvador Luria of MIT.

The award recognizes Delbrück's research in the years 1937 to about 1952. There is a fairly direct line from his and Emory Ellis's early work on the growth of viruses, through his and Luria's early work on viral genetics, to Hershey's prime evidence that DNA carries genetic instructions, to Watson's and Crick's climactic discovery of the double helix structure of DNA in 1953. But perhaps even more, the prize honors Delbrück's unifying influence on the developments in the new field of molecular biology in that period.

Delbrück was leader of the informal Phage Group of scientists, a group born one summer at the Carnegie Institution's genetics research laboratory at Cold Spring Harbor, New York, and meeting at Caltech during each

Continued on page 10

In 1969–Two Nobel Prizes



Biologist Max Delbruck and physicist Murray Gell-Mann become the Institute's twelfth and thirteenth winners

Gell-Mann: Order Out of Chaos

His three major contributions have given hope that man may someday understand what matter is really made of

"What is really at the bottom of everything?"
"Quarks."
"Quarks?"
"Quarks."

Aside from scientific insight, a capacity for hard work, and a touch of genius, the quality that seems to set Nobel Prizewinners apart from their peers is the courage to walk to the beat of a different drum—the daring to challenge accepted concepts in order to find their own answers to the mysteries of the universe.

Murray Gell-Mann, professor of theoretical physics at Caltech, had this special quality almost from the day he entered Yale at the age of 15 and chose physics, by a narrow margin over archaeology, as his pursuit in life. Gell-Mann, 40, has been in the running for the Nobel Prize since 1953 when he published the first of his contributions to particle physics at the age of 24.

In welcoming Gell-Mann to the faculty as an associate professor of physics in 1955, Caltech president Lee DuBridge said, "Dr. Gell-Mann is one of those exceptional

Continued on page 14

Delbruck . . . *continued from page 8*

academic year to evaluate progress. These two institutions were described as the "Mecca and Medina of the Phage Group to which the faithful made their periodic hadj" in the introduction to a collection of essays written in honor of Delbrück's 60th birthday in 1966. Although the Group didn't begin to assume much importance until after the war, its origins were earlier—a meeting of Delbrück and Luria in 1940. In 1945 Delbrück taught the first of his famous summer courses in phage at Cold Spring Harbor; after that, taking the course became the *sine qua non* for a person to be considered a phage biologist.

Phage—or bacteriophage—is a kind of virus that attacks relatively simple, single-celled bacteria. Although the existence of bacteriophages had been known about for years, it was not until the mid-thirties that their applicability for the study of biological reproduction was recognized. Delbrück's and Luria's early work was really a fresh start for phage. They set aside other people's results for the preceding 25 years, began again, and produced an exciting new area of research characterized by simplicity, elegance, and precision.

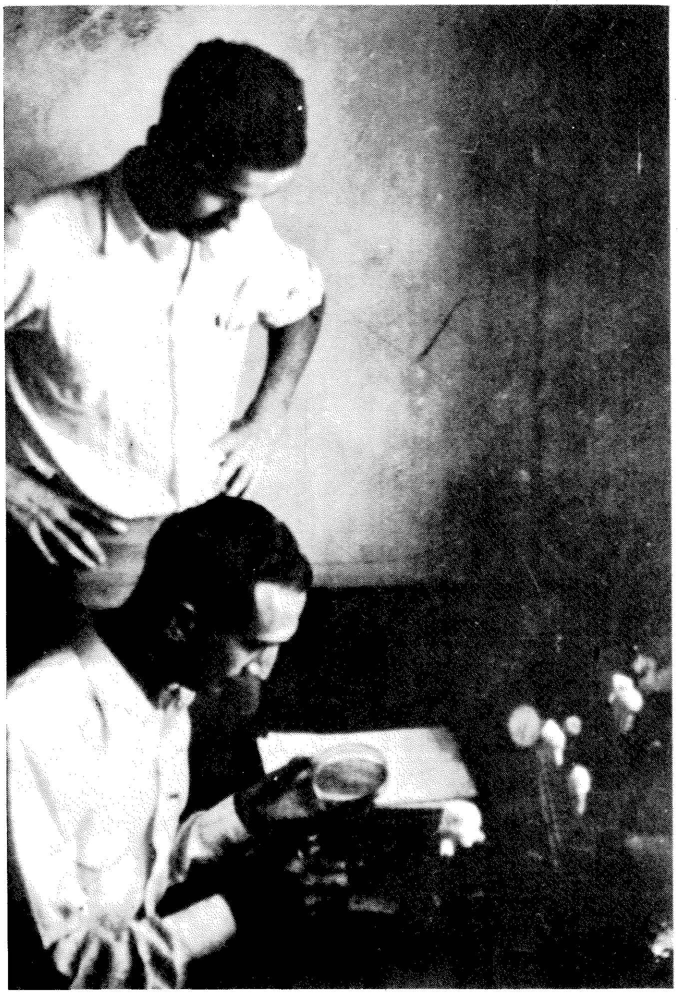
The group concentrated on seven strains of virus, all of which infected the bacterium *E. coli.* They were identified as T1 through T7, and most of the work was done with T2 and T4. The mechanism they studied was the way the phage infects the host cell, which later bursts and releases mutiple progeny of the infecting phage.

In the early thirties Delbrück was well launched on a brilliant career in physics. He had taken his PhD in 1930 under Born and Heitler at Göttingen with a thesis on the "theory of homoplanar bonding of the lithium molecule." He had written a paper earlier with Eugene Wigner on group theory and quantum mechanics, and identified a kind of elastic scattering of photons in the coulomb field known as the Delbrück Effect. Following his graduate work, he studied physics in Bristol, Copenhagen, Zurich, and Berlin. In a period of about four years he worked with or under seven men who ultimately won the Nobel Prize in physics.

Delbrück, youngest of seven children in a large and distinguished family of German statesmen and scholars, developed an early interest in astronomy—largely, he says, "as a means of finding my own identity in an environment of many strong personalities, all of them senior to me, many of them with high accomplishment, but none in science." During his graduate study he shifted to theoretical physics, a natural move in light of the revolution in physics occurring then and centered at Göttingen.

While in Copenhagen, Delbrück became interested in biology as a result of Niels Bohr's speculation that aspects of quantum mechanics might have applications to other fields, particularly biology. In 1932, with his interest turning to biology, Delbrück moved home to Berlin, largely

In the early thirties Delbruck was well launched on a brilliant career in physics



Delbrück and Luria met in 1940; here they work together in 1941 at Cold Spring Harbor, which later became the summer home of the Phage Group.

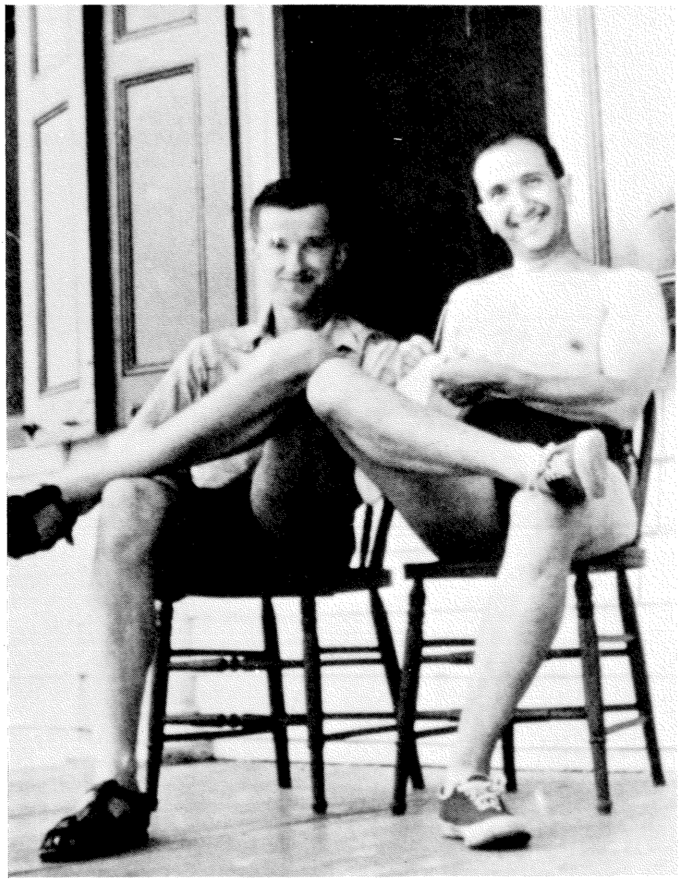
Phage Group members at Caltech lunching with Delbrück in 1949 are Jean Weigle, Ole Aaloe, Elie Wolman, Gunther Stent, and G. Soli.

in hope that the proximity of the various Kaiser Wilhelm Institutes would help him learn the new field. Starting in 1934 a small group of physicists and biologists met privately, mostly in Delbrück's mother's house. Several papers resulted from the meetings; part of one of those papers (by Timofeeff, Zimmer, and Delbrück on mutagenesis) was restated ten years later in a little book called *What is Life?* by Nobel physicist Erwin Schrödinger. Most biologists took little notice, but several excellent physicists in that immediate postwar period read Schrödinger's account of the "Delbrück Model" and subsequently found their way into phage biology.

Delbrück, with the support of the Rockefeller Foundation, left Germany in 1937 and came to study biology at Caltech. He was attracted, as were many others, to Thomas Hunt Morgan and Alfred Sturtevant, the *Drosophila* geneticists. In his two years at Caltech his interest in viruses solidified, and he and Emory Ellis did their early work on the growth of bacteriophage. When the war broke out in Europe, Delbrück chose to remain in the United States. Many members of his family in Germany became leaders in the anti-Nazi resistance, and many (including his brother, brother-in-law, and several cousins) were killed. After two years at Caltech he took a job in the physics department at Vanderbilt University in Nashville, Tennessee. He remained there until 1947, when he was brought back to Caltech by its new biology division chairman, George Beadle, another of Caltech's Nobel Laureates.

Delbrück met Luria at a dinner with two German physicists in Philadelphia in late 1940. Luria says, "The talk was mostly in German, mostly about theoretical physics, and mostly above my head." But afterwards he and Delbrück spent two days experimenting in phage plating methods in Luria's laboratory at Columbia University. At that time the two men were probably the only ones interested in molecular biology aspects of phage. They agreed to meet for further collaboration in the summer of 1941 at Cold Spring Harbor where Delbrück was to attend a symposium. They worked together again in the fall of 1942 in Nashville—Delbrück the German alien, Luria the Italian, almost alone in the field while other scientists concentrated on wartime research projects.

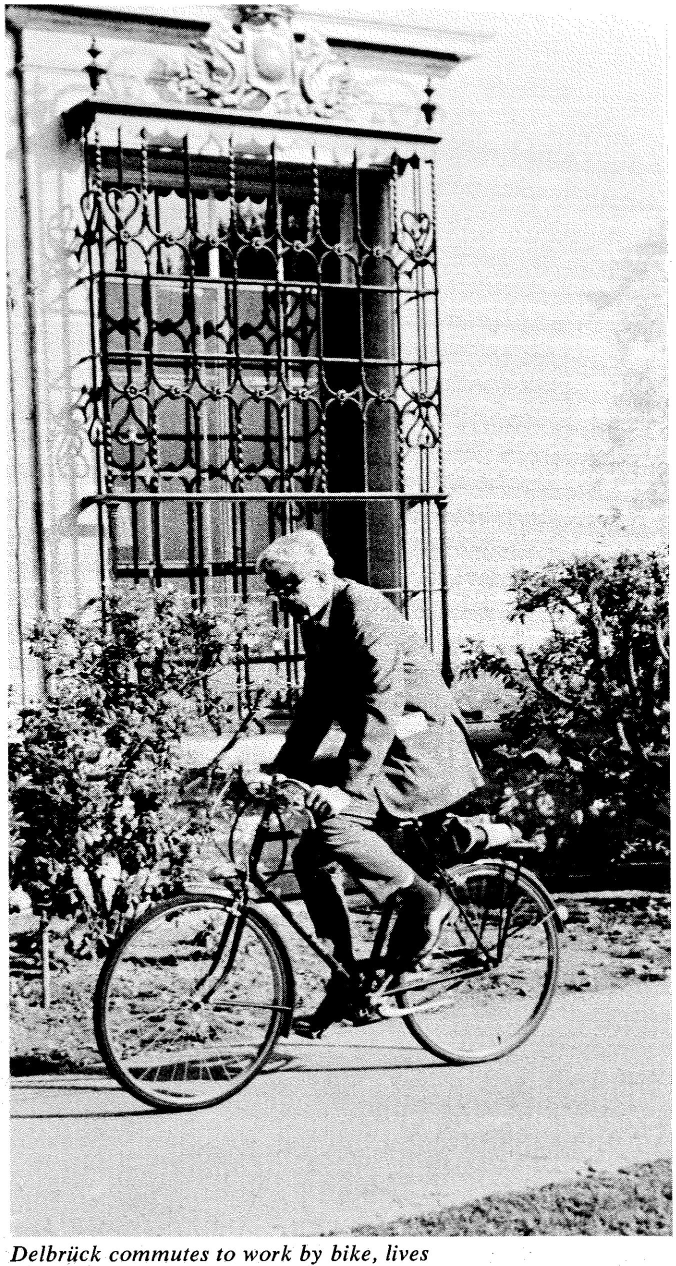
From 1942 to 1944 they published five papers (one with Thomas Anderson). Delbrück and Luria sensed the potential importance of what they were doing and worked to attract others to the field. Eight people, including the three 1969 Nobel Laureates, showed up for a meeting of the Phage Group in Nashville in 1947. Today hundreds attend the annual phage meetings in Cold Spring Harbor.


Delbrück and Luria at Cold Spring Harbor, 1953.

The late forties and early fifties, with the Phage Group growing and secrets of genetics being revealed little by little, were exciting times at Caltech. Thomas Anderson, who did early electron microscopy of phage, says that "at each phase in our groping toward discovery, Max Delbrück seemed to be present not so much as a guide, perhaps, but as a critic . . . an enquiring, and sometimes merciless, logician. If one persevered, he would be fortunate to have Max as conscience, goad, and sage."

With experiments being done almost nonstop, Delbrück, always anxious to keep workers elsewhere in the world up to date, sometimes used forceful techniques to get results into print. He would take his colleagues to Caltech's marine biology laboratory at Corona del Mar, lock them up with paper and pencils, and order them to write. Delbrück's wife, Manny, typed up the reports as rapidly as they were written. Participants criticized each other's drafts, and at the end of three days each would have a completed paper.

On other occasions Delbrück would stop all work in the lab to take everyone available to the desert for a few days of talk and fellowship. Caltech biologist Seymour Benzer recalls that sometimes Delbrück would declare Wednesday and Thursday to be the weekend. Then they would drive off into the sand until the car stuck; that determined the campsite. The next day was spent digging the car out. Desert trips are still a favorite means of entertaining visitors—at least for Delbrück. Luria long ago refused to visit Caltech unless he was granted immunity from camping.



Delbrück commutes to work by bike, lives near campus with his wife and two younger children. Two older ones are in college.

Delbrück had taken up biology expecting that perhaps radical new principles, comparable to quantum mechanics in physics, would be revealed in the course of its development. But biologists encountered no "wave/particle" kind of paradox as physicists had 25 years before; molecular genetics was explained by conventional processes.

In the early fifties, with phage "in good hands," Delbrück turned to studies of the nervous system, which have since turned out to be the "hot" area of biology. And, just as he began his study of biological reproduction with the lowly phage, he has taken up a simple fungus called *Phycomyces*—whose growth is affected by light—as a way of understanding sensory processes. There is now a small *Phycomyces* Group, and Delbrück gives a course on *that* topic each summer at Cold Spring Harbor.

Luria, in reflecting on the Phage Group a few years ago, said, "Seldom has a group of men been so richly rewarded as have we, the molecular biologists, whom the physicist Max Delbrück, more than anyone else, guided to the exploration of the deep mysteries of life."

But Delbrück's influence has been broader, even, than molecular biology. He is a lively member of Caltech's—and the world's—community of scholars, endowed with a warm humanitarianism all his own. Generations of students and colleagues have been stimulated to insight through their associations with him. According to Caltech colleague and former division chairman, Ray Owen, "There has never been a Nobel Prize more deeply deserved than his."

theoretical physicists who have attained great stature at a very young age. He will be invaluable to our program of training new scientists and carrying on research at Caltech."

When he introduced Gell-Mann at a press conference last month on the morning of the Nobel Prize announcement, Robert Bacher, Caltech provost and the former chairman of the division of physics, mathematics and astronomy, said: "Dr. Gell-Mann has contributed probably more than anyone toward bringing order out of chaos in high-energy physics . . . We have all been expecting this man to win the Nobel Prize, so it doesn't come as a surprise to us. It was just a matter of when."

And Richard Feynman, a Nobel Laureate in his own right, who was largely responsible for Gell-Mann's coming to Caltech and who has worked closely with him ever since, said about his friend and colleague:

"This event marks the public recognition of what we have known for a long time, that Murray Gell-Mann is the leading theoretical physicist of today. The development during the last 20 years of our knowledge of fundamental physics contains not one fruitful idea that does not carry his name . . . If further confirmation is needed that some scientists can be as sensitive and as active toward human problems as any humanist, we are proud to exhibit Gell-Mann."

