1980-81 PRESIDENT'S REPORT
CALIFORNIA INSTITUTE OF TECHNOLOGY

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CALIFORNIA INSTITUTE OF TECHNOLOGY
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On the cover:
Robinson Laboratory of Astrophysics, left, and Mudd Laboratory of the Geological Sciences were part of the growth of the Caltech campus during the 1930s.

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Report of the President

Marvin L. Goldberger, President

"Eating the seed corn" is a phrase that has often been used to describe the various wounds, present and future, that society is inflicting upon itself in science and technology. I have been unable to track down the earliest usage, although the Oxford Dictionary has a reference to "seed corn" in 1587, and I have read that the Pilgrims were admonished not to eat the seed corn by the Indians or perhaps vice-versa. At any rate, I want to discuss some of the serious problems posed by careless use of intellectual resources that are vital for the survival of humankind.

I shall consider three aspects of the problem: the impact of proposed cutbacks in financial aid to college students, the loss to academic science and engineering of prospective graduate students and young faculty opting instead for lucrative employment in industry, and finally and perhaps the most serious, the near-catastrophic situation in science and mathematics teaching in elementary and secondary schools.

Cutbacks in Financial Aid

The original administration proposal for FY'83 was for a *$2 billion* cut from the FY'81 level of financial aid to college and university students. This comes at a time when college graduates constitute 14 percent of the population. However, at the same time, 25 percent of the nation's jobs are professional, technical, or managerial — the sort that most often require training beyond the high school level. It is clearly in the national economic interest to preserve the strength of the higher educational establishment.

Higher education is expensive. A four-year undergraduate program at Caltech can cost more than $40,000; graduate and professional training can add $30,000-$60,000 more. Federal funding over the past two decades in the form of scholarships, grants, loans, and self-help programs has enabled us to welcome not only the talented children of the wealthy but also the talented children from families of limited means.

Drastic cuts in financial aid will threaten important principles that have been the foundation of the U.S. educational system. The first of these is access to higher education for all who can benefit from it. Savings to the government are small compared with the human loss and the costs of social programs for those trapped in poverty by ignorance. The second is the freedom of choice for students among the 3,000 American public and private colleges and universities. The third is that indebtedness incurred by students must be kept low enough to enable them to discharge their financial responsibilities in a reasonable way. Fear of oppressive obligations can prevent young people from seeking the education necessary for them to achieve their full potential.

In a rush to trim waste and weed out the undeserving, we must not eat the seed corn of a generation of bright young minds. The short-term financial gain will cost the nation dearly in the future. If you think education is expensive, consider the cost of ignorance.

Loss of Engineering Students and Faculty

A growing crisis in science and engineering is the loss of students and faculty to industry. Because the problem is particularly acute in engineering, I'll concentrate on that.

The brightest students are leaving the universities upon receiving bachelor's degrees. The higher salaries offered by industry are a contributing factor, but there is another important reason: in some fields of engineering, the real action is in industry. This is especially true in those fields where large investments in the latest and best equipment are required in order to be at the leading edge of technology. For example, only a very few universities will be able to afford the multimillion-dollar investment to maintain a research-caliber integrated circuit fabrication capability. Similarly, few if any universities can compete with the major oil companies in research facilities for resource geology.

The same problems make an academic career unattractive for those people who do go on to Ph.D.s in engineering. Students see their professors scrounging for research grants to work on obsolescent equipment. Why should a new Ph.D. choose to work at a university, if it is just an inferior version of an industrial research lab? Of course, an academic career does have the advantage of a much lower salary (with a teaching load thrown in)!

Industry is eating the seed corn of its own future, albeit with short-term gains. Fortunately some industrial leaders are not unaware of this, and are doing something about it.

The Exxon Education Foundation, for example, has taken an important step to address both of these problems. They have given $15 million to 66 universities in the form of two different kinds of grants: three-year $50,000 teaching fellowships to engineering graduate students, and $100,000 grants over a five-year period to engineering departments, usable at their discretion to augment salaries of junior faculty or to provide research funds for them. (Caltech has been awarded three fellowships.)

In my opinion, this may be the most effective mode for university-industry collaboration. Universities are best for training people and doing fundamental research that often takes a long time to carry out and that has a long gestation period before industry can use it. I don't rule out the value of joint research projects between universities and industry, but short-term research projects directed to a specific problem are not the universities' strongest suit.