Gell-Mann, who earned his PhD in physics at MIT and went on to study at Princeton under Oppenheimer, has devoted his scientific career to finding the ultimate elementary building block of matter, a search that has been compared to looking for the bottom of a well extending into infinity.

The quest for the bottom of the well has led Gell-Mann through an Alice-in-Wonderland world of "strangeness" and the "eightfold way" to the wondrous "quark." Although he is the first to admit that the search is not over, his selection for the Nobel Prize is worldwide recognition that Gell-Mann has brought man a giant step closer to understanding the elemental nature of matter.

Sweden's Royal Academy of Science, when it announced the 1969 Nobel Prize for physics, which carries with it a cash award of $72,800 (the highest in history), explained:

"Dr. Gell-Mann has produced fundamental work in nearly all domains of his field, and his contributions have, in many cases, been of decisive importance for the further

The development during the last 20 years of our knowledge of fundamental physics contains not one fruitful idea that does not carry his name

Nobel Prizewinners Gell-Mann and Richard Feynman (shown here in 1960) have been "working together separately" at Caltech since 1955.

Gell-Mann does his best to explain "strangeness, eightfold way, and quarks" to television newsmen on October 30, the day the Prize was announced.

development of physics. This is particularly true of his discoveries concerning the classification of elementary particles and their interactions."

In pointing out the significance of Gell-Mann's first discovery concerning particles with strong interaction, the Royal Academy stated:

"An epoch-making discovery of new particles had been made in 1947 by two researchers, Butler and Rochester. The new particles discovered by them were produced so copiously in collisions between nucleons and pions—another strongly interacting particle group—that one was forced to conclude that they had strong interaction with other particles. Therefore they ought to have a very short mean lifetime.

"However, experiments showed they had considerably longer lifetime. This seemingly strange behavior, which gave rise to the name 'strange particles' for these entities,

Three-fourths of the household: wife Margaret, Gell-Mann, and son Nicholas, 6. (Nobel Prize or not, tomorrow is Halloween.) Daughter Lisa, 13, is elsewhere.

resisted many attempts at an interpretation until it became explained through the theoretical discovery published by Gell-Mann in 1953."

The basis of Gell-Mann's theory is that each particle in the nucleus of the atom can be assigned a degree of "strangeness" according to the number of steps in its disintegration, and that each particle can be distinguished in this way from its neighbors, just as a neutron is distinguished from a proton by its different electric charge. (Unknown to Gell-Mann, a Japanese physicist, Nishijima, came to the same conclusion in Tokyo at about the same time.)

Gell-Mann's second major contribution to the understanding of matter was the Eightfold Way theory that he introduced in 1961. This theory was also advanced independently by Yuval Ne'eman of Tel-Aviv University.

By the time Gell-Mann introduced the Eightfold Way, more than 100 particles had been produced by bombarding atomic nuclei with the use of high-energy accelerators. No longer was the term "elementary" reserved for the proton, neutron, and electron; and physicists searched for relationships that would at least enable them to classify the particles. The hope was to produce a theoretical structure comparable with Mendeleev's periodic table of the elements. Gell-Mann's Eightfold Way theory was the greatest breakthrough in this effort. It provided a scheme for classifying subatomic particles into several families of eight or ten members each, according to such characteristics as spin, parity, and electrical charge.

When the known particles were arranged according to the scheme of the Eightfold Way, one family that should have had ten members was found to have only nine. One particle required by the theory was missing, but Gell-Mann was able to predict all of the distinguishing characteristics of the particle.

Working from Gell-Mann's predictions, a team of 33 scientists at the Brookhaven National Laboratory set out to look for the missing particle, using the 33 BeV proton accelerator. Since the particle could not be found without knowing exactly what to look for and where to look for it, the discovery of the missing particle, omega minus, by the Brookhaven team in 1964 was widely acclaimed as a striking confirmation of the Eightfold Way. Gell-Mann's theory had passed a test that could mark a turning point in particle physics.

Of all the strongly interacting particles that participate in the nuclear force, which are the basic building blocks? What are they made of? Gell-Mann's answer, which suddenly put all the physics textbooks out of date, was the "quark." In his third major contribution to his field, Gell-Mann theorized that all particles are made up of quarks and anti-quarks.

Gell-Mann defined a quark as a "very peculiar particle with an atomic mass number of ⅓ and a charge of +⅔ or −⅓. He said, "There are three kinds of quarks: one with charge +⅔ and two with charge −⅓."

The term quark is another example of Gell-Mann's literary bent, which shows up in all the names he has given to his great theoretical contributions. The idea of "strangeness" comes from Francis Bacon's line: "There is no excellent beauty that hath not some strangeness in the proportion." The Eightfold Way appears in the Buddhist teaching: "This is the noble truth that leads to the cessation of pain. This is the noble eightfold way. . ."

With tongue in cheek Gell-Mann speculates on the derivation of quark. "One possible derivation of the name —scholars are already disputing this, some assuming it comes from the German word for rotten cheese—is from the heading of a page in *Finnegans Wake* where Humphrey Chimpden Earwicker rolls over in his sleep to hear a clock strike, and the text says, 'Three quarks for Muster Mark.' "

"Are quarks actually real objects?" Gell-Mann asks. "My experimental friends are making a search for them in all sorts of places—in high-energy cosmic ray reactions and elsewhere. A quark, being fractionally charged, cannot decay into anything but a fractionally charged object because of the conservation law of electric charge. Finally, you get to the lowest state that is fractionally charged, and it can't decay. So if real quarks exist, there is an absolutely stable quark. Therefore, if any were ever made, some are lying around the earth."

But since no one has yet found a quark, Gell-Mann concludes that we must face the likelihood that quarks are not real.

Without a trace of disappointment he says, "Actually that is just as well; mathematical quarks are even easier to work with than real ones, because certain restrictions imposed by the reality of the particles can be dispensed with. And, working with mathematical quarks, we can begin to make a fairly satisfactory theory of the detailed properties of meson and baryon levels."

Gell-Mann, who is Robert Andrews Millikan Professor of Theoretical Physics at Caltech, has earned more than his share of honors. He received the Dannie Heineman Prize of the American Institute of Physics in 1959; the Ernest Orlando Lawrence Award from the Atomic Energy Commission in 1966; the Franklin Medal of the Franklin Institute of Philadelphia in 1967; and last year he won the John J. Carty Medal of the National Academy of Sciences as well as the Research Corporation Award.

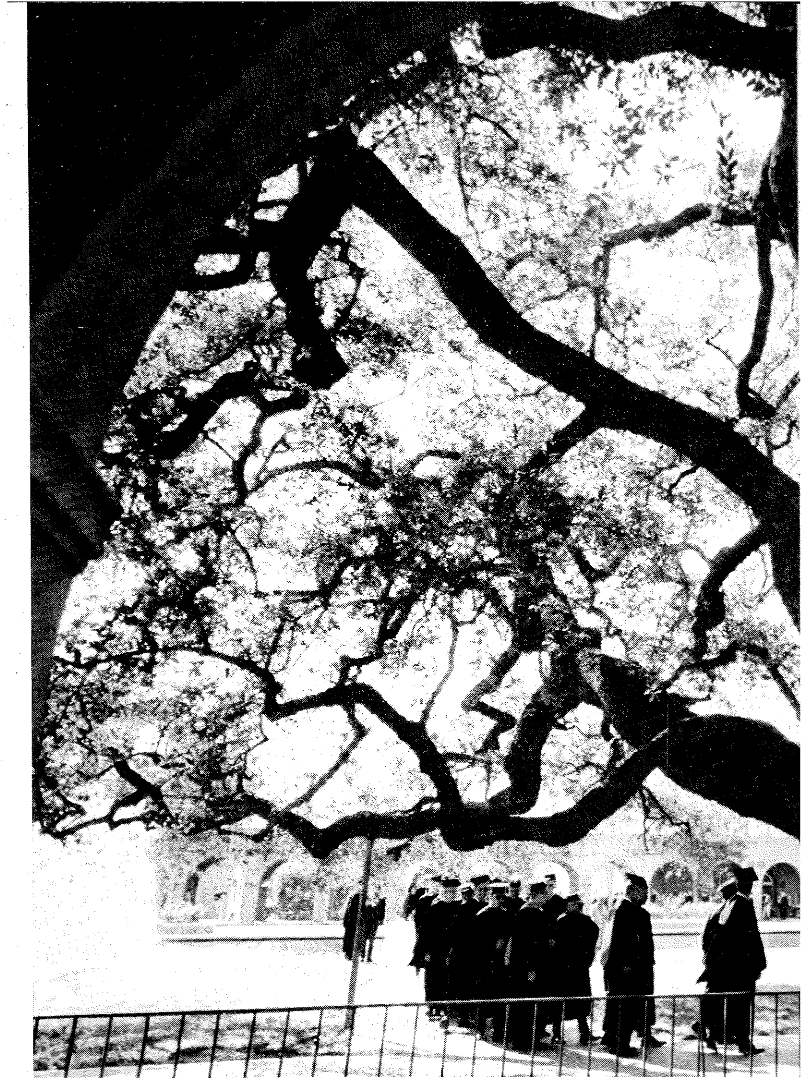
But with all the honors, including the Nobel Prize, Gell-Mann has not lost sight of his goal to uncover the secret of matter.

"I think particle physics is where atomic physics was in the early years of the century," he says. "We're getting an outline of an underlying structure, but there is still no complete theory of either strong or weak interactions which enables us to understand what is really happening at the bottom of everything."

Gell-Mann has also managed to keep his eyes on the world around him. He is an ardent conservationist who actively campaigns for the preservation of wildlife and the expansion of natural parks. On one recent vacation he flew to Africa with his wife, Margaret, for a photography safari by Land Rover.

Murray Gell-Mann is a humanist who happens to be a physicist. You can only speculate about what he would have discovered had he opted for archaeology instead of physics. Maybe even Atlantis, way down there at the bottom of everything.

The Inauguration of Harold Brown



It was, as it should have been, a very special day. Even the skies were clear, and the sun unseasonably hot.

It was a *big* day. Almost 4,000 people came to see the ceremony, so that bleachers had to be put up at the far end of Beckman Mall along San Pasqual St.

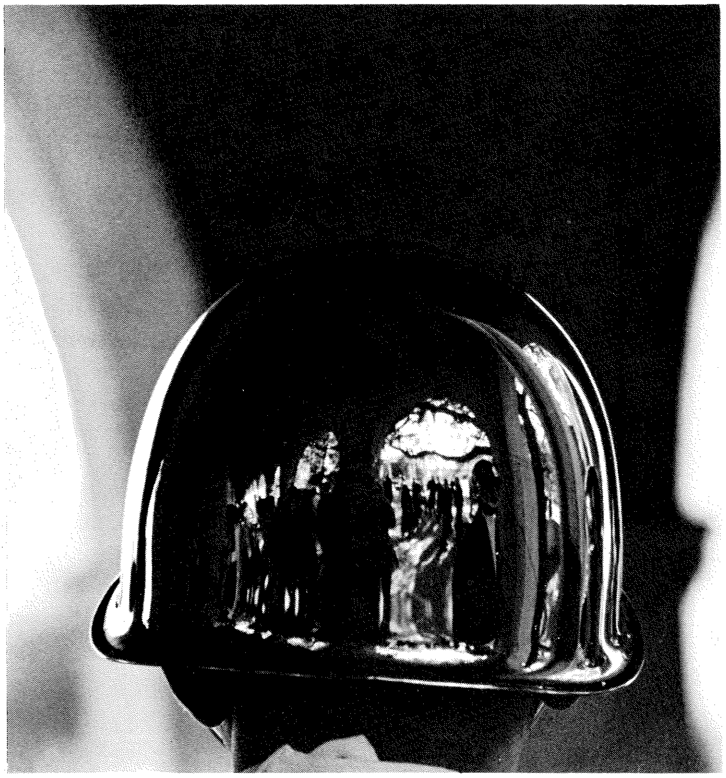
It was a colorful day. The academic procession included delegates from 204 colleges and universities and 43 learned societies, 8 Nobel Laureates, and 7 recipients of the Caltech Alumni Distinguished Service Award.

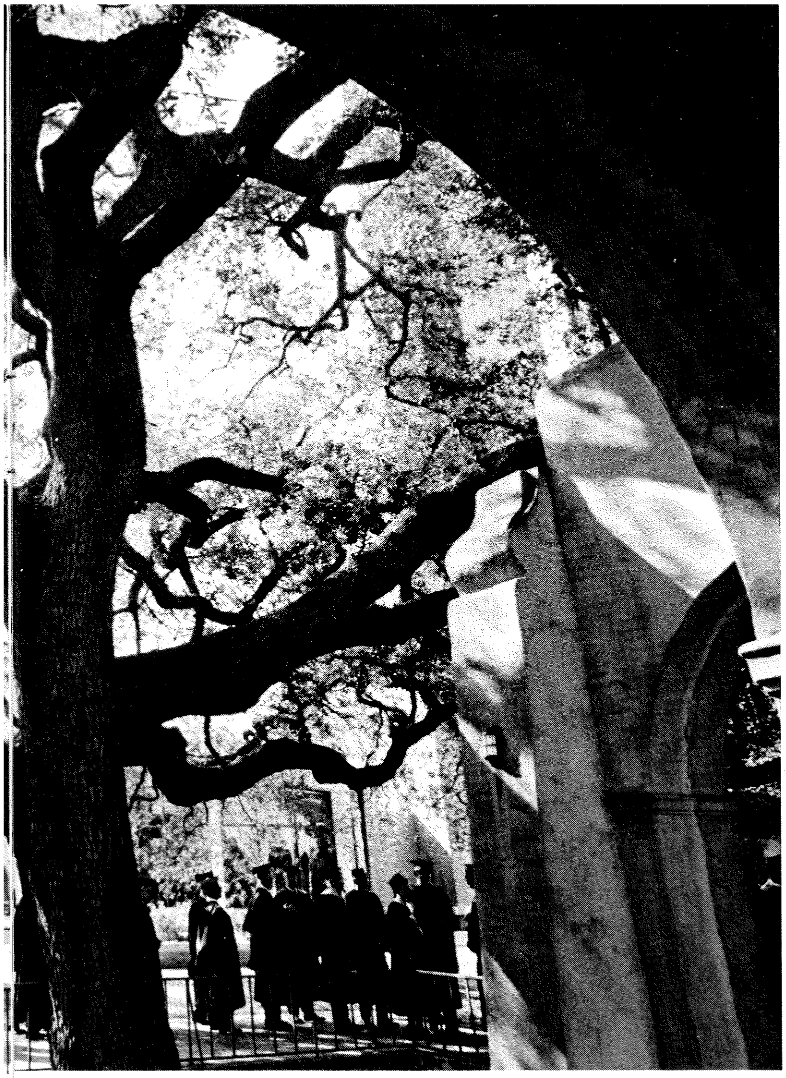
It was an impressive day. In the formal ceremony of investiture, by which Harold Brown officially became president of the California Institute of Technology, the academic hood placed on his shoulders was that of R. A. Millikan—who, like Brown, had received his PhD in physics from Columbia University.

It was a family day. At a special luncheon for distinguished visitors in the Athenaeum (which had never before served 720 people) the speaker was L. A. DuBridge, who left the Caltech presidency last year to become science adviser to President Nixon.

It was a full day. In the late afternoon the faculty gave the Browns a champagne reception. In the evening the students had a twilight buffet in Winnett Plaza, then capped it with a rock concert in Beckman Auditorium.