Another consequence of the flight of potential graduate students to industry is that the fraction of applications for graduate training from foreign students has increased greatly. Admissions committees are faced with a set of equally unpalatable alternatives: setting an arbitrary quota for foreigners and ending up with fewer total students; or, to forestall this, lowering admission standards; or taking the best students regardless of country of origin and watching foreign admissions increase from one-half to perhaps three-quarters or more.

These alternative strategies will all lead to fewer Ph.D.s for work in the national security area, where U.S. citizenship is generally a requirement. The no-quota option will surely lead to a higher percentage of foreign-born future faculty. The limiting cases are totally foreign faculties teaching totally foreign graduate students or, if you limit admissions sufficiently, no faculty teaching no graduate students — and no undergraduates as well.

What about the supply of engineering students? How can we encourage a greater fraction of the overall diminished pool of students in the rest of this decade to choose engineering? The high salaries engineers now command will surely be a factor, though they are certainly less in comparison with those of doctors and lawyers. Engineering students of the future, like those of the past, will probably choose the profession because they like it, not because it pays better. If that is true, then we should be seriously worried because there are forces in society that discourage students from discovering engineering.

The problem is that engineers are all but invisible. Who has ever seen an engineer in a TV show? Ever read a novel with an engineer as the hero? Seen such a movie? If an engineer does turn up in the media, it is most often in a negative context. Even

President Goldberger and the undergraduate shown here were two of the participants at one of the Caltech faculty-student conferences, which provide a way to strengthen communication in areas of mutual concern. Some of the challenges of maintaining a high level of scientific education — jeopardized right now on several fronts — can be approached through regular discussion.

at the time of fantastic engineering accomplishments, like the moon landing or the recent encounters with Jupiter and Saturn, TV never shows the project engineer, who made it all possible.

Engineers are also becoming invisible in their creations. Modern technology is becoming so complex that children can't really understand that the projects are man-made, let alone identify with the engineer who made them. In my childhood, I built a crystal set, then a small radio receiver with tubes, and I could easily imagine the people who made those old Atwater-Kent radios with the funny shape. Today's hi-fi equipment is impenetrable. So are home computers. They are so smart they seem almost magical. Who could imagine building such a thing herself?

The invisible engineer is held responsible for technology that is often frightening — nuclear weapons, ICBMs, Agent Orange, cluster bombs, pollution, nuclear reactors. These negative aspects of technology attract attention. Never mind all the marvelous benefits that we simply take for granted. Forget that they are in reality the only hope for humankind in an over-populated, under-resourced world of the future. Technology is not newsworthy.

An attack on the problem of the invisible engineer is very difficult. It requires the most sophisticated use of the media by devoted and talented people. I believe it is vital for our future as a technologically based society to set about the job of making engineering attractive to our young. Technical knowledge may indeed be dangerous — but consider the dangers of ignorance.

Science and Mathematics in Elementary and Secondary Education

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We are eating the scientific and technical seed corn in another way. The decline in science and math education in schools is probably even more serious for the long run.

In the bad old days, many of us learned high school math and physics from the basketball coach. Only a very lucky few were taught science and math well enough in the 1930s and 1940s that we could be trained in scientific disciplines. The Russian *Sputnik* put an end to that indifference to the quality of education in science. Suddenly, the United States became aware of the national importance of scientific literacy. All over the country, research scientists rudely grabbed the task of revising the school curriculum in science and math from the hands of the educators.

Some splendid programs came out of that effort. A completely new high school physics course was developed — the Physical Sciences Study Committee (PSSC) program — which brought the insights of modern physics to high school students coherently and correctly for the first time. A similar effort by mathematicians produced the New Math during the same period of professional commitment and government support.

One of the first by-products of this effort to teach real science in the schools was the observation that teachers had to be retrained in order to use these new programs. All these projects — rethinking the content, writing the textbooks, developing labs, training teachers at all levels — were carried out by scientists and mathematicians themselves and supported largely with government funds.

But that was more than 20 years ago. Now almost all of those projects lie in disarray. New Math was in the end judged to be a failure, mostly because there were too many teachers in too many schools who were not able to teach mathematics and could only go through textbooks with titles that suggested mathematics. The same thing happened with PSSC physics, but even more quickly. There the problems were compounded by the need for investment in new lab equipment.

So here we are in the 1980s, just about where we were before *Sputnik*. The ranks of the good teachers of math and science have been emptied by the collection of new opportunities in high-technology industry and in the whole range of uses for computer programming. Education itself has been in recession, with a shrinking school population and increasing pressure on the taxes that support public schools.

Here and there in particular schools around the country a few teachers still turn out a few well-trained high school graduates who are able to take the advanced placement tests in math and science. We get them at Caltech. Those kids still get scores in the high 700s (out of a possible 800), and they go on in scientific and technical fields with the expected success. The vast majority of students in all the schools — who depend on well-designed math and science programs well taught by people who understand the subjects and are interested in them — are being left out in the cold. They come to college with little or no preparation for science or engineering courses.

Equally disheartening, students whose education ends with high school do not get the necessary competence to make sense out of an environment increasingly dominated by sophisticated science and technology.

Only one-sixth of high school students now take physics courses. Enrollment in advanced mathematics shows the same trend — fewer than half take more math than a single required course in algebra. SAT scores in mathematics, designed to test general understanding rather than specific knowledge, have been declining for over a decade. Federal funds that once supported all the efforts to improve science and math teaching have steadily shrunk, and little remains. More than 90 percent of National Science Foundation funds for science and engineering education in FY'82 were cut out of the proposed budget.

It is easy to understand why general interest in elementary and secondary science education has declined. Fewer children in school means fewer parents involved in the problems of the schools. The boom times in science education coincided with the prosperity of the whole economy, when it seemed there was enough money to do everything. Now economic growth has slowed and inflation has bitten into our wealth. Property taxes that support the schools have become a heavy burden on older taxpayers with less direct interest in children's education. School boards have chosen to treat science as an educational frill, worth only the average of 25 minutes a day that elementary school teachers now spend on it.

Unfortunately, a good deal of the current indifference to the quality of science and mathematics education does not represent reasoned choice among priorities based on clear understanding. The necessity for scientific literacy has never been more impelling. Look at the "Help Wanted" pages of any major newspaper. Engineers, technicians, analysts, programmers, and all the other kinds of technical specialists are in great demand. There are no longer that many white-collar jobs for people without some degree of technical competence. Clerks aren't needed to file papers when the new office system can find and display any document in seconds.

Letting math and physics courses go to the basketball coach wasn't a good idea even in the 1930s. Today it is a national disaster. Living in a world with limited resources demands the most creative possible use of science and technology. The difficult decisions in every public issue require scientifically literate citizens with scientifically enlightened leadership.

The new desk-top computers can make an important difference in the classroom. They cannot altogether compensate for the absence of gifted science and math teachers, but they can be used to give some critical understanding now largely missing in the schools. (I am not now discussing the programs that are for sale off the shelf. Those so-called "learning programs" are most likely to succeed in programming the student.) Using computers in classrooms to give students genuine understanding in science builds on concepts developed in the study of artificial intelligence. Seymour Papert of MIT is one of the leading exponents in this new use of computers, and I recommend his book *Mindstorms** to anyone interested in learning about what can be done.

I also take some comfort from another new development in science education, or perhaps I ought to call it the rediscovery of an old pattern of science education. I am talking about the recent flowering of books and articles and, yes, even TV programs, by scientists who have undertaken the demanding and difficult job of trying to communicate to non-scientists something of what makes science both interesting and important. A whole collection of new magazines about science has hit the newsstands, and the "Nova" programs on television have been joined by regular weekly science features on commercial networks.

These developments follow the old tradition in science as practiced by Galileo, Newton, Faraday, and the others who wrote about their scientific discoveries in books for all the literate public of their times. Their audiences were of course very small and elite. Today our scientific heroes are taking that principle much further. They believe, as I believe, that an understanding of science is critically important to everyone. This understanding and the capability of making insightful uses of it are truly the seed corn on which our future must depend. The benefits we can get from increasing and enhancing scientific understanding will repay all of our very best efforts.

I would like to conclude by mentioning some of the members of the Caltech community who merit special attention in this report.

Honors

The Nobel Prize in Physiology or Medicine has again been awarded to a Caltech faculty member. Roger Sperry, Hixon Professor of Psychobiology, shared the 1981 prize for his extraordinary research into the secrets of the cerebral hemispheres. The chairman of the Division of Biology in this President's Report has written at length about Professor Sperry's research; I wish only to reiterate Caltech's pride in his remarkable accomplishments.

**Mindstorms* by Seymour Papert; Basic Books, N.Y.C., 1980.

Earle Jorgensen, a member of the Board of Trustees since 1957, and Harry Volk, a trustee from 1950 to 1980, were presented with the first Robert A. Millikan Medals for distinguished service to the Institute. Leaders in the business communities of the state and the nation, both men brought to Caltech the deep understanding and powerful insights that they used so successfully in their own careers.