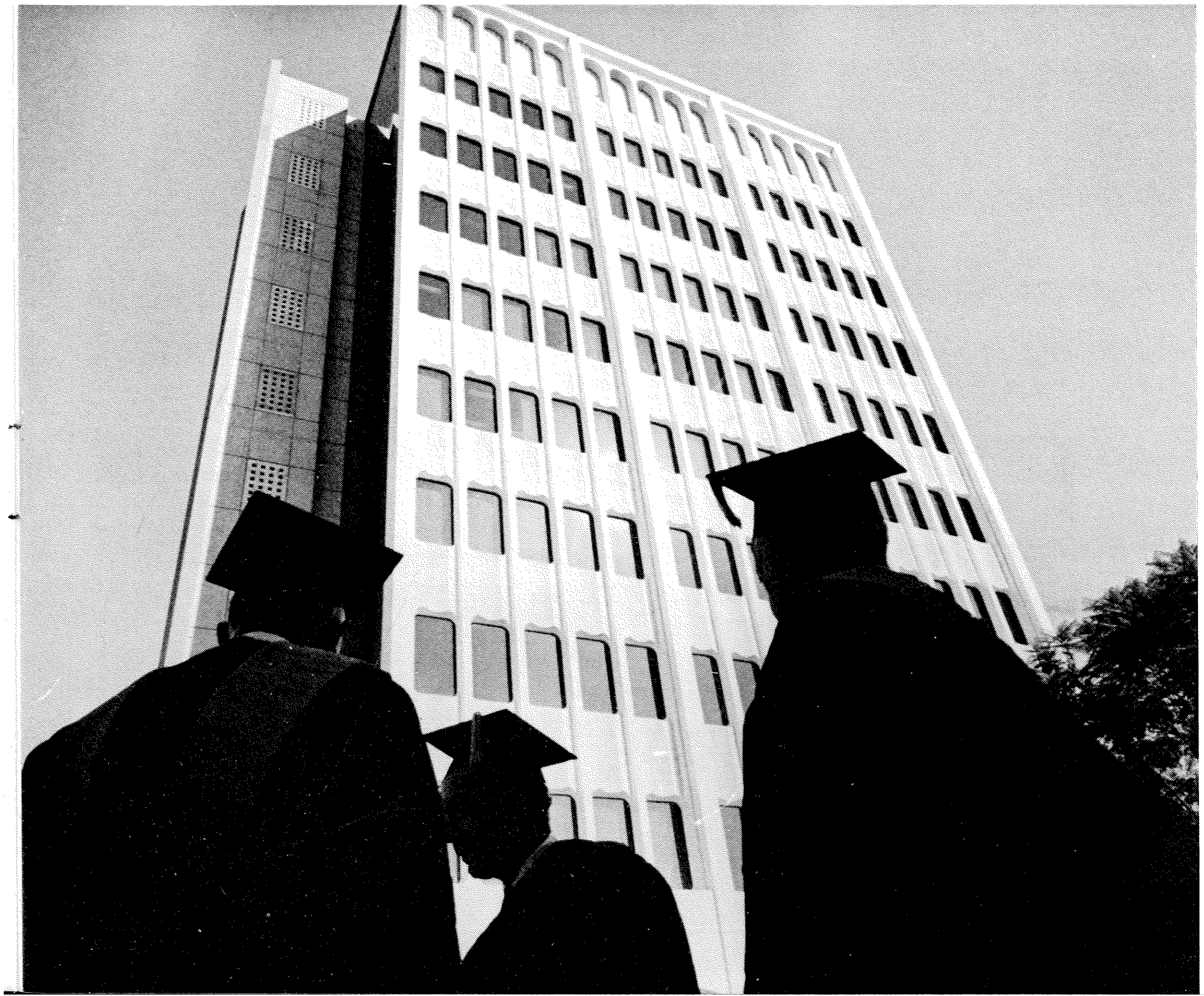
It was, as it should have been, a very special day.





"A man very well endowed to forward the supreme mission of this institution, to reaffirm in this time of technology the primacy of the human being . . . I present our new president, Dr. Harold Brown."

—Trustee Thomas J. Watson Jr.



Colene Brown offers her own congratulations to the new president.

The Nobel Laureates in the academic procession picked up an added starter at 3:30 a.m. on Inauguration Day when Caltech's Murray Gell-Mann was notified he had won the 1969 Physics Prize. His fellow marchers are Caltech's Max Delbrück, 1969 co-recipient of the Prize in medicine and physiology, and his boss—Carl Anderson (chairman of the division of physics, mathematics and astronomy), physics winner in 1936.

Inaugural Address of
Harold Brown
October 30, 1969

Caltech: A Singular Opportunity

"I believe that mankind can find an acceptable existence only by proper understanding of science and utilization of technology, not by their rejection. And I believe that Caltech's particular qualities and potential demand that we create not only new discoveries and applications, new sciences and technologies, but new ways of seeing nature, man, and society."

When I visited the California Institute of Technology just over a year ago to discuss the possibility of becoming its president, what I experienced was anything but a polite sherry-drinking ceremony. It was two and a half days (and two late evenings) of straightforward question-and-answer, on both sides, with faculty and students. We reached, I think, deeply into each other's concerns and hopes.

Those days left me tired and rather bruised, but exhilarated too—buoyed up by the honesty and intellectual competence, the aspiration and compassion, that I had seen. There was a lot to think about and to be challenged by in those sessions. Among the many perceptive questions asked of me, one was especially thought-provoking. It was—"Why are you interested in being a university president, and why of Caltech in particular?"

In answering such questions, historical perspective is sometimes useful. A century ago, as Lord Bryce tells us, the university president was virtually a monarch, responsible only to God, which in the academic case meant the governing board. A half century ago the faculty wrested a good deal of power from the president, and now the students are seeking their share.

Insofar as university presidents are kings today, we seem to have reverted to a still earlier form. It is that of those kings of ancient times who, after a short term of rule, were slain. Then they were either eaten in a Dionysian frenzy or plowed into the furrows in order to encourage the growth of the crops.

So it can't be the hope of comfort and security that encourages me—or anyone else—to become president of an institution of higher learning.

Can it be that I am an example of what Dr. Lawrence Peter cites in his recent book, *The Peter Principle*? He writes that people who have exhibited what he calls "summit competence" have a "strong tendency to sidestep into another hierarchy—say, from the army into industry, from politics into education, from show business into politics and so on—and reach in the new environment that level of incompetence which they could not find in the old. This is compulsive incompetence." I will say only that such a compulsion is not my conscious motivation.

Since World War II it has been the style of most university presidents to preside over, or to spearhead, great expansions of faculties and student bodies, massive

"Why are you interested in being a university president, and why of Caltech in particular?"

The universities are now being assailed as having sold out to the power structure, and as having forsworn scholarship.

building programs, and large-scale organization of scholarship and research. Centers, institutes, and laboratories have been financed largely by federal and partly by state funds, and by private and foundation support when it could be obtained.

As a result of this evolution, our universities have become much more closely involved with American industry, American government, and American attitudes. The universities are now being assailed as having sold out to the power structure, and as having forsworn scholarship. Somewhat contradictorily they are also charged with being irrelevant to the problems of modern society. In these circumstances, the university president is not likely to find himself in a position of unchallenged prestige—the quest for which, then, can't be the reason for coming to a university.

Yet our great institutions of learning present an unequaled opportunity to make a long-range contribution to society. In my view, this is particularly true at Caltech. By producing new knowledge and new leaders, we in the universities can grapple with the problems not only of today but of the next decade, and of the next century. I have found before, and find now, a particular challenge in working to relate the activities and goals of a highly professional, effective institution—on its own terms, the best in the world—to the larger perspectives and aspirations of the world of which it is a part. This opportunity, and this challenge, are what have brought me to Caltech.

The basic values of our educational institutions and our society are now being contested. Our universities are under scrutiny and under attack. Rational thought is under scrutiny and under attack. And science and technology are under scrutiny and under attack. These institutions and values, until very recently, were the most respected of all.

I suggest that this change in attitudes results from the inevitable failure of these most respected institutions to solve quickly all of our problems, or even the most desperately urgent ones. They have not solved the problem of control of weapons of mass destruction. They have not extricated us from a divisive and damaging local war. Poverty still exists in our own country and to an even greater degree in the rest of the world. We still live with the degrading reality of racial oppression. We face increasing environmental pollution. The growing human population is not many doublings away from disaster.

All of this causes many—both young and old, left and right, some of our best people and some of our worst—to denounce our society and its works. Particular criticism and even hatred have been directed against the universities, against their products, and against the industrial civilization which those products, in turn, have combined to create. In their disappointment, many people have turned against science, technology, reason—and against us, their practitioners. The student who cries, "What we need is to think less and to feel more!" and the legislator who says, "Cut off government aid where students misbehave!" are both exhibiting this reaction. This situation presents a great challenge, and a real danger, to the universities and to society.

We must understand and respond to what is sensible in the criticism of our society and our universities. New times require new ways; we must find them. We must educate those outside the university community about what we do, and explain why our work is vital to man's spirit as well as to his material well-being. We must resolutely defend the rational process, science and technology, *and* the human values from the know-nothings of our day. We must defend them from those who would legislate against freedom of thought and inquiry no less than from those disrupters who would destroy without any idea of what they—or others—would then build on the rubble. If either group succeeds, the universities will be destroyed before they can be improved.

We know that rationality is not all there is to man's nature. Indeed, 2,300 years ago Aristotle defined man not as reasoning, but "*capable* of reasoning." And the non-rational part of man's nature has recorded some of his most luminous as well as his most shameful deeds.

An institution of higher education is by its nature dedicated to the humane values and also to rationality, whose offspring are science (the knowledge of ourselves and the universe) and technology (the ability to change ourselves and to influence our surroundings). These are the central concern of this particular institution, and together they constitute the essence of our modern civilization.

I believe that mankind can find an acceptable existence only by proper understanding of science and utilization of technology, not by their rejection. And I believe that Caltech's particular qualities and potential demand that we create not only new discoveries and applications, new sciences and technologies, but new ways of seeing nature, man, and society. These views convince me that Caltech presents a singular opportunity to me and to all of us who are a part of the Institute community.

Now the question arises, how can the Institute's president act most effectively to help turn these opportunities into achievements?

It seems to me that the president of an educational institution cannot merely preside. Nor can he simply direct. He must lead.

To lead is perhaps the most difficult and complex method of all, yet the combination of actions that it comprises offers the best hope of getting something done. It requires the active use of persuasion, rather than either simply being persuaded by others (presiding) or coercing them. Leadership rests largely on the inspiration generated by mutual respect, by shared feelings, and by the interplay of personalities. It includes, of course, day-to-day administration and management. It includes the duty of informing people—within the Institute and outside it—of the nature of our activities. The president must resolve and unify the diverse interests and views within the Institute sufficiently so that action can at least sometimes proceed. He must do so with a high sensitivity to the full range of opinions of the members of the Institute community, but without merely averaging those opinions. And finally, the president must be the focal point for interaction of the Institute with its outside constituencies —our neighbors, our private benefactors, governmental organizations, and the interested public.

Decisions cannot be made by instant and universal balloting. Under some circumstances they must be made by individuals, and those individuals must take responsibility for them. But unexplained and arbitrary

The president of an educational institution cannot merely preside. Nor can he simply direct. He must lead.

We do not limit our aspirations to internal tranquility. Inevitably, we will be measured by our academic activities and our effect on the world.

administrative action, whether on business affairs, curriculum, relations with the external community, or the future evolution of the Institute itself, needs to be avoided. And there is a need to obtain as wide a spectrum of views as possible—from faculty, students, and nonacademic employees—on important questions before the corresponding decisions are finally made. To that end, I intend to continue to establish advisory councils, informal and formal, on a wide variety of matters, to the principal administrative officers of the Institute.

The most important point about governance is that the Institute *is* a community with shared interests and shared responsibilities. If we are not to be governed by others from outside the Institute, we must govern ourselves—and we must be clearly *seen* to govern ourselves.

Of course, we do not limit our aspirations to internal tranquility. Inevitably, and properly, we will be measured, and will measure ourselves, by our academic activities—teaching and learning, performing research and fostering scholarship—and by our constructive effect on each other and on the world around us.

The academic tenets laid down at Caltech almost 50 years ago have persisted to this day. Hale, Noyes, and Millikan established a number of fundamental principles:

Confine the expansion of the academic program to areas where Caltech can be truly outstanding.

Teach in an atmosphere of research.

Concentrate on science and engineering while at the same time encouraging a broad cultural outlook—thus avoiding, as Noyes said, "the narrowness common with students in technical schools and the superficiality and the lack of purpose of many of those taking academic college courses."

It is remarkable how apt those thoughts and those principles (and those words) appear today. But the contexts in which our activities are carried out are changing more rapidly than ever before. They will continue to change as time goes on, as the state of human knowledge changes, as the world changes, and as the people at the Institute change.

In the face of such change, I want now to reiterate Caltech's dedication to excellence—indeed to preeminence—to research and teaching, and to science and engineering as the center, but not the whole, of our attention. You all know some of the areas in which the Institute has been active for the past 50 years. Those areas remain fruitful for learning and for research, and for teaching and training, because they are central to human knowledge and to human activities.

A large part of our interest involves the physical universe. The work ranges from the subnuclear world—the study of the very smallest bits of matter and their structure—to astronomy—the study of the very largest bodies of matter that we know. It covers a great deal in between—the dynamics of reactions among molecules, ions, and atoms, and the seismic activity of the earth, to name but two disciplines.

Another area, connected with the first through chemistry and physics, includes the study of life—the DNA molecule, the cell, the nervous system.

A third area includes the applications of such knowledge, through engineering, to human activities.

From supersonic flow to water quality, from fracture properties and earthquake engineering to plasma dynamics, Caltech engineers are at the frontiers of technology.

Many of these disciplines have come together, knit by interdisciplinary ties. A decade ago we joined radio and astronomy to our activities in optical astronomy, nucleosynthesis, and theoretical physics to create a center of such studies unequaled in its depth, breadth, and brilliance. We have begun outstanding work in bioengineering, joining together biology, chemistry, chemical engineering, and fluid dynamics. Further interdisciplinary opportunities beckon. The interaction among astronomy, geology, and space exploration is a promising one. There is enormous potential in the synthesis of information theory with behavioral biology as a new approach to psychology. Economics and engineering can combine to aid rational decision-making about the problems of society, though the setting of the fundamental goals of the society is not the province of either discipline. I can't promise that the approach of science will allow us to understand man and his interactions with his fellows in the same way that we understand the interaction of nuclei in a star or the interaction of chemical compounds in a cell. I do know that we had better try to understand the nature of man if man is to survive.

The mutual impact of science and technology with economics, politics, and social patterns is already a matter of particular interest to scholars of the social sciences and humanities here at Caltech, as well as to our scientists and engineers. I believe we should develop even greater capabilities on the frontiers of certain disciplines in the social sciences. We should specialize in a small number of new activities, such as social or humanistic psychology and the history or sociology of science, in addition to attempting to work toward them from science itself.

As part of our effort to find ways in which to help solve the problems of the nation and the world—particularly those for the creation of which science and technology must bear a substantial responsibility—we plan to hold during 1970 a series of four conferences, each in its way exemplifying an interaction between science and technology on the one hand and human behavior and society on the other. These conferences, on Genetics and Behavior, on Technology and Development, on the Population Problem, and on Technology and Environment, will bring leading scientists, engineers, social scientists, and humanists to the Institute to participate. Such activities will do much to speed the evolution of Institute programs in these fields.

In view of its small size, Caltech must select carefully what it does. And what we do, we must do in a special way, appropriate to our particular nature. In new as in continuing activities, we insist on excellence as a minimum, and seek preeminence. Our history, and our aim, is not replication but innovation. To restate our founding guidelines in a modern framework, it is our goal to make our activities at Caltech exceptional, and to have them relate to other activities at the Institute, thus providing a unity and effectiveness that is possible only at a small institution of outstanding competence. By these guidelines, it seems unlikely that we would want to grant PhD's in English literature or ancient history. On the other

Our history, and our aim, is not replication but innovation.

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hand, our faculty may well decide in the future to give doctoral degrees in some fields of economics and in some areas of psychology.

Our small size and particular talents should also govern the interaction of the Institute with other elements of the society of which it is a part. A major force motivating our insistence on excellence in teaching and research is our belief that these activities are more than ends in themselves—though they are that, too. They are the basis of our ability to contribute in the long run to the solution of the world's problems, those unsolved problems I mentioned earlier as the source of so much justified discontent. We must also consider our contributions in more immediate terms. Caltech, though an international institution in its scope and influence, its faculty and students, remains a citizen institution of Pasadena and southern California. There are many problems that touch the Caltech community directly. Beyond participation by individuals in community service, the Institute as a good citizen has a responsibility to help meet these needs.

Our country is under domestic strains greater than it has experienced since the Civil War. Our urban ghettos suffer debilitating human blight which produces explosive forces. This community, like this nation, cannot remain half affluent and educated, half impoverished and disadvantaged. Caltech of course cannot do—and should not try to do—all that must be done. But because Caltech is a teaching institution, I believe we have a special and continuing duty to encourage excellence in the public elementary and secondary school education around us. We must encourage young people in the development of their scientific interests. Especially is this true of disadvantaged students who need to be shown that intellectual activity in general is open to them. Some of our students have shown the way over the past 18 months by teaching in the Pasadena and Los Angeles schools for a few hours a week. During this past summer a faculty-organized project brought two dozen junior high school students to live, work, and learn on the Caltech campus, to see what laboratory science is like. Activities like these can be the beginnings of a significant and unique Caltech contribution.

Another community problem that affects us all is environmental pollution—which in the Los Angeles Basin is manifested most obviously as smog. As technologists, we have a particular duty to take the lead in its solution. Though the strongest constraints are economic, political, and sociological, the technological alternatives define the boundaries within which these other forces must operate. Here again, students, faculty, and some of the off-campus activities of the Institute, including the Marine Biology Laboratory and the Jet Propulsion Laboratory, must combine to provide a framework in which individual members of the Institute can contribute to the solution of community problems.

Institutions, like men, must be considered both as creatures of their environment and as entities in themselves. Each of us says, "I'm me"—a collection of emotions, desires, sense impressions, and self-replicating DNA—a seer of stars, singer of songs, poet, composer, discoverer of natural laws, maker of tools—"and I want to be thought of as a *person*, worthy, independent of what I need and of what I produce for others."

As we think of ourselves as an institution—and the

Institute *is* its people—we want, and deserve, to be valued for what we are and what we aspire to. But as individuals must also view themselves in terms of their needs and their products—intellectual, metabolic, social—so too we must ask: Where does and where will the Institute get the support to do what its aspirations require? And how will it generate its products—knowledge, research, technology, scholars, scientists, engineers, educated men?

A private university, by virtue of its autonomy, and by deriving a substantial component of its income from tuition, endowment, and gifts, has a greater freedom to follow its own path. We have been free to emphasize quality and to concentrate on activities which we ourselves select. We will continue vigorously to seek the support from the private sector that makes this latitude possible. Together with federal grants and contracts, such support will allow us to move into new areas at the same level of excellence.

Caltech, moreover, is a very special private university. It is special in its ratio of faculty to students, in the dedication of its trustees and alumni, in its research orientation, and in its small size, which allows new forms of interaction and experimentation. Most of all, it is special in the quality of its faculty and of its student body.

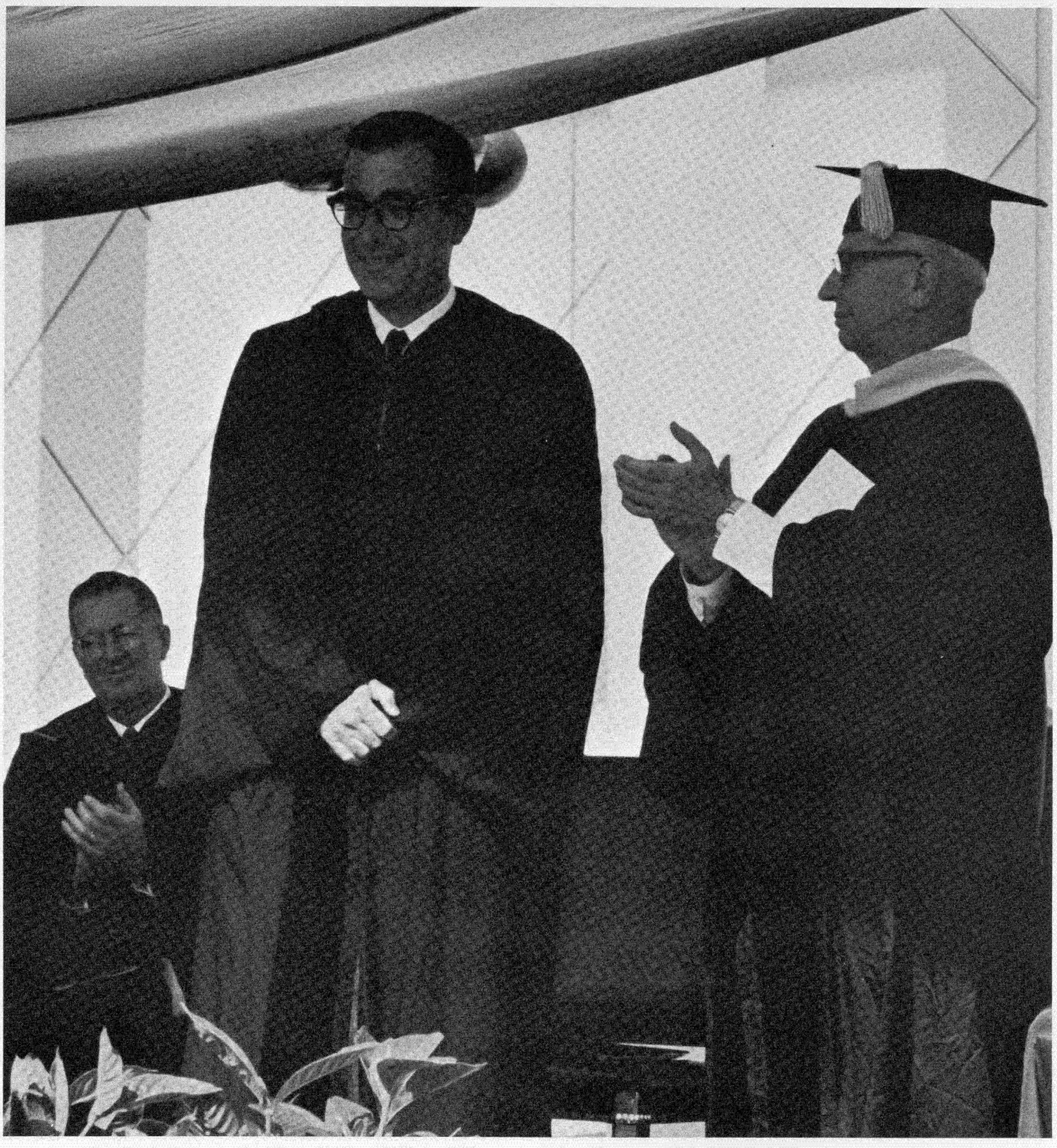
We have demonstrated success in finding new ways of doing things, and we continually renew our dedication to that end. We shall continue to set new standards of excellence. We have created and will create entirely new disciplines. We have produced and will produce the people who can do the same in future generations.

Indeed, people are central to the activity of the Institute. As recognition of this fact, we plan to establish several new named chairs, including Institute Professorships. We hope that others will follow the wonderful example of the Associates of the California Institute of Technology, who decided this year to establish the DuBridge Professorship.

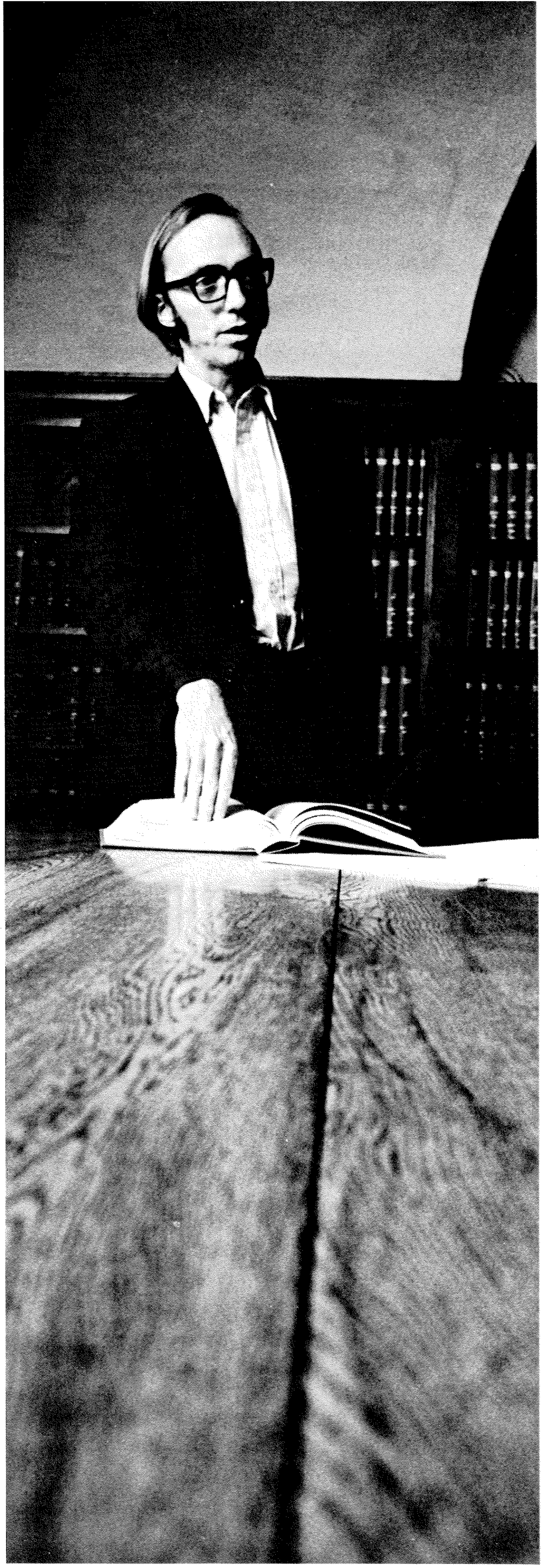
The community, the Institute and its people, the life of learning, the advancement of reason and humane values—these are the responsibilities of the university president in our day. I assume them gladly, but with humility before the magnitude of the task at hand. I am especially aware of how great a burden rests on one who follows in the footsteps of Robert Millikan and Lee DuBridge. The Institute is already a monument to their achievements, and I will be loyal to the magnificent tradition they created and sustained.

We want our institutions to give maximum opportunity and freedom to the individual in learning, in doing research, or in any other role. And yet we also want the Institute, by its stature and strength, its continuity and shelter, to provide that same kind of support to those who may be associated with it in the future. This requires that we give it loyalty beyond our own immediate personal satisfactions. I pledge myself to the goals of providing opportunity and freedom for the individual, and reinforcing the strength and stature of the California Institute of Technology which makes that freedom and opportunity possible. And in achieving these goals, I ask your help.

We have created and will create entirely new disciplines. We have produced and will produce people who can do the same in future generations.



Lee DuBridge, president from 1946 to 1969, leads the applause for his successor.



The Death of a Star

by Kip S. Thorne

A star is only a glowing pause in the inescapable contraction of a gas cloud to an uncertain, sometimes fantastic, end

Nuclear fuel is the lifeblood of a star. By steadily burning nuclear fuel in its deep interior, a star replenishes the heat that radiates from its hot surface into the cold depths of interstellar space. Each day our sun burns 10^{13} of its 10^{27} tons of fuel in the center of its million-mile sphere. Unfortunately for any star, its fuel supply is limited. Eventually—after about 10 billion years for the sun, after only 5 million years for a star 30 times as massive—a star exhausts its nuclear fuel, and dies.

What throes convulse a star when its fuel is consumed? What remnants does it produce? These questions have intrigued astronomers and physicists for half a century. The first glimmerings of an answer were provided nearly 40 years ago, but only since 1963 has the entire picture been brought into sharper focus. That picture is characterized by extremes: temperatures of billions of degrees, densities of tons per cubic inch, explosions that can rip stars apart, and the sudden and complete collapse of entire stars. Surges of cosmic rays, gravitational waves, neutrinos, and X rays announce a stellar death. Nothing else in the universe, except the distant blaze of a quasar and the birth of the universe itself, has been as violent.

The fate of a star is determined largely by its mass when it exhausts its nuclear fuel. Small stars die the gentlest of stellar deaths. They shrink to about the radius of the earth and rest there forever as white dwarf stars, gradually dimming as they slowly cool to zero temperature. The earth itself, being 330,000 times less massive than the sun, has always been in a dead, cooling state.

Larger stars die violently. They contract slowly at first and then collapse catastrophically. A sudden release of energy may convert this collapse into a supernova explosion, ripping the star apart and scattering the fragments into interstellar space. In some cases, the star may shrink with increasing rapidity, not stopping until it becomes an ultradense neutron star. The collapse may even be unstoppable; the star may totally disappear from

Adapted from *Science Year, The World Book Science Annual.* © 1968 Field Enterprises Educational Corporation.

Kip Thorne, associate professor of physics the rest of the universe into a "black hole" in space.

White dwarf stars and supernova explosions have been observed and studied in detail by astronomers, and neutron stars are probably being observed now in the guise of pulsars. The laws of gravity and of the structure of matter convince us that black holes must also exist. In describing them, however, we theoretical physicists are out on a limb. We have no firm observational support. In the coming decade, astronomers may put us on firmer footing —or they may destroy our theories altogether.

Most stars in the universe are small—less heavy than 1.4 suns. Consider first the plight of such a star when it has consumed all the nuclear fuel in its interior. Kept hot, boiling gases could resist the relentless crush of gravity. But the dying star continues radiating its remaining heat; its heat pressure weakens, and gravity pulls it inward. The gravitational compression reheats the interior, and half the heat generated flows outward to the star's surface, where it radiates away. The other half, which is trapped in the interior, pushes the temperature upward, and the increased radiation and gas pressure act to retard the contraction of the star.

Gravitational compression and heating cannot continue indefinitely. When, after millions of years, the star has diminished from hundreds of thousands of miles to several thousand miles in diameter, its central temperature has climbed to nearly a billion degrees. The density of matter at its center has risen from several pounds to several tons per cubic inch. According to Newton's law, the force of gravity within the star increases too, as the star grows smaller, by the inverse square of its radius. Despite the growth of gravity, the compression of a small star gradually stops. The star is now a white dwarf.

Electrons in the star's atoms prevent the compression from reaching still higher densities and temperatures. According to the uncertainty principle, no particle likes to be compressed. The smaller the particle's mass and the smaller the volume into which it is compressed, the larger is its resistance to further compression. In the star, at densities of a few tons per cubic inch, the opposing pressure from lightweight electrons becomes large enough to counterbalance forever the pull of gravity.

After billions of years, a white dwarf cools to a "black cinder," drifting endlessly through space. Such will be the fate of more than a thousand hot, but dim, white dwarfs that astronomers have studied through their telescopes. Such must be the eventual fate of our sun.

Like smaller stars, a star larger than 1.4 suns is crushed by gravity after it exhausts its life-sustaining fuel. Unlike smaller stars, however, it cannot create sufficient electron pressure to halt its contraction. When the compression has reached white-dwarf densities, the force of gravity within the star has become so huge that it overwhelms the combined pressures of electrons, heat, and light. With each contraction, gravity's advantage increases. Every part of the star rapidly accelerates its fall toward the center.

Whether and how this collapse halts is determined by the star's mass, its chemical composition, and how fast it is spinning. Only another decade of intensive work by theoretical astrophysicists and observational astronomers may tell us exactly how each property fixes the fate of a specific star. We know today, however, what possible fates a star can suffer, and we are quite certain that some stars encounter each of them as they die.

The collapse of large stars may generate a gigantic nuclear explosion, as was first pointed out by Fred Hoyle and Caltech's William A. Fowler. The star's outer layers, if incompletely burned, may suddenly ignite and explode as a supernova, blowing themselves into interstellar space, to shine for a few months as brightly as a billion normal stars.

In other cases the nuclear explosion may be too weak to eject the outer shell. The entire star may continue to collapse, with rising densities and temperatures, until its core, falling fastest, becomes as dense as an atomic nucleus. This, and subsequent events, have been predicted by large electronic computers at Caltech and elsewhere, using highly complex mathematical techniques developed to design hydrogen bombs. (The conditions in a collapsing star, although enormously more severe than those at the center of an exploding hydrogen bomb, generate similar shock waves in the hot gas shells.)

During the core's collapse, which lasts only a few seconds, the electrons in its atoms, unable to resist, are squeezed into the atomic nuclei, transmuting protons into neutrons. The collapse quickly packs 10^{57} neutrons side by side, as in a giant atomic nucleus. At such close range they exert an enormous repulsion. If the collapsing star weighs less than two suns, the neutrons absolutely resist further compression and halt the collapse almost instantly.

As the outer shells of the star fall violently onto this hard neutron sphere, their impact creates enormous heat, which converts their collapse into an explosion. The core's surface temperature zooms to hundreds of billions of degrees for a fraction of a second, then drops to 10 billion degrees as most of the heat energy changes into neutrinos.

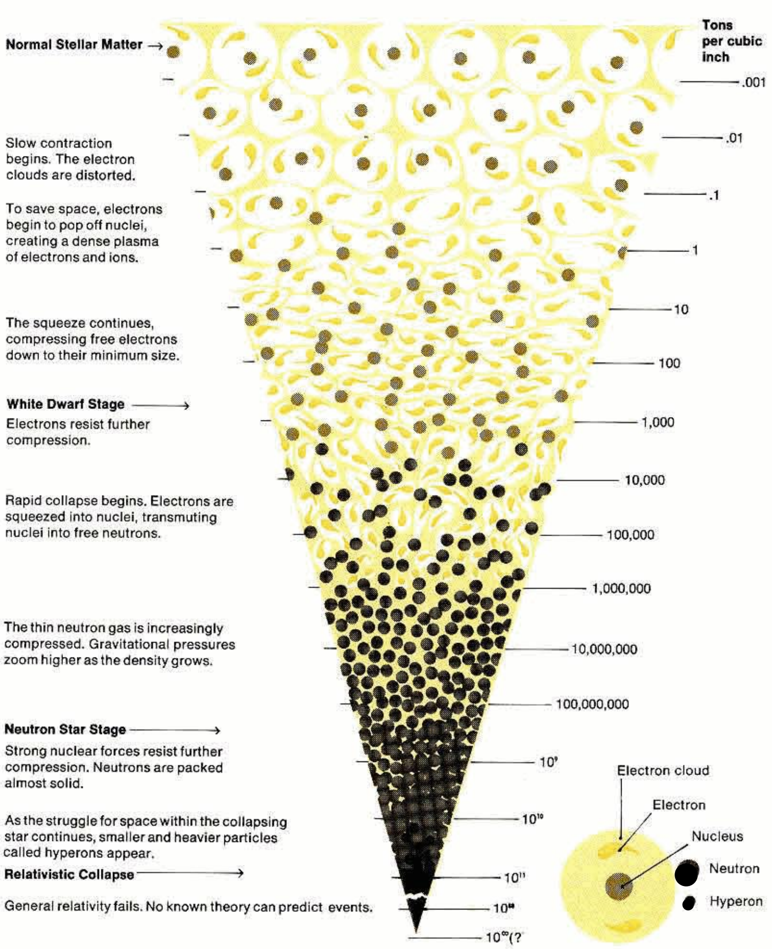
Neutrinos are near-massless particles, like photons (particles of light); but in enormous numbers they can carry large amounts of energy. Under normal conditions a neutrino can hardly "see" matter at all. For example, all but one in a billion neutrinos emitted by the nuclear reactions at the sun's center pass unhindered through the sun into interstellar space. In a collapsing star, however, because the densities and temperatures are so much higher, neutrinos can travel only a few yards before they scatter off the collapsing matter. They diffuse outward through the infalling layers, losing much of their enormous energy and heating the star's outer layers to tens of billions of degrees. These temperatures produce such huge pressures that the collapse of the layers is reversed. The outer layers eject explosively, and, like the layers ejected by a nuclear explosion, they may produce brilliant supernova fireworks.