Transitions

Administrative changes found C. J. Pings, vice provost, dean of graduate studies, and professor of chemical engineering and chemical physics, resigning to become senior vice president for academic affairs at the University of Southern California. We wish him well. James J. Morgan, vice president of student affairs, is now acting dean of graduate studies.

Two trustees returned from government service to our board; we welcomed back Shirley Hufstedler and Thomas J. Watson, Jr. And J. Paul Austin, who had served on the board since 1975, resigned.

The ten professors who were appointed professor emeritus in 1981 have earned the respect and admiration of their peers at Caltech and in the wider academic community. They are: James F. Bonner, professor of biology; Leverett Davis, Jr., professor of theoretical physics; Marshall Hall, Jr., IBM Professor of Mathematics; George W. Housner, Carl F Braun Professor of Engineering; Donald E. Hudson, professor of mechanical engineering and applied mechanics; Paco A. Lagerstrom, professor of applied mathematics; Rodman W. Paul, Edward S. Harkness Professor of History; W. Duncan Rannie, Robert H. Goddard Professor of Jet Propulsion and professor of mechanical engineering; John Todd, professor of mathematics; and Robert L. Walker, professor of physics.

In Memoriam

It was with sadness that the Caltech community received the news of the untimely death of Peter John Young, who received his Ph.D. here in 1978, served as a research fellow from 1978 to 1979, and was appointed an assistant professor of astronomy in 1979.

We suffered a grievous loss in the death of Nobel Laureate Max Delbrück, Board of Trustees Professor of Biology, Emeritus, whose outlook on science was universal. "Science," he said, in a commencement speech at Caltech in 1978, "is not merely a matter of the latest results discussed in *Science, Nature,* and *Physical Review Letters;* it is an immensely greater effort, a cultural effort ranging through the centuries and millenia." Biology division chairman Lee Hood writes about Max and his enormous contributions to knowledge in his report. We all miss him and his wise counsel.

Division of Biology

Leroy E. Hood, Chairman

Prominent in our minds during the past year have been the biology division's two most recent Nobel laureates — Max Delbrück, whose death in March 1981 terminated a long and tremendously important association with the division, and Roger Sperry, who received the distinction of a Nobel Prize in fall of 1981, ending many years of speculation by his friends and colleagues who knew that he had been nominated for this highly deserved award. This year's report from the Division of Biology is devoted to these two scientists.