The entire collapse—past white-dwarf densities to neutron core, the infall of matter onto the core, heating, liberation of neutrinos, and transfer of their energy to the outer layers of the star—takes only a few seconds. The explosion may shine as brightly as a billion stars for several months, however, and the glow of the remnant gas clouds can persist for thousands of years.

Whether produced by a nuclear explosion or by the formation of a neutron core, one such supernova explosion is observed each year in a hundred million million stars; in our Galaxy, about one every three centuries. On July 4, 1054, for example, Chinese astronomers observed a supernova explosion that lasted for about a year. Today we still see the luminous remnant of that star's outer layers as the beautiful Crab Nebula. Now several light-years across, the nebula is still energetic enough to emit radio waves, X rays, and light of all colors.

Studies of gaseous supernova remnants, plus detailed observations of scores of supernovae in distant galaxies, help motivate and guide theoretical calculations of stellar collapse. Although these calculations give us a good explanation for the observations, we are not certain it is the right explanation.

Matter's Struggle for Space in the Crush of Collapse



The heavier a particle, the smaller the volume it is able to occupy. Atoms in a shrinking star are thus crushed, in turn, to electrons and nuclei, neutrons, and increasingly heavier hyperons. Whether each can counter gravity depends on the star's mass: Less than 1.4 suns, free electrons stop the slow compression; less than 2 suns, neutrons will halt the collapse; more than 2 suns, no particle is able to resist gravity.

If it is correct, deep within the starburst of some supernovae should be a collapsed neutron core, or neutron star. It should weigh between one-fifth and twice the mass of the sun, and be packed in a sphere between 8 and 400 miles in diameter. Its density will thus be about a billion tons per cubic inch. When first formed, it should have a temperature of billions of degrees at the center and several hundred million degrees at the surface. During the first few seconds of its life, it should emit as much energy —about 10^{52} ergs—in gravitational waves and neutrinos as a star emits as light and heat during its entire normal lifetime. For several thousand years a neutron star should be a brighter source of X rays than the sun is of light. Its surface will not cool to a few thousand degrees until 100 million years after its formation.

In August 1967 a team of astronomers at the Mullard Radio Astronomy Observatory in Cambridge, England, detected strange signals—radio-wave bursts spaced with perfect regularity, one each 1.33730109 seconds. When their discovery was announced in February 1968, it aroused great excitement. Were these strange pulsars (about 50 others had been discovered by mid-1969) the communication beacons of an advanced civilization? Or were they a natural phenomenon?

By now we know with confidence that the radio bursts of pulsars are natural; they probably come from rapidly rotating neutron stars that beam narrow "pencils" of radio waves in our direction once or twice during each rotation. (The term "pulsar" is a misnomer; "rotator" would be better.) The most rapidly rotating of the pulsars lies in the heart of the Crab Nebula. It, like the nebula, is a remnant of the supernova of 1054 A.D.; and it emits not only beams of radio waves but also beams of light and of X rays.

According to the computer simulations, many neutron stars may form without accompanying supernova fireworks. Some stars should collapse to neutron stars without ejecting their outer layers; others may eject these layers, but the gases will be so opaque that the bright inner light cannot escape. Moreover, the violent collapse need not produce a neutron star. In fact, if its neutron core weighs more than two solar masses, it cannot become a neutron star. The increased mass strengthens the gravitational attraction sufficiently to overwhelm even the strong repulsive forces between neutrons. Gravity takes over and pulls the core back into catastrophic collapse, a collapse that quickly makes the star so small—less than 4 miles in diameter—that even light can no longer escape from its intense gravitational pull. In essence, the star creates and plunges into a black hole in space.

Black holes cannot be understood by using Newton's laws of gravitation. Gravity is so strong near a black hole that these laws break down and must be replaced by the laws of general relativity theory, which Albert Einstein formulated in 1915. Einstein's laws were first applied to the study of gravitational collapse in 1939 by American physicist J. Robert Oppenheimer and one of his students, Hartland Snyder, at Caltech and the University of California, Berkeley. Their prediction, that gravitational forces could grow so strong that starlight would not leave the star, was so startling that, had not World War II intervened, it would probably have become a subject of intense investigation. Shortly after his pioneering study of gravitational collapse, Oppenheimer turned his attention to the development of the atomic bomb.

Oppenheimer did not renew his study of collapsing stars after the war, and relativistic collapse remained mainly in the backs of the minds of astronomers and physicists. "A strange phenomenon indeed," they tended to think, "but of no relevance for the astronomy of our times." In 1963 that attitude changed suddenly. Quasi-stellar radio sources, or quasars, had been discovered, and the enormous difficulty of explaining their large power output —10^{40} watts—forced astrophysicists to consider collapse as a likely energy source. At the same time, Stirling Colgate and Richard White at the University of California's Lawrence Radiation Laboratory were just completing their first computer simulations of supernovae and had verified the Hoyle-Fowler prediction of the central role played by collapse.

In essence, the star creates and plunges into a black hole in space.

By 1967 hundreds of theoretical physicists had converged on the problem of collapse from a variety of directions: relativity theory, mathematical physics, astrophysics, plasma physics, high-energy physics, nuclear physics, and nuclear weapons research. Astronomers, too, had begun to ask themselves whether collapse might explain other astronomical phenomena, and how they might observationally verify or discredit the ideas of the theoretical physicists.

As a result of the recent research, it is evident that the collapse of a star cannot be halted if its collapsed neutron core has more than two solar masses. In fact, according to Einstein's theory of relativity, from this point on, any resistance—no matter how large—will itself generate a still larger gravitational attraction. Gravity inevitably wins. It crushes the entire star through the black hole, down to infinite density. A region forms in space and time inside the black hole that has zero volume and possesses infinitely strong gravity at its boundary. This region is called a singularity of space-time. Within it will be the entire collapsed star. Any object—light, particle, man, or planet —that subsequently wanders too near can never escape. It is swept quickly into the unseen singularity at the hole's center. Overwhelming gravitational forces stretch the object out of shape and compress it, like the star, to infinite density.

How near the singularity dare a spaceship approach before it would be captured forever by gravity, no matter how strong its rocket engines? The point of no return, called the gravitational radius, is the edge of the black hole itself. To an outside viewer, the edge is a sphere 25 miles in circumference that surrounds a singularity containing a collapsed star twice as heavy as the sun. The circumference is proportionately larger if the star is more massive. If a quasar a billion times heavier than the sun were to collapse to a singularity, its black hole would be 12 billion miles, or .002 light-year, in circumference.

It will be impossible for an astronomer—or any other observer—to ever see the singularity of a collapsed star because no light ever escapes from a black hole. He might see the star collapse, however. A nearby observer would see the star shrink rapidly at first, but as it nears the gravitational radius, starlight is caught and held for a long time by gravitational forces, escaping only slowly toward his eyes. Even at the speed of light, photons and particles take a long time to traverse the rapidly stretching space just outside the black hole. The collapse will thus appear

The star could not remain at the same point in space where it collapsed, but would have to burst forth at some other, distant point or in some universe different from our own.

to the observer to slow down. Light emitted from the star's receding surface requires successively longer times to reach him. No matter how long the observer waits, he will never receive light emitted after the star falls into the black hole, but will always—at least in principle—be receiving the last few photons that are emitted from just outside it.

The outside observer, then, will have great difficulty witnessing catastrophic collapse. The collapse will grind to a halt at the gravitational radius, and the star will hover there, quickly turning redder and darker but not smaller. After a few seconds for a normal star—or after a few days for a collapsing mass as heavy as a billion suns—it will be virtually black and invisible. Only its intense gravitational field will be left. Moreover, the "winking out" of a star should usually be hidden from the eyes of astronomers by the luminous outer layers that the star has ejected before plunging within its gravitational radius.

Both neutron stars and black holes should have strong gravitational fields, and this may help to reveal their presence. Since most stars are not alone (like the sun) but come in pairs (binary systems) revolving about each other, it is likely that many neutron stars and black holes will be orbiting with normal stars. An optical astronomer looking at the normal star will see its spectral lines shift back and forth in wavelength as it moves in orbit alternately toward and away from the earth. About 799 stars with such shifting spectral lines have been studied by astronomers over the last 50 years. In about half of these cases the companion star has been seen, and it is perfectly normal. But in several hundred cases the companion star is unseen. In most such "single line binaries" the unseen star is probably a small, normal star, whose light pales in the brilliance of its larger companion. But in 10 cases the shifting spectral lines indicate that the unseen star is heavier than the visible star—between 1.4 and 25 solar masses. Some of the unseen stars might be black holes or neutron stars. These 10 cases, and others, will be studied intensively in the coming years.

In some binary systems, matter ejected from the normal star may pour down onto the surface of the neutron star or into the black hole. The infalling matter should be heated by collisions to million-degree temperatures and higher, and emit X rays and gamma rays. This might be the explanation for some of the X-ray sources observed by telescopes carried aboard balloons, rockets, and satellites. Neutron stars younger than 1,000 years should be hot enough to emit X rays even without infalling matter.

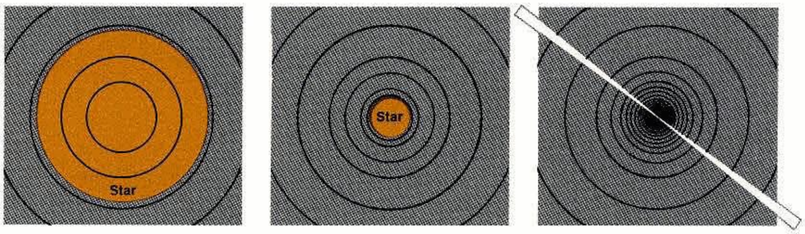
For the few seconds as they form, neutron stars and collapsing stars should emit large numbers of high-energy neutrinos. Since matter is almost transparent to neutrinos, they are quite difficult to detect. Forerunners of cosmic neutrino observatories began operating, however, in 1966 and 1967. To reduce interference from cosmic rays, they were built in deep mine shafts in South Africa, South Dakota, and Utah.

As a neutron star or collapsed star forms, it should also emit huge energy as gravitational waves. The first serious gravitational wave detectors were built by physicist Joseph Weber at the University of Maryland. Since 1967 those detectors, giant aluminum cylinders which should vibrate when hit by a gravitational wave, have been sensing about one "event" per month. To theorists this is simultaneously exciting and disturbing: The wavelengths (about 200 kilometers) and duration (a few seconds or less) of the waves that Weber seems to see are just what a collapsing star should produce; but the number of events is higher than expected by several orders of magnitude! Either something is wrong with the theory, or something is wrong with the experiment, or both.

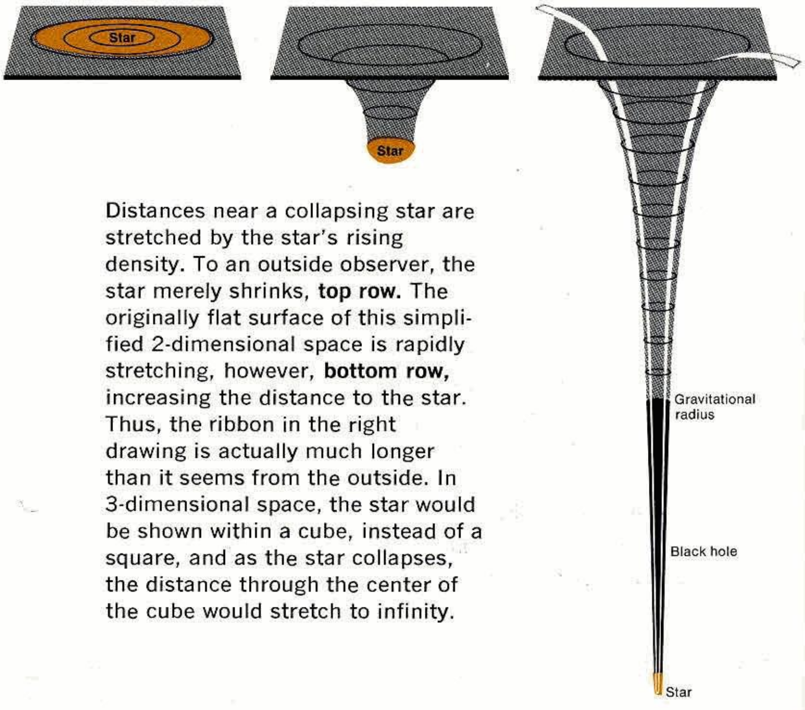
Although astronomers have firm observational evidence

Space Swallows a Star

The outside view of a collapsing star

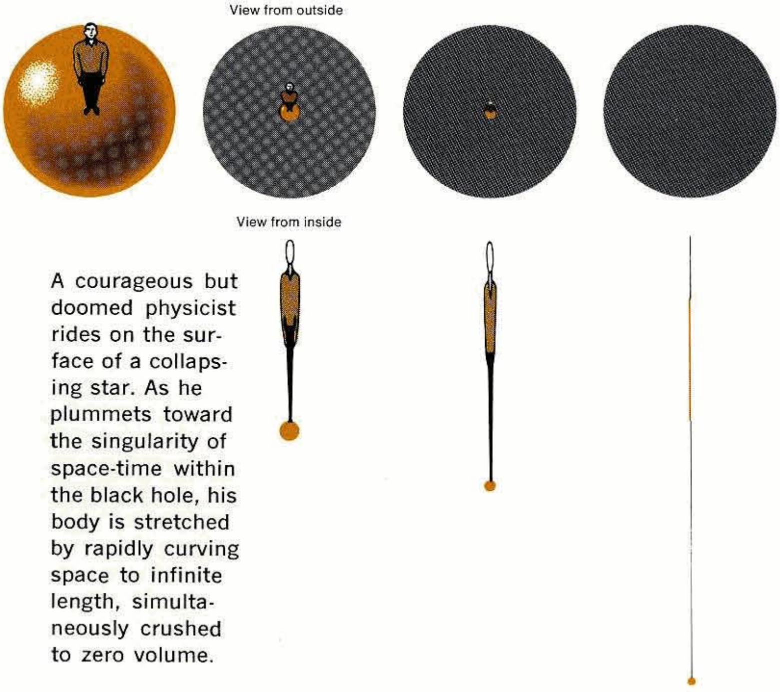


The infinite stretch of space



Distances near a collapsing star are stretched by the star's rising density. To an outside observer, the star merely shrinks, **top row.** The originally flat surface of this simplified 2-dimensional space is rapidly stretching, however, **bottom row,** increasing the distance to the star. Thus, the ribbon in the right drawing is actually much longer than it seems from the outside. In 3-dimensional space, the star would be shown within a cube, instead of a square, and as the star collapses, the distance through the center of the cube would stretch to infinity.

Two Views of Gravitational Suicide



A courageous but doomed physicist rides on the surface of a collapsing star. As he plummets toward the singularity of space-time within the black hole, his body is stretched by rapidly curving space to infinite length, simultaneously crushed to zero volume.

for the existence of white dwarfs and neutron stars, there is as yet no firm evidence for black holes or the collapse that forms them. How then, without proof, can physicists take seriously a theory that predicts a fantastic crushing of stars to zero volume and infinite density? General relativity theory, which makes these predictions, is inadequately tested by experiments. But the only competitive gravitation theory that agrees as well with experiment, the scalar-tensor theory developed in 1961 by physicist Robert Dicke and his student Carl Brans at Princeton University, predicts an almost identical end for the collapse. There too, calculations suggest, a singularity arises, and matter falling into it becomes infinitely dense.

Deep inside the black hole, though, Einstein's theory of gravitation must fail, just as Newton's theory failed throughout the black hole. Einstein's theory might be valid, however, until the density reaches about 10^{88} tons per cubic inch, which is 10^{79} times as dense as a neutron star. This density would be obtained by crushing the sun to one-millionth the diameter of an atomic nucleus. The theory that predicts behavior in such extreme conditions is not yet known. Thus a star might conceivably escape complete crushing, but it is certain that nearly complete crushing and a near-singularity must arise.

The problem is further complicated by the fact that real stars are not perfect spheres, but are slightly twisted and deformed. As they collapse, their deformations should grow. Although the relativistic collapse of idealized spherical stars is now well understood, theoretical physicists are only starting to make headway in understanding how deformations will affect collapse. The most powerful mathematical techniques are proving barely adequate to analyze the problem.

The most significant result is due to Roger Penrose, a mathematical physicist at Birkbeck College, University of London. Making reasonable assumptions about the universe, he showed that, once an entire star collapses within its gravitational radius, no deformation can prevent it from creating a singularity.

Penrose's theorem does not say, though, that all—or even any—matter in the collapsing star will be caught and crushed in the singularity. In a spherical collapse, the entire star must be crushed. In a nonspherical collapse, surprisingly, although a singularity will be created, all or part of the star might survive in some cases. This conclusion is supported by a mathematical example of collapse, due to former Caltech student James Bardeen and the Russian Igor Novikov, in which an entire star collapsed into the black hole but completely avoided its singularity.

This star could not remain, however, at the same point in space where it collapsed, but instead would have to burst forth at some other, distant point in the universe or in some universe different from our own. The deformed black hole acted as a "wormhole" to sweep the star from one region of space and time to another. Several physicists, including Novikov and the Israeli Yuval Ne'eman, have speculated that quasars might be the explosive reemergence of massive collapsed stars.

Although we know that some collapses should completely crush a star, and that others should lead to its reexplosion elsewhere, we do not know which fate is most common. Einstein's theory, when we understand it better, may predict that crushing occurs almost always; or it may predict that crushing occurs almost never. No external observer will ever be able to see into the blackness within the gravitational radius to tell us which is right. The events that theoretical physicists predict happen there can never be proved.

Almost never, that is. The gravitational collapse of a star, as viewed from its interior, is but a trifling preview of the ultimate contraction that may crush our presently expanding universe in another 70 billion years. Our universe seems to have exploded to create this space and time, and we are trapped inside its gravitational radius. No light can escape from the universe. Although man need never collapse with a star, he cannot avoid collapsing with the entire cosmos, if he still exists 70 billion years hence. He may discover then whether the universe avoids the singularity to reemerge again.

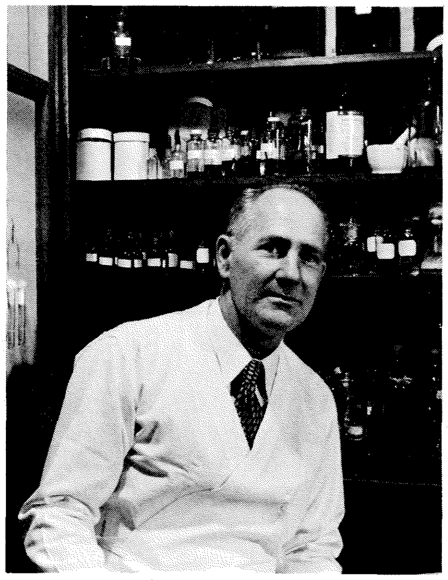
For the time being, a dedicated physicist can only (in principle) ride down on the surface of a collapsing star—or jump into the black hole after it—to test his theories about the black hole's interior. Of course, he could never get back out or communicate his results to the outside. But who—aside from legislators enacting antisuicide laws—is to deny a man the right to his own personal pursuit of knowledge?

The Month at Caltech

Trustee Diversification

Caltech's board of trustees has elected four new members. Following a decision at their November 1 national meeting to increase the size of the board from 40 to 45, the trustees added George W. Beadle, Otis Chandler, Robert S. McNamara, and Ruben F. Mettler, bringing the total current membership to 42. The increase in size of the board will permit a wider variety of interests from all areas of the country.

With his election to the board, George W. Beadle, 66, resumes his connection with the Institute where he was a member of the faculty from 1946 to 1961. In 1958, while he was professor and chairman of the biology division at Caltech, Beadle won the Nobel Prize in physiology and medicine for his research on the role of genes in controlling biochemical reactions in the bread mold *Neurospora*. He became president of the University of Chicago in 1961, a position from which he retired in 1968. Since his retirement he has served as director of the American Medical Association's Institute for Biomedical Research. Beadle is the author of a well-known textbook on genetics, and co-author with his wife, Muriel, of *The Language of Life*, which won the 1967 Edison award for the outstanding science book for youth. He is a member of the National Academy of Sciences and the American Academy of



Biologist Beadle

Banker McNamara

Engineer Mettler

Publisher Chandler

Arts and Sciences, and has received honorary degrees from 28 universities and colleges in this country and abroad.

Otis Chandler, 41, publisher of the *Los Angeles Times,* is the third member of his family to serve on Caltech's board of trustees. His father, Norman Chandler, is a 28-year member and was recently elected vice chairman of the board; his grandfather, the late Harry Chandler, was a trustee from 1920 until his death in 1944. Otis Chandler received his BA degree from Stanford University in 1950 and then served two years in the Air Force. He joined the Times Mirror Company, the parent firm of the *Los Angeles Times,* in 1953, and became publisher of the newspaper in 1960. He has won journalistic awards from the Universities of Missouri and Southern California and an honorary doctor of laws from Colby College.

Robert S. McNamara, 53, former Secretary of Defense and currently president of the World Bank, was graduated from the University of California at Berkeley in 1937. In 1939 he received his MBA from the Harvard Graduate School of Business Administration and served as an assistant professor there from 1940 to 1943. During World War II he worked for the U.S. War Department in Britain, setting up a statistical control system over the flow of materiel, money, and personnel. He also served with the U.S. Air Force in India, China, and the Pacific and was awarded the Legion of Merit and promoted to lieutenant colonel before his discharge in 1946. For 14 years after the war McNamara served as an executive of the Ford Motor Company; he was made president in 1960. In 1961 he became defense secretary under President Kennedy, a position in which he worked closely with Caltech's president, Harold Brown, who was Secretary of the Air Force from 1965 to 1969. Since April 1968 McNamara has been president of the World Bank and also of the International Finance Corporation and the International Development Association.

Ruben F. Mettler, 45, assistant president and executive vice president of TRW Inc., and chairman of President Nixon's task force on science policy, is a Caltech graduate. He received his BS degree from the Institute in 1944, his MS in 1947, and his PhD in electrical and aeronautical engineering in 1949. Mettler began his career as associate director of the guided missile research division and Thor program director for the Ramo-Wooldridge Corporation (a precursor of TRW). From 1962 to 1968 he served as president of the TRW Systems Group, where he directed space programs for the Vela, Pioneer, and Orbiting Geophysical Observatories satellites. Under his leadership the TRW group also developed the lunar module descent engine for the Apollo program, contributed ideas for modernizing the Minuteman ballistics missile program, and helped with the Navy's program for integrating its antisubmarine defense. Mettler has received many honors for his engineering work: In 1955 the Junior Chamber of Commerce listed him as one of America's ten outstanding young men; in 1964 he received the "engineer of the year" award from the Engineering Societies of Southern California; and in 1966 he was given Caltech's Alumni Distinguished Service Award.

Treatise on the Thesis

It is one of the unenviable duties of the dean of graduate studies at Caltech to read every graduate thesis every year. In 1969 there were about 125 of them—upwards of 20,000 pages—with most of them submitted close to the deadline for getting degrees in June.

But now it is fall, and the spring reading marathon is so far away that Dean H. F. Bohnenblust can speak of it almost affectionately, as he did at an outdoor dinner welcoming new graduate students on October 3 in Winnett Plaza:

There is something that is really very characteristic about the theses in geology. They are terribly long, and in a certain sense this is very satisfying. It is rather discouraging to come into my office in the morning, and there in my "in" basket is a huge stack of theses which I am supposed to read. Well, each thesis appears in duplicate, so whenever I get a nice fat geology thesis, I read it through, and I have suddenly a big second one disappearing. That is gratifying. In addition, I must say one thing: Among all the theses that I have seen at Caltech, it is the geology theses which I enjoy the most. They are descriptive, and they are interesting, and I can understand most of them.

Biology and chemistry are two fields which are an excellent example of interdisciplinary work. They work in many respects in common; in fact, they do more than that. They list the same course in the catalog under different titles; biology such-and-such, and chemistry such-and-such, and it is the same course. That has a tremendous advantage. The student need only take one course. One year he lists it under biology, and the next one he lists it under chemistry. It is very useful. Chemistry theses, of course, are full of hexagons. That I have observed. They also involve teamwork, and when I sign the final approval of a chemistry thesis, I am rather uneasy. I am never sure whether I am giving an additional degree to a member of the staff, or, worse than that, maybe I am awarding the degree to the wrong student.

As far as mathematics is concerned, they have the shortest theses. Every thesis is read by an official reader, because we try to make sure that every so often there will be a sentence that has a noun and a verb. The readers like the mathematics theses because there is no sentence with a noun or with a verb; it is all hidden in a symbol and an equality sign. A mathematics thesis starts very simply with one assumption; then you look at the last page and there is the conclusion. In between you find a sequence of self-evident lemmas.

Physics theses are frankly the ones I like the least. What is more, they remind me of the nightmare of the contract bridge player. He held four aces, four kings, four queens, and one jack, and after very scientific bidding he finally reached a contract of seven no trump. Lo and behold, the man on his left led with a green card he had never seen before. Well, when you read a thesis in physics, somehow they always come up with a new particle that you have never seen before.

Finally, this leaves engineering. Now,

this is really much too complex an organization to speak about. It is the biggest division and it contains many specialties. Frankly, I think that some of them are completely indistinguishable from each other, such as applied mechanics and mechanical engineering. Thank God, Dean Lurie, who is associate dean, is reading the theses in engineering now. But before he helped me, I remember at least one difficult case: You know, a thesis begins with a title; then after a while comes a page where the student dedicates his thesis to somebody he really cares for. I found that page filled with mathematical symbols; no explanation. Well, I spent a whole night trying to figure out what he was trying to say. All I can tell you is that after a long search I finally discovered that he was speaking about the cross product of two vectors and was dividing the cross product by the first vector and by the second vector, and that left the X. So when I analyzed the symbols, slowly the sentence came out and the dedication was to Maxine, his wife. Of course, I could not let that go by, so I spent another night of work explaining to him how I had deciphered what he meant to say in his dedication. A few years later he came back to me and said, "You know, that really convinced me that somebody had read my thesis."

I would like to conclude with one remark wherein I am really quite serious. I have concentrated on theses in speaking about the different options, and, for all of you who are going to go on for the PhD degree, naturally the thesis work will be the important part of your program. Somehow you are registered as "graduate students." I do not quite like the name student—it implies to some extent that you came here as an outsider, as an individual, and that you will be with us a certain time and leave as an individual. I would like to emphasize very much that the research that you will be doing here while you are on the campus is not only your own research, but it is part, and a vitally important part, of the research effort of the university as a whole. For this reason, I would much prefer not to look at you as just students, and I hope that you will not feel that you are just students, but that you are members of our research staff.

Honorary Degree

Harrison Brown, professor of geochemistry and of science and government, received the honorary degree of Doctor of Science from the University of Cambridge on November 1 on the occasion of the 150th anniversary of the Cambridge Philosophical Society. Brown, who also serves as foreign secretary of the National Academy of Sciences, received this tribute at the Cambridge ceremony:

Consummate scientist and jazzman Brown

> Young Americans, in order to be able to afford college education, cannot rely like our young men on grants from public funds. Often they must to a large extent make their way by their own gifts and sweat. Even so this man, being an expert pianist, scraped together the means of embarking on his studies by performing in nightclubs, whether solo or as leader of his own jazz band or producing songs of which he had himself composed both the words and the music. Hence no doubt the confidence, hence the keen and enterprising spirit, with which he initiated his bold plan of collecting all the springs of scientific knowledge into one reservoir, so that anyone who wishes to be informed of the best attestation for any measurement could have somewhere from which he might most conveniently derive it. But he could never have acquired the authority necessary for so great an undertaking if he had not himself been a consummate scientist. For this is the man who determined the age of the earth by much more certain proofs, through scrutinizing the lead found in isolation in iron and in stone meteorites. He has also propounded a probable theory of the origin of the planets.
>
> Nor as a researcher into atomic nuclei does he think that the dangers that can result from such studies are no responsibility of his. Indeed it was at his instigation that the Federal Government of the United States set up its Arms Control and Disarmament Agency. And he has also been anxiously exercised about that other great worry of farsighted men, the fear that the nations may perish rather through excess of population. For what-

> ever concerns man he takes to be his concern.

This graceful tribute is actually a translation of the original which, befitting the occasion, was delivered in Latin. Scholars who have not had recent occasion to use the Latin for "nightclubs" and "jazz band" may be interested in the original wording of the third sentence of the tribute:

> Velut hic olim, ut erat scitus clavichordii, in noctuvigilorum tabernis sive solus sonans, sive dux symphoniacis quasi Corybantiis aera geminantibus consonans, sive cantica promens quorum ipse et verba et numeros composuerat, facultates ad studia capessenda corrasit.

Armin Deutsch

Armin J. Deutsch, staff member of the Mt. Wilson and Palomar Observatories, died on November 11 of a heart ailment and complications. He was 51.

Deutsch discovered that giant red stars generate great stellar winds which carry matter through space. His research included study of the composition and rotation of stars, star clusters, cool stars with unusual chromospheric activities, and a group of magnetic stars called peculiar A stars.

Born in Chicago, Deutsch graduated from the University of Arizona and got his PhD from the University of Chicago. He was an assistant astronomer at Perkins Observatory in Delaware, Ohio, in 1946-47; an instructor at Harvard Observatory from 1947 to 1950; and since 1951 had been a staff member of the Mt. Wilson and Palomar Observatories and the Carnegie Institution of Washington.

Arms Limitation Delegate

Harold Brown is one of six members of the delegation appointed by President Nixon to participate in strategic arms limitation talks between the United States and the Soviet Union. Accompanied by his wife, Colene, Brown flew to Helsinki on November 11 for the first talks, which are expected to take about three weeks.

This first session will determine topics, ground rules, and a meeting place for future discussions. Brown was a member of the U.S. team that helped negotiate a nuclear test ban during discussions which began at Geneva in 1958-59.

DuBridge Professorship

The Associates of the California Institute of Technology have launched a fund-raising project to establish and endow a Lee A. DuBridge professorship in honor of the Institute's former president, who is now President Nixon's special assistant for science and technology. The Associates are a group of public-spirited citizens (now numbering about 400), interested in the advancement of learning, who were incorporated in 1926 as a non-profit organization "for the purpose of promoting the interests of the California Institute of Technology."

While they hope that the professorship may be rotated among the various fields of scholarship at Caltech, the Associates would like their first candidate to be someone whose interests are "in an area of biological sciences in which an understanding of behavior is important or in an area of science or technology which is closely associated with Dr. DuBridge's career or interests."

Award

Cornelius Pings, professor of chemical engineering, won the $1,000 Professional Progress Award for 1969 from the American Institute of Chemical Engineers. The award recognizes his work in "theoretical and experimental developments in the fundamental behavior of fluids, particularly in the critical region."

Graffiti

Simple declarative statement painted on the construction fence surrounding the site of Baxter Hall of the Humanities and Social Sciences:

GOD GRADES PASS/FAIL

Who's In Charge Here?

Paul Saltman '49, PhD '53, biochemist and provost since 1967 at Revelle College of the University of California at San Diego, continues to report back to Caltech on his trials and tribulations as an academic administrator.

In June 1968, E&S carried his "Provost, Proteins, Protest, Pot: Higher Education in America Today." Herewith, some highlights from his most recent informal report, made at a dinner meeting of the Friends of the Caltech YMCA:

Can you imagine my coming to Caltech in 1945 and stepping into Robert Millikan's office and saying, "God damn it, Bobby, here are 15 non-negotiable demands. Now shape up!"

I grew up in a very liberal, permissive household, learning how to letter signs and carry placards and the like, so it *never* occurred to me that some student —some freshman—might walk in and give *me* 15 non-negotiable demands. But it happened.

I am concerned with universities today, and I would like to try to describe a kind of environmental problem which involves three sub-species—administration, faculty, and students—that operate within this ecological niche called a university, which is also dependent on other sub-species like governors and trustees and indignant citizens and blacks and chicanos and industrial-military complexes.

First there are administrators—a strange lot. What do we have with respect to governance of universities? Grayson Kirk at Columbia? Two hundred and fourteen years without a single faculty meeting? Pusey at Harvard? When the going gets tough, call the cops; don't talk to your faculty? S. I. Hayakawa with a tam o'shanter and the frayed ends of a loudspeaker cord? Who's in charge here? Who becomes the dean? Who becomes the provost?

At a time when we are living with a very rough and ragged interface in the interaction of technology and science, how much have our institutions, with the great minds of science and technology,

Provost and negotiator Saltman

interacted with the men of the social sciences and the humanities to take some positive, dynamic step in the form of education today? Are we still living with the Morrill Act of a hundred years ago, worrying about land grant colleges and what we are going to do in the classical sense about agriculture in the United States? Who is looking toward the leadership of the university in the dynamics of the city in America today? Columbia? Berkeley? Caltech? UCSD?

I am very disturbed that over the years we have failed to recognize the problems of dynamic leadership in universities and colleges, that we always made the dean out of the guy who didn't publish quite enough to get his promotion, whose wife was very active in Faculty Wives, and who has two lovely kids. How many of them have really been involved in studies of problems of adolescent behavior and the concerns of a modern student in a modern society? Very, very few.

If you're going to pay a guy to be an administrator, he damn well better be in the game all the time as an administrator, 100 percent. And when you're paying him to lead, he'd better be out in front, and he'd better not be some kind of pacifier, trying to cool it. Because they've got more cans of gas than we have water.

If the students have reasonable claims, you work on them; if they're unreasonable, you call them on it. And you don't move capriciously and fast; you move slowly and evenly and steadily. You keep all of your moves completely wide open on top, and you go out on the plaza and you tell them what's happening and you involve the whole student body.

And you better not be shocked when you get half through and some kid steps up and calls you a "fascist pig," because he's sure as hell going to do it. You better have some answer for him in terms of, "Well, what are you doing about making this a better place, and are you involved?"