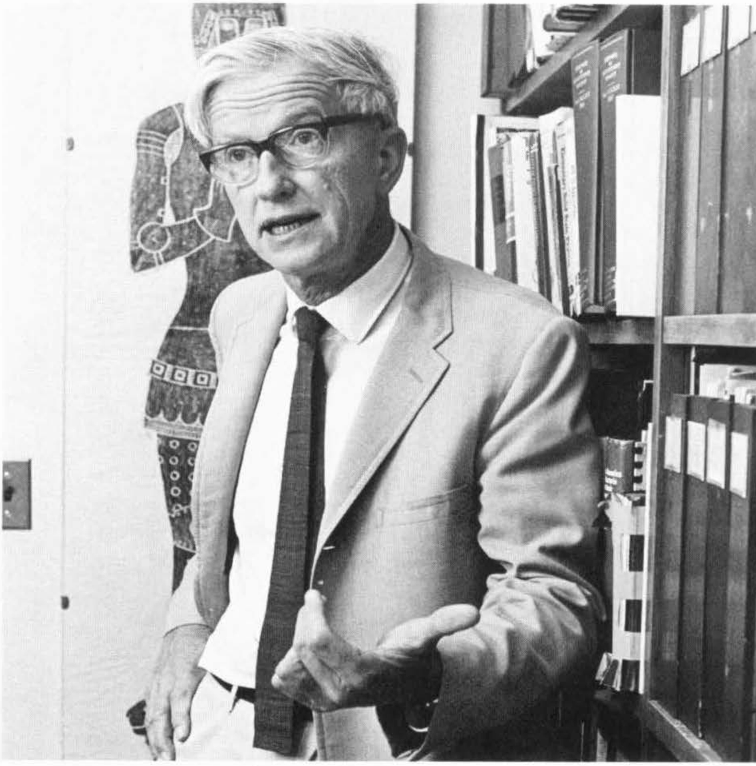
Max Delbrück

The Nobel Prize in Physiology or Medicine for 1969 was awarded jointly to Max Delbrück, Salvadore Luria of the Massachusetts Institute of Technology, and Alfred Hershey of the Carnegie Institution of Washington for their work concerning the replication mechanism and genetic structure of viruses. The announcement of this award by the Caroline Institute of Stockholm stated, "These discoveries first of all imply a deeper insight into the nature of viruses and virus diseases. Indirectly they also bring about an increased understanding of inheritance and of those mechanisms that control the development, growth, and function of tissues and organisms. The work of the three, centering on bacteriophage, which are viruses that invade bacteria, since around 1940 has had great impact on biology in general. Over the years our debt of gratitude to the three leading figures of bacteriophage research has continually increased." Beyond this, the pioneering work on bacteriophage is widely believed to have provided a key intellectual basis for the main thrust of research in molecular biology, which has mushroomed since 1940.

This outcome could hardly have been foreseen when Max came to Caltech in 1937 as a research fellow, to collaborate for two years with Emory Ellis, who at that time was a research assistant in biology. In the basement of Kerckhoff, where they conducted their first single-step growth experiments with bacteriophage, Max was guided by the knowledge that reproduction was the intellectually challenging idea in biology that was critical to understanding life and integrating living processes into the physicist's way of seeing the world. To him, trained as a theoretical physicist in his native Germany, the possibility of doing biological experiments with bacteriophage and obtaining results that could be treated as firmly and quantitatively as nuclear disintegrations, and subjected to the same kind of critical scrutiny as an experiment in physics or chemistry, was a revelation. This attitude and style set the tone for his whole career in biology, and for many of his disciples.

When George Beadle brought Max back to Caltech as a professor in 1947, the development of molecular biology was already on its way. Since 1940, Max had close contacts with Hershey and Luria, and the first of the famous "Phage Courses" at the Cold Spring Harbor Laboratory on Long Island, New York, had been offered by Max in 1945. In these courses, many of the scientists who became major figures in the molecular biology of the 1950s and 1960s came under his influence, and not only succumbed to the fascination of work with bacteriophage but also were imbued with Max's style of research, which was then propagated to further generations of molecular biologists. Many of these students were, like Max, converts from a background in physical science.

At Caltech, this educational tradition continued among the many young scientists who passed through Max's laboratory or became his associates. Following the elucidation of a structure and possible replication mechanism for DNA by James Watson and Francis Crick in 1953, the biochemical genetics of George Beadle and his colleagues was gradually transformed into molecular biology, and the ranks of its practitioners grew larger and larger, at Caltech and in many other institutions. Once this movement gained a momentum of its own, Max became restless and looked around for a different direction for his own intellectual interests. In 1952 he decided to begin an exploration in a totally different direction — to attempt to understand the molecular basis for the response of organisms to stimuli — ultimately, the molecular basis for the science of neurobiology. Again, he looked for a system that was simple enough to provide hope that precise, physically interpreted experiments, analogous to the experiments with bacteriophage, could provide an entrée into a complicated field. The result was the decision to focus his research on the behavior of a primitive fungus, Phycomyces. This organism responds to stimuli such as light or



Max Delbrück, Board of Trustees Professor of Biology, Emeritus, who died in March 1981, contributed to the division as well as to the world, through his influence and his research. His work was formally recognized in 1969 when he was awarded the Nobel Prize in Physiology or Medicine.

the presence of neighboring individuals by modifying the growth rate and growth direction of a thin sporangiophore, or stalk, which grows up from a substratum to support a capsule that releases spores. The expectation was that understanding how a measurable physical signal is transduced into a measurable behavioral response would have general significance in living systems.

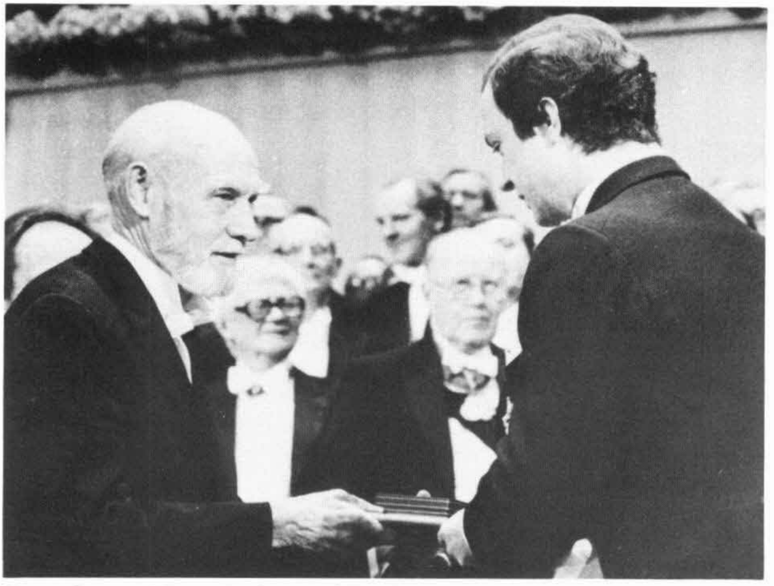
Max died before this expectation was fully realized. Although the Phycomyces responses are fascinating in their own right, and Max's leadership created a group of scientists throughout the world who are exploring the physical, chemical, and genetic basis for these responses, they have not yet turned out to provide keys to understanding the mechanisms of response by elements of the nervous system of higher organisms. The success, and the significance, of the Phycomyces work at Caltech has been in a different mode — again, a style and a manner of thinking that have influenced many students and colleagues. Max remains an inspiration for the members of our division who regard themselves as representing a particular category of biophysicists — those who perform precise measurements on the behavior of a biological system and then try to deduce a physical model for the internal mechanisms of the system that can explain its behavior. Of course Max, and most others who have tried this approach, also recognized the power of both biochemical and genetic tools for characterizing the structure and functional capabilities of such systems. In this later portion of his career, Max's most important contributions to Caltech continued to be as an educator for everyone from undergraduates to fellow faculty members who fell under his influence. This education took place not only in the laboratory but on the famous desert expeditions that Max and his research group and family organized. Also famous was his annual lecture course, labeled "Biophysics," in which Max usually tackled a new subject about which he wished to learn in more detail. Beginning in the 1950s with subjects such as radiation biology and sensory transduction mechanisms, the subject matter changed each year, and in the 1970s became more philosophical, including a detailed study of the epistemology of science.

When the scheduled date for Max's retirement approached in 1977, he was appointed to a special position as Board of Trustees Professor of Biology, Emeritus, which allowed him to continue an active research group, and allowed us to continue growing with him, until his death. His death in a sense marks the end of an era, but his life, his accomplishments, and his influence on the lives of others will continue to find expression in eras to come.

Roger Sperry

Roger Sperry was awarded half of the 1981 Nobel Prize in Physiology or Medicine in recognition of his contributions to understanding the function of the human brain — specifically, his work on the functional specialization of the two hemispheres of the brain and the new insights that his work provided into the implications of the specialization and separateness of the two hemispheres. The other half of the award also recognized contributions in neurobiology, and was awarded to Professors David Hubel and Torsten Wiesel of Harvard University for their contributions to our understanding of the processing of visual information by the brain.

When Roger Sperry came to Caltech as Hixon Professor of Psychobiology in 1954, most of his colleagues expected him to continue his elegant studies of how neural connections are established during embryological development and reestablished by regeneration after injury. This, of course, he did. During the next 20 years in a series of beautiful anatomical, behavioral, and physiological experiments, Sperry demonstrated the exquisite



Roger Sperry, Hixon Professor of Psychobiology, received a Nobel Prize in Physiology or Medicine from Sweden's King Carl Gustaf on December 10, 1981. Members of the Division of Biology have won five of Caltech's nineteen Nobel Prizes.

precision with which neural processes find their predetermined targets and make functional connections. This work culminated in his widely accepted chemoaffinity theory of neurospecificity, which states that neurons have unique biochemical labels that match in complementary fashion those of the appropriate target cells. This fundamental work in neural development forms the basis for much of the present research in developmental neurobiology.

In 1954 most of Sperry's colleagues probably were not expecting the revolutionary development and exploitation of a new line of research that he pioneered during the next 25 years. With his introduction of the split-brain preparation, in which the two cerebral cortices are separated by midline division of the corpus callosum and anterior commissure, a new era of investigation of cortical function by behavioral techniques began. The original findings with split-brain cats and monkeys were dramatic. With the cerebral commissures cut, events perceived, learned, or remembered by one half of the brain were unknown to the other half. With respect to cognitive functions the operation produced two competent but separate individuals within one body. In the impressive series of experiments that followed, most of the key features of inter-hemispheric communication have been examined, anatomically localized, and to a large extent understood. Work in the field of interhemispheric interactions continues actively throughout the world.

The split-brain preparation also permits direct comparison of the cognitive abilities of the two separated sides of the same brain. With the availability in the 1960s of a series of human patients, their cerebral commissures cut to restrict the spread of otherwise uncontrollable epilepsy, Sperry began an amazingly productive study of the specialization of the two sides of the human brain for cognitive functions. The clear demonstration and bold generalization that the left half of most human brains is specialized for analytic, sequential, and linguistic processing while the right half is superior in holistic, parallel, and spatial abilities have not only revolutionized research in neuropsychology, but have also had a major impact on educational practice. Although aspects of cerebral laterality had been recognized for well over a century, a clear, effective statement of its nature and extent, capable of interpreting and directing experimental studies, was not available until Sperry's remarkable findings and forceful interpretation.

Sperry's approach to research characteristically incorporates a strongly focused and individual attack on key questions coupled with an equally strong aversion to events not immediately relevant to major issues. One important exception is his willingness to work extensively with graduate students even though their eventual contributions to his research program may be far from clear. In keeping with his goal-oriented approach, most of the 20 students who received their Ph.D.s with Sperry remember an initial suggestion similar to: "Read some of the recent papers from our lab and then find something really important to study." As a result of this free directive he has supported an exceptional variety of thesis topics — some clearly related to his immediate interests and others quite unrelated. He has also left to his students the task of determining how closely or how independently to work with him — a freedom most of them first wonder about but soon begin to appreciate and consider important to their individual scientific development. Sperry fosters this flexibility in research style with full recognition that it best accommodates the idiosyncrasies of Caltech students and maximizes their input into his research program in psychobiology at Caltech that has proved so successful.

Division of Chemistry and Chemical Engineering

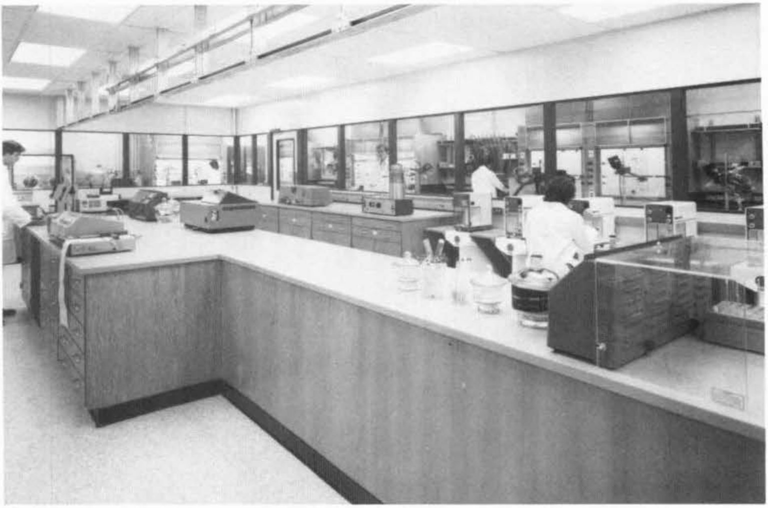
Harry B. Gray, Chairman

During 1980-81, the Division of Chemistry and Chemical Engineering not only continued and expanded its active research programs, but renewed its commitment to undergraduate education. Construction was completed this year on the Mead Undergraduate Laboratory, a new facility unique in design and function. Simultaneously, the undergraduate laboratory curriculum was revised to include the use of modern instrumentation and techniques. The division is particularly proud of this model laboratory and the educational program that is now in operation.

Research programs featured here highlight many of the scientific endeavors undertaken during the year. David Evans and Robert Ireland are developing methods for controlling asymmetry in the synthesis of organic compounds; George Gavalas is leading his group in experimental and theoretical studies related to coal utilization; and Norman Davidson, Judith Campbell, and Carl Parker are actively investigating fundamental properties of DNA. A chemical catalysis program brings together the interests of nine research groups within the division. The following reports of these activities will serve to illustrate the variety of recent research advances made in chemistry and chemical engineering at Caltech.

Mead Undergraduate Laboratory

The undergraduate chemistry laboratory courses were formerly conducted in the Gates Chemical Laboratory, built in 1917 — the second building on campus. After the 1971 earthquake, Gates had to be abandoned, so a "temporary" building was hastily erected and fitted with the old furnishings and equipment. While members of the chemistry faculty conducted



The completion of the Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory makes possible a new level in student safety and teaching effectiveness. A revised curriculum now incorporates a five-course laboratory sequence that prepares chemistry students to enter a research group by their junior year.

laboratory courses in these less-than-satisfactory quarters, they began to redesign the curriculum to improve instruction in modern techniques and to develop plans for a modern laboratory facility. This year both objectives have been reached. A five-course laboratory sequence prepares students to enter research groups by their junior year. Emphasizing the teaching of laboratory methods for the preparation, purification, and characterization of both organic and inorganic compounds, the courses fully integrate these two traditionally separate disciplines.

A major renovation of our temporary building into the new Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory has also been completed. These facilities resemble research laboratories in many ways. Each student is assigned a hood, a small bench, and a shared sink. All chemical work is done in the hood, eliminating the fumes and odors ordinarily associated with an undergraduate lab and minimizing exposure to possibly harmful chemicals. There are two labs, each of which has the hoods and sinks on the periphery, and a glass-walled room in the center. These inner rooms house the many instruments needed for measurements and characterization. Teachers can monitor all their students at all times. This innovative design achieves a natural unification of "wet" chemistry and modern instrumental techniques. Caltech undergraduates for years to come will enjoy the very best and safest laboratory facilities available anywhere.

Asymmetric Organic Synthesis

The synthesis of architecturally complex organic molecules depends upon the absolute control of molecular asymmetry, the structural feature which results in a molecule's "handedness." Although the creation of asymmetry, or asymmetric induction, is routinely carried out in enzymatically mediated biological processes (such as the synthesis of glucose), chemists have found it extremely difficult to control the absolute topology of such reactions under normal laboratory conditions. Over the last several years Professor David Evans and his research group have achieved unprecedented success in this important area of asymmetric induction in their studies of the aldol process, one of the pivotal reactions of biosynthesis. They have developed laboratory equivalents to enzyme-mediated aldol condensation reactions by exploiting — for the first time — the organizational capacity of sterically demanding zirconium and boron metalloids. These laboratory reactions create new asymmetry with greater than 99.5 percent efficiency. The complementary research efforts of Professor Robert Ireland have been directed toward the use of carbohydrates in organic synthesis. The molecular asymmetry embodied in this class of inexpensive, naturally occurring substances has been permuted into a diverse set of "chiral building blocks" that may be readily integrated into the total syntheses of a range of naturally occurring substances. Both the Evans and Ireland research groups have been applying this asymmetric synthesis technology to the construction of macrolide, ionophore, and β-lactam antibiotics.

Coals and Fuels

In the last few years, increases in the price of petroleum are prompting the expanded use of coal — in electrical power generation and in conversion to liquid and gaseous fuels. Professor George Gavalas and his students are conducting experimental and theoretical studies pertaining to several of these facets of coal utilization. For example, in the area of coal combustion and gasification, the interpretation and prediction of reaction rates have been previously hampered by the lack of proper means to describe changes in the pore structure during reaction. Gavalas developed a random capillary model that provides a simple yet rigorous description of the evolving volume and surface area. In terms of this model he explained experimentally observed variations of particle size and density in coal combustion. Such variations must be carefully monitored in applications such as fluidized combustion where they affect particle loss and the overall combustion efficiency. Further work in this area will concentrate on the possibility of enhancing the rates of combustion and gasification by externally added catalysts.

One of the most important applications of coal gasification is in the production of synthesis gas ($CO+H_2$), the starting material for the production of ammonia, methanol, liquid hydrocarbons, and a host of other organic chemicals. Synthesis gas is produced by the reaction of steam with coal or other solid or liquid fuels. However, part of the fuel must be burned with oxygen to provide the heat that is required for the reaction to occur. This supplemental combustion reaction currently uses pure oxygen rather than air to prevent product dilution with nitrogen. Gavalas and his students have studied experimentally a novel chemical reactor allowing the production of synthesis gas using air for the combustion step while preventing product dilution. The reactor involves two compartments, one for the steam-carbon, the other for the oxygen-carbon reaction. Molten sodium phosphate recirculating between the two compartments acts as the heat carrier and allows the separate evolution of the synthesis gas and the combustion gases. In such a system, the reaction takes place between carbonaceous particles (coal or coke) suspended in the molten salt and air or steam bubbles rising through the suspension. Since the reaction takes place by direct contact between gas bubbles and solid particles, the reaction rate depends on a combination of chemical and fluid mechanical factors. The experiments conducted provided new information on factors such as the rate of particle attachment on bubble surfaces.

Pyrolysis and gas-phase or liquid-phase hydrogenation are among the most promising routes to liquid fuels