By and large, the academic administrator is a person who has not by his own personal concern with research been a great researcher, nor by his concern with teaching been a great teacher. He has become somehow or other more and more involved with the problem of management—and I use that term pejoratively.

Faculties in universities are an interesting group. There was a time (Oh, it was a sweet time) you would fill out your form for the NIH and you'd say, "Well, how much do I want this year? $150,000—$250,000—they've got a lot of money. And if not, then there's the NSF and the AEC." And, oh, the greenery just flowed.

There was a time—and it was a good time because science did prosper and the journals filled to overflowing with interesting articles—that a professor became a free entrepreneur, beholden to no one. He moved nomadically with his grants and with his tents from place to place in the desert of academe, seeking the best kind of real estate that he could get his hands on and the minimum teaching loads and the maximum chance to do his own thing. I emphasize that, because now the students want to do their own thing too—and it's very funny how the professors are uptight about that.

The fact of the matter is that the professor's main concern was to his peers. He was playing the federation meeting. How were *you* doing? Were you playing the men's room or the main stage? Where were you when your slides were shown? And on which airplane to Washington were you? And on what councils of government did you sit? And for whom did you consult so that you could have a couple of extra bucks to go off and do a little extra skiing or surfing or what you will? You were not beholden to students. And that's too bad, because I think that's what the universities are all about: teaching and learning. When the professors shirk their duty in this, we're in real trouble.

Then there are students—the bushy-haired, the weirdos, the wild ones, the bare feet up against the lectern while you're trying to teach. You're trying to show some sort of consideration—or magnanimity—and the SDS is out flying the North Vietnamese flag on the plaza and the Marines are marching in from one side and the citizens of La Jolla from the other, and the professors are going "Oh, my God. What'll we do?" And the governor is saying, "Get that flag down."

I really have figured it all out. The students of America are giving everybody the old Italian high-sign. You can laugh at it—but it's very tough to do, and it's getting tougher. Because the gesture is increasing in violence, and it is giving me great fear.

Great fear because I see within the context of the university today a very unfortunate circumstance taking over—the sense of self-righteousness of students, lauded by some of their faculty. I don't believe in this Children's Crusade. Yes, there are problems in the society. No, the students don't have all the answers. Because if they did, what the hell am I doing being a provost and a professor? Do you want to turn it over and walk away? The answer is no; and they don't want you to either. But they do want leadership and guidance.

And they are very, very bright. And they are very concerned. And what are we doing in a university for them? Seeing if we can load them down with more calculus and thermodynamics?

This problem came to me most clearly when I found out that they had hung the second provost in effigy, and then in reality, on the basis of dorm visitation rules—a great educational problem. The fact of the matter is that nobody was asking students how they wanted to live in a residence hall.

And you begin to worry as a biologist when you know that a woman becomes a woman physiologically between 13 and 15 years old in our society, but we're still treating them like adolescents when they come into a university at 18 and 19. And yet we have never asked the students to participate in the governance of their own lives within a university. We have never asked students how they felt about what they were learning in a university. We have never asked students to help in the decision-making process of higher education.

Whenever we brought this point up to our faculty, they would say, "Well, what the hell do *they* know?" And when the students would be given a chance to say what was relevant or irrelevant, they would say, "Well, you know, man, like it's gotta be relevant."

"Like what has to be relevant?"

"Like, you know, man, make it relevant—like, you know, black and white—like, you know, sensitivity—like, come on, like—"

It's hard to listen to or understand that kind of communication. I finally figured out what the problem was. They had never been asked to really state the problems and their solutions, neither in high school nor in junior high school nor any place.

Let me end with an upbeat, Pangloss, comment, because I feel that things aren't going downhill forever. I'll tell you what's going to happen this year. Saltman predicts that what happened at Stanford last spring is the model of what is going to happen at UC this year. There is going to be such a hue and cry for the stopping of military research on university campuses that the students—and probably the faculty—will bring Berkeley to a screeching halt until it disperses all of its holdings in Livermore and Los Alamos.

Students at Caltech—it may take them a little longer—are going to be investigating every grant that any faculty member ever had and any consulting that he does for any agency of the federal government or private industry that has in any way, shape, or form a relationship to the military-industrial complex—whatever that may be. That's going to be the real low point. That's when the real barricades are going to have to be built.

We have failed to move smartly, failed to give leadership in universities, and failed to be out on that cutting edge in terms of our concern and involvement with the total world scene. The universities have not taken that kind of initiative and sparkle that they should have had long ago in trying to make changes in a world that we are so sensitive to.

I think we're going to live through the year, and I think we're going to live through Ronald Reagan and the violence that he does to us and the violence that the regents do to us and the violence that the *San Diego Union* does to us and all kinds of ways and shapes and forms of violence, be they in the form of the environment which surrounds us or the violence that is within.

But I think that it's time to be making some very positive kinds of changes. Two years ago when I came down to San Diego, I was appalled by the three-cornered game that was being played, with administrators in one corner, faculty in another, and students in another. We tried to put together the governance for the college that involved every level—the faculty, the students, and the administration—with every kind of problem: curriculum, buildings, life in the residence halls, course structure, grading, effectiveness of teachers. And it was very curious. You know who resisted first? It's hard to believe, but it was the students. They didn't want any part of it.

"Hey, man, you're corrupting us. You're over 30, you're a fink, you're a fascist, you're an animal, you're part of the military-industrial complex, you took federal money, you're a whore. I don't trust you."

It's taken us just about a year and a half, and the students have finally agreed to come along. But when I presented bylaws that had been worked out for the college governments to a faculty meeting, guess who all of a sudden is very uptight? The faculty, bless their hearts.

Cried a physics professor, "You mean to say I'm going to have students on a judicial committee judging *my* actions on a campus?"

I said, "That's right."

"Who are they to judge me?"

And they talk about community in a college? The faculty is very nervous, you see; we have black militants on the campus now, and they stomp into academic senate meetings and scare the hell out of every faculty member there, and the faculty runs, crying "I'm guilty, I'm guilty. What do you want?" And when they get in the confines of a meeting where they can vote privately, I am very nervous that they are going to manifest their masculinity in the quietude of a ballot box, but not out front on the plaza where it counts.

The time has come for universities to live in 1969, not in the days of the Morrill Act, and not in the good old days just after the war when we were all getting the big grants from Washington. We have to be much more concerned with how we can interact in a society of students and teachers in which we become the models for the society that we wish to build. If we sit around waiting for somebody else to write the folksong or to build the barricade, it will be too late. We must be the model. Now.

Research Notes

Sampling Curriculum

How can a student get a realistic idea of what is ahead for him in engineering or science before he has to choose a specific field of study? Is there a way for him to try out possibilities in different areas before he is committed to one? Offering courses in the freshman year that give glimpses of what it can be like at the upperclass or graduate student's level is one answer to questions like these.

Changes in curriculum two years ago reduced the number of requirements for freshmen and, for the first time, allowed them to choose electives. Consequently, some faculty interested in demonstrating what is available in their own academic fields have been experimenting with new courses for Caltech freshmen.

One such course is E5, a one-term laboratory in engineering and applied science. This course introduces the student to the field at an earlier stage than before, and teaches the elements of the experimental method in an engineering context.

Within the framework of a formal course, the project combines features of actual laboratory research, especially the fact that the outcome of most experiments is unexpected. The student has considerable freedom in selecting experiments, and insofar as possible the experiments are small "facilities" rather than set procedures. After he is introduced to the apparatus and instrumentation, the student has considerable latitude in the direction his effort can take—depending on his interest—and in the depth and sophistication to which it can be carried—depending on his ability.

The experiments, designed and built by nine members of the division faculty, are grouped into four categories (solid-state and nuclear engineering, wave propagation, fluid mechanics, and mechanical-chemical engineering). Students select one from each group for the term's work, and spend an average of two weeks (six lab hours) on each experiment.

Fifty freshmen elected E5 during the two terms it was offered. (Five reelected it in order to work for a second term on the experiments they had not chosen the first time.) Of the 34 freshmen who chose engineering as a major at the end of 1969, 25 had taken E5. "Presumably the engineering faculty now knows its incoming students better than it has in the past," says Bradford Sturtevant, associate professor of aeronautics who is in charge of the program. "We also hope the converse is true."

Counting Photons

The 200-inch Hale telescope at Palomar Observatory, designed in the thirties and built in the forties, continues to improve as a research tool because of the revolution in electronics that has come about since the telescope began operating in 1948. The latest improvement is a photoelectric spectrometer that can record incredibly small amounts of light in 32 wavelengths simultaneously.

The designer of the spectrometer is J. B. Oke, professor of astronomy and staff member of the Mt. Wilson and Palomar Observatories, who is using the instrument to look at quasars, globular clusters, and dying stars such as white dwarfs.

Oke is also observing "peculiar" galaxies (Seyfert, N-type, Zwicky-Compact, and Markarian galaxies), which have minute, extremely bright nuclei. The nuclei of these galaxies share many characteristics with quasars: They are variable, have strong emission lines; most of the radiation from them probably comes from a nonthermal source, and may be synchrotron radiation. Some of the brightest of these galaxies have luminosities in the range of the least luminous quasars. Research in the last two or three years lends support to current theories that some galactic nuclei are not simply denser concentrations of the stars and gases that surround them.

The spectrometer that observes these galaxies and stars was built at a cost of about $250,000. It is unique in that it subtracts the light of the night sky automatically, making it possible to observe objects fainter than the sky itself. The device can actually count the light, photon by photon, and can obtain information from objects as dim as 22nd magnitude stars. Because such stars, even with the 200-inch telescope, are not visible to the eye, a television system will eventually be added to help the observer guide the telescope to the faint objects.

The spectrometer is installed under the 200-inch mirror at the Cassegrain focus of the telescope. The electronic controls and data system were built in the Observatories' astroelectronics laboratory under the supervision of staff member Edwin Dennison. The work was supported by the Advanced Research Projects Agency and NASA.

Measuring Marsquakes

Mars, midway in size between the earth and moon, is an important link in planetary studies; more information about its evolution may yield a clearer picture of our own planet.

Geophysicists at Caltech and four other universities are now building a lightweight instrument that will, in a few years, be making detailed studies of Mars' seismicity or lack thereof. Such information would give scientists important information about Mars' internal stress and its evolution as a planet.

The development of the equipment is part of the Martian Seismic Experiment, a NASA-supported project. The work is led by Don L. Anderson, professor of geophysics and director of Caltech's seismological laboratory, where technicians are designing and assembling the two-pound instrument.

The device will be similar to those developed for the Ranger, Surveyor, and Apollo lunar missions. It will monitor background noise continuously, as well as count the Marsquakes and supply other detailed data. It is expected to detect movement as small as one ten-millionth of an inch and to speed up its transmission of data when a quake occurs. Thus equipped, the Mars experiment should determine whether observable seismicity due to quakes and meteor impacts exists and, if so, what its frequency is.

Obviously, not all of the questions can be answered by a single short-lived experiment, but researchers have a lot to look for in the first results. Radar measurements indicate large-scale topographic features such as mountains and plains, and craters have been photographed by Mariners IV, VI, and VII. These indicate that Mars is a differentiated planet and may possess a crust. The small seismometer can tell whether Mars is now dormant or if there are internal activities causing movement of the surface.

The level of extremely small temblors might also serve as a rough indicator of meteorological activities such as wind and atmospheric pressure. Such phenomena interact effectively with the ground to produce seismic energy and can be detected over large areas by seismic observatories.

Books

CURE FOR CHAOS
By Simon Ramo
David McKay Company, Inc. . . . $3.95

Reviewed by Roger G. Noll, associate professor of economics.

Three times during the 1960's an American President established (and Congress later ratified) a major national goal. In 1961 President Kennedy proposed that the United States land a man on the moon during this decade. In 1964 President Johnson declared a War on Poverty that would eliminate poverty by the nation's 200th anniversary. And two years ago President Johnson proclaimed the national goal of building 26 million housing units in ten years, thereby eliminating all substandard dwellings.

America's performance in reaching its national goals is not spectacular. While in this, the year of Apollo, we have achieved a most demanding technological objective, nevertheless no one seriously believes that the two social goals will be reached, or even closely approached. What must we do to make the progress toward solving the nation's social problems match our technological progress?

Simon Ramo's answer to this vexing question is rather simple: We can find "Fresh Solutions to Social Problems through the Systems Approach" (the subtitle of Ramo's short book). According to Ramo, complex technical problems and social problems are sufficiently similar that analytical techniques useful in solving the former can be successfully applied to the latter. Ramo's book, a discourse on the methodology of social problem solving, advocates the application of systems analysis in such diverse areas as public education, medical care services, transportation, economic policy, and environmental quality.

By systems analysis Ramo means at least two things. On one level systems analysis suggests an orderly, objective formulation of a problem, considering all relevant factors. According to Ramo, "We want 'human' problems approached by the careful setting down of clear goals, the articulating of available alternatives, and the comparing of conceivable paths for satisfactoriness against equally carefully laid out criteria."

Ramo contrasts systems analysis with the "piecemeal" approach, which is characterized by attacking subcomponents of a problem without considering the interactions of the subcomponents. To illustrate his point, Ramo contrasts the efficiency of the telecommunications system with the inefficiency of the transportation system.

Simply to consider objectively all relevant factors is no more than to adopt a rational approach to problem solving. Systems analysis is more than this. It involves employing professionals from several disciplines, accumulating and manipulating significant amounts of data, constructing and using complex mathematical models based upon sound theory, developing and applying technological gadgets, extensively using computers, and deriving an "optimal" solution.

Certainly the logic of the systems approach is unassailable: Who could eschew sound theory, good data, appropriately constructed mathematical models, or any of the other components of systems analysis? But on a more practical level, systems analysis will still prove of little use in attacking social problems if we are unable to supply it with the inputs required for its effective operation.

As Ramo suggests, systems analysis must be based upon a sound theoretical foundation, in the same sense that good engineering is based upon sound physics and chemistry. Unfortunately, social science theory is as yet too underdeveloped to be useful in many social problem areas. With the exception of economics, where reasonable theoretical models now do a tolerably good job of predicting some types of economic phenomena, most areas of social science are only beginning to develop useful theoretical tools. Researchers in some disciplines, such as psychology, sociology, and cultural anthropology, are still in the prescientific stage of gathering and categorizing data, while making little or no attempt at building theoretical models.

While systems analysis seeks "optimum" solutions, it does not determine the values to be optimized. Systems analysts themselves are not responsible for establishing the objectives of their analytical models; in fact, as Ramo points out, a precondition to good systems analysis is that the goals be clearly specified for them.

In military and space programs the government has been able to specify its goals clearly, but this has not been the case in social areas. Citizens do not generally regard themselves as experts in military tactics, international relations, or science and engineering policy, but they do have strong feelings about social issues.

Perhaps this difference is partly the consequence of the underdeveloped state of social science theory, but it goes far beyond that. Social programs by their nature touch the lives of citizens in ways a space program never can, involving a full array of personal attitudes, experiences, and prejudices. Consequently, the objectives of social programs, being the result of compromise, are normally fuzzy and often mutually contradictory: e.g., maintain both full employment and price stability, or give every child the opportunity to reach his full intellectual potential (which probably implies racial and social integration for poor kids but segregation for rich, white kids).

Under the far less than perfect conditions of social policy formulation, systems analysis is not only less effective, but can actually do positive harm. Because the technical aspects of social problems have better theory, are supported by better data, and are amenable to the establishment of more specific and less controversial objectives, the incentives are strong for systems analysts to overemphasize the technical side of social problems. Ramo slips into this trap in his illustration of a systems approach to improving educational

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Simon Ramo, vice chairman of the board of TRW Inc., is a Caltech alumnus (PhD '36) and has been on the Institute's board of trustees since 1964.

performance. His "solution" emphasizes computers, closed-circuit TV, and other gadgets, while ignoring the critical motivational aspects of education (the social environment, the student-teacher relationship, etc.).

Even if all these difficulties could magically be swept away, there remains one further, perhaps insurmountable, barrier to systems analysis solving our social problems. During the 1960's most everyone agreed that it would be a "good thing" if we ended poverty, provided better education, improved the transportation network, and cleaned up our deteriorating natural environment, as well as go to the moon. But the last item on the list was backed up by a multibillion dollar annual appropriation during the entire decade. While American society may well believe that solving our social problems is a "good thing," it may not be willing to underwrite the cost. The problem is further complicated by the fact that while no space-monster lobby developed to oppose solar system exploration, there are groups in our society who benefit (or believe they benefit) from many of our social problems, and who will fight very hard against solving them. As long as a political majority can be maintained by a government professing support for "good things" but unwilling to pay for them, systems analysis is not going to solve our social problems.

Book Notes

SUPERCONDUCTIVITY IN SCIENCE AND TECHNOLOGY

Edited by Morrel H. Cohen
University of Chicago Press......$5.95

This book contains the edited proceedings of a 1966 conference on superconductivity held at the University of Chicago. Among the seven contributions is one on "Quantum Engineering" by James Mercereau, PhD '59, research associate in physics at Caltech. What this and the other papers attempt to answer is whether large-scale technological applications of superconductivity can be expected, and if so, when. Cohen is professor of physics at the University of Chicago.

SCIENCE NEWS YEARBOOK 1969/1970

Compiled and edited by Science Service
Charles Scribner's Sons $9.95

As Lee DuBridge points out in his introduction, communication between the scientist and layman is of critical importance in our increasingly technological society. This yearbook, based on material originally published in *Science News,* brings together in layman's terms the latest information in various fields of scientific endeavor, breaking it down into nine parts: Biomedicine, Space, Astronomy, Physics and Chemistry, Earth, Engineering and Technology, Environment and Ecology, Behavioral and Social Sciences, and Science Policy.

FULL HOUSE

By C. C. Cawley, '32
A. S. Barnes and Company......$3.95

Here's the latest challenge for puzzle addicts. These 100 puzzles are all based on card games, although, the author claims, no knowledge of the games themselves is necessary—"The only thing you really need is your brain." And for those who find even that unreliable, the answers are in the back of the book.

SCIENCE, ART AND COMMUNICATION

By John R. Pierce, '33, PhD '36
Clarkson N. Potter, Inc. $6.00

In this latest collection of his writings, John Pierce, one of the country's most distinguished scientists and inventors, looks into our future as a technological society. Pierce is executive director, research, communications sciences division, Bell Telephone Laboratories.

COHOMOLOGY OPERATIONS AND APPLICATIONS IN HOMOTOPY THEORY

By Robert E. Mosher and Martin C. Tangora, '57
Harper & Row $12.95

This book, intended for the advanced topology student, explores the interaction between cohomology and homotopy and traces the development of these two topics into higher constructions, the secondary operations and compositions, and the Adams spectral sequence. Mosher is associate professor of mathematics at California State College at Long Beach; Tangora is instructor in mathematics at the University of Chicago.

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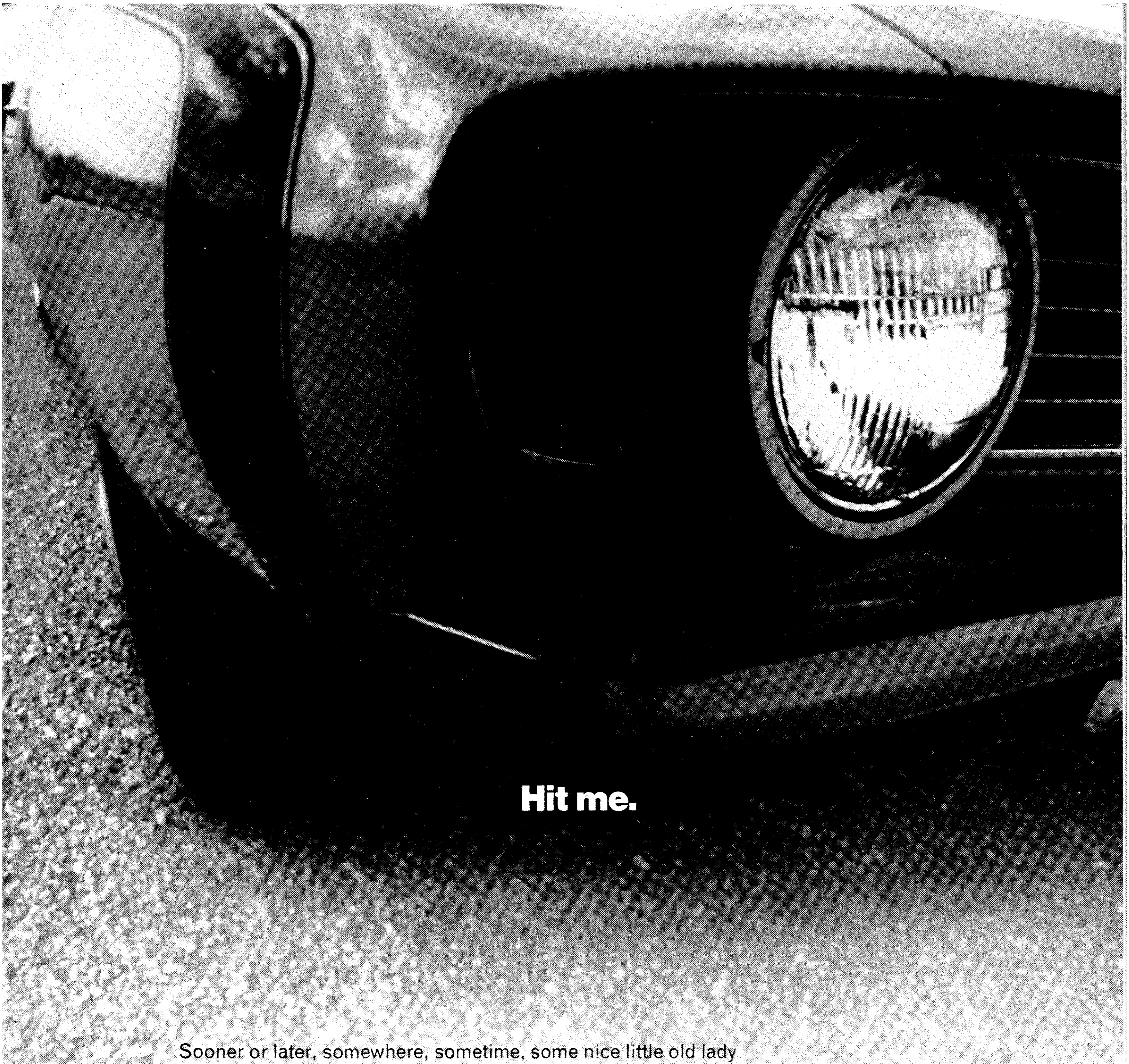

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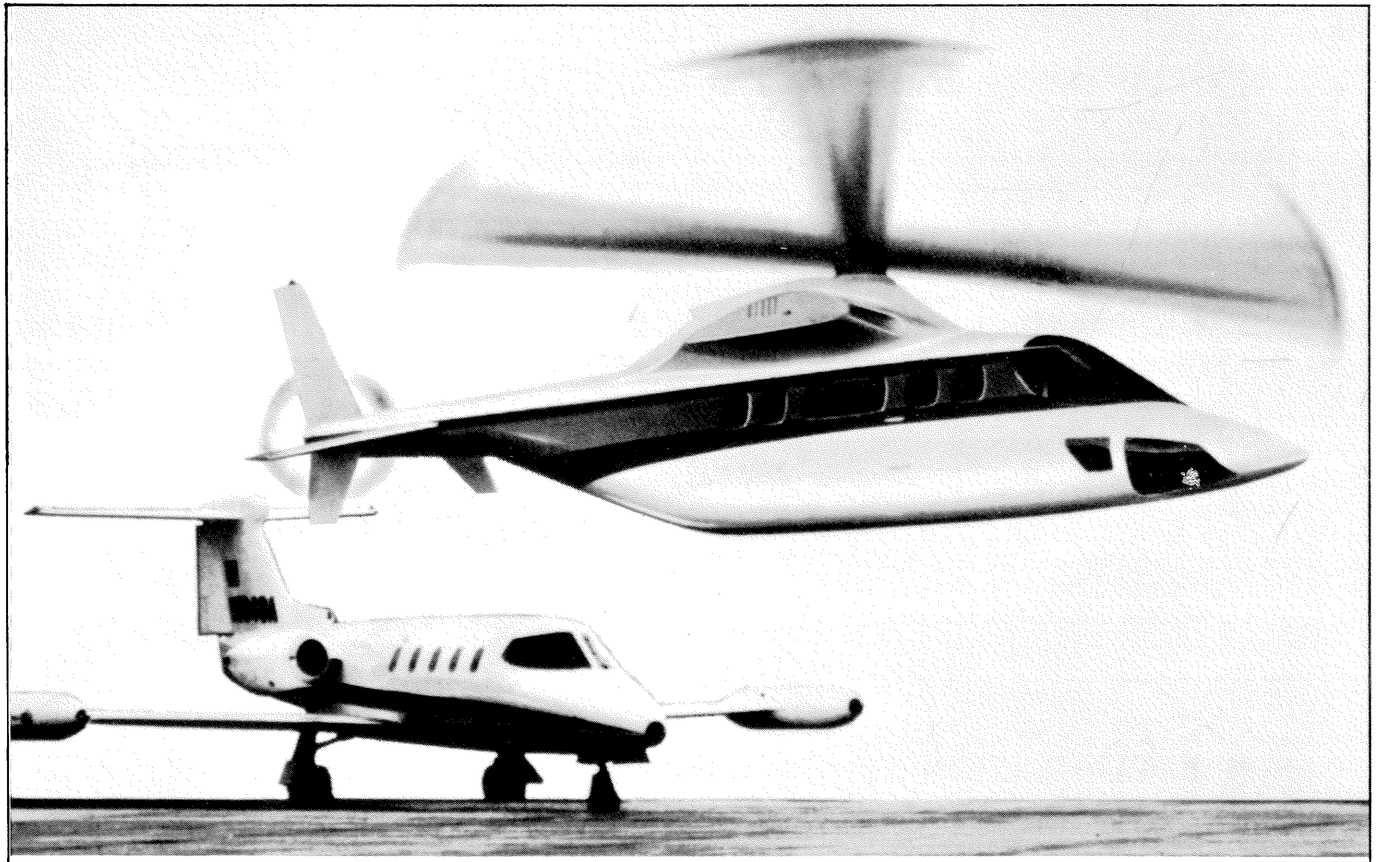

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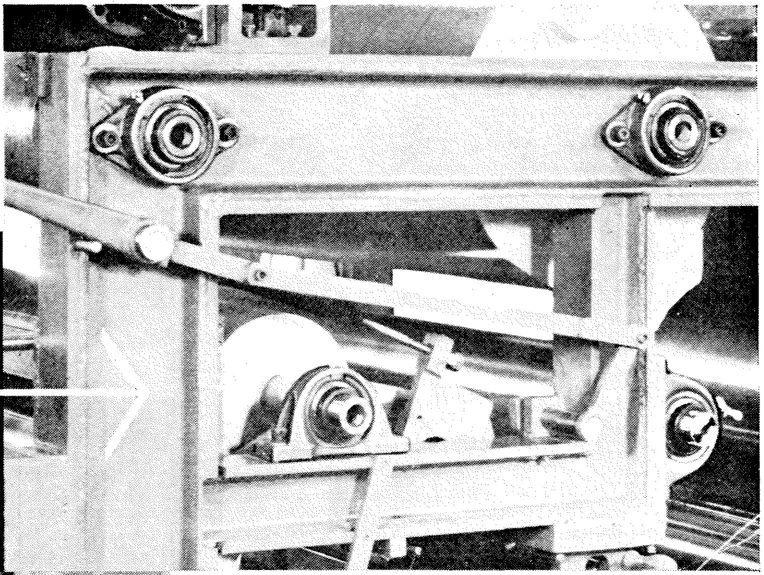

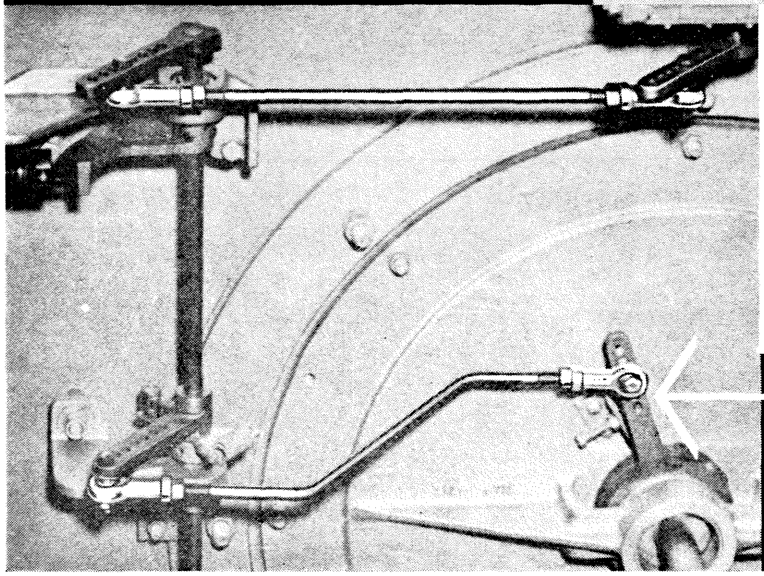

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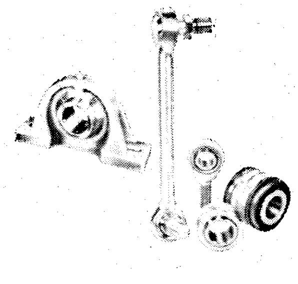

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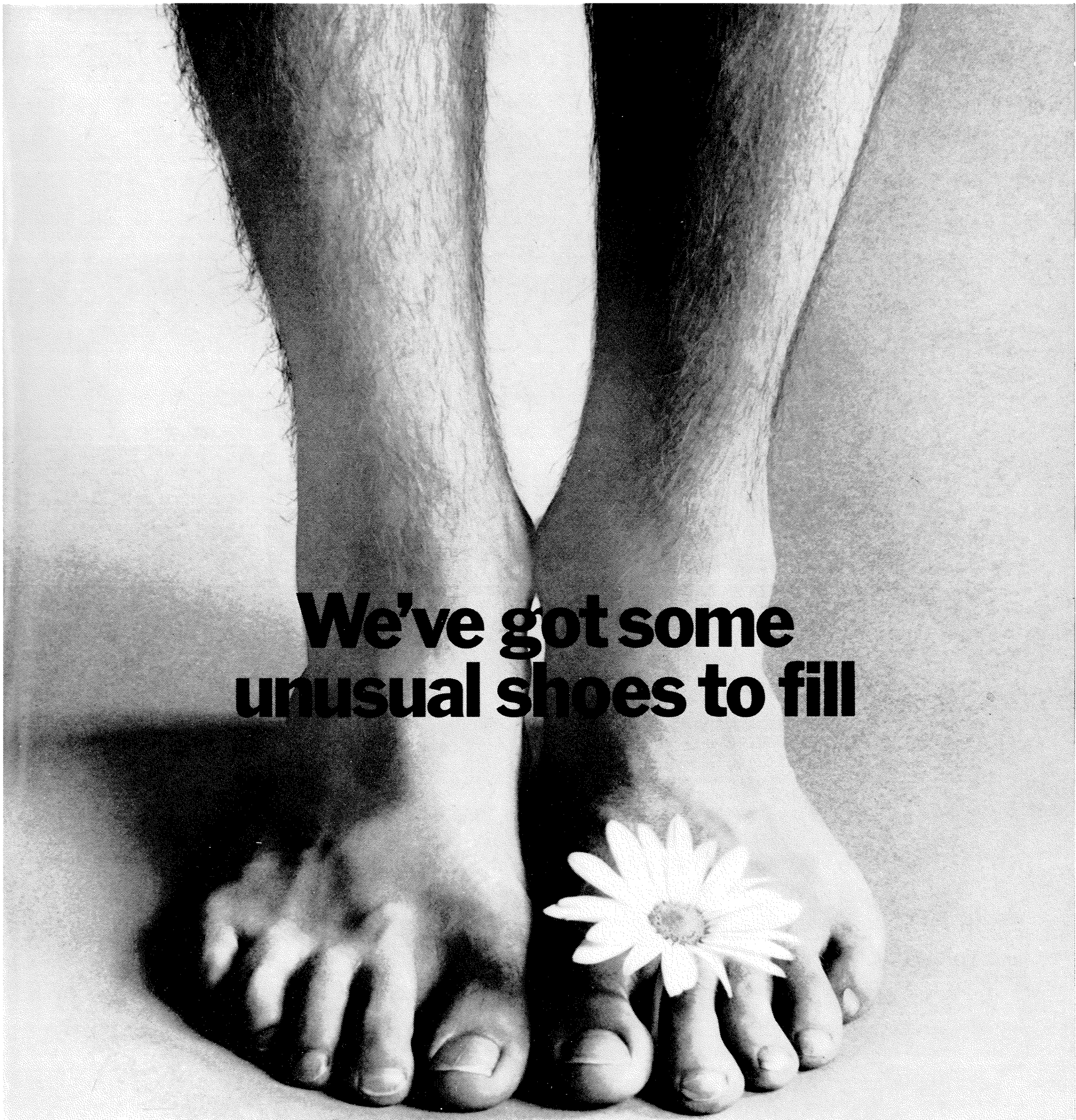
We've got some
unusual shoes to fill

We want engineers who want to get away from it all.

If you're the kind of engineering student who can't stand the thought of someday sitting at the same desk in the same office day after day, then you're one kind of engineer we want. The kind of engineer we want for a career in technical marketing.

Engineers in this field spend most of their time out in the field. Systems sales and application engineers are always on the go. Talking with customers, selling products and systems. Solving other people's problems.

To do that, you have to understand a lot more than engineering. You have to understand people and how to communicate with them. And that can be one of the toughest jobs there is.

Does it sound like a job you're up to? Then maybe General Electric's Technical Marketing Program has a place for you.

Or places, rather. You might start out in upstate New York. And move on to southern California. Or Atlanta. Or Minneapolis.

But wherever you decide to move with GE, you'll be learning the business. Learning in months what it takes some engineers years to learn.

Our Technical Marketing Program is the one way to get away from it all and, at the same time, get ahead.

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For more information about technical marketing at General Electric, please write to
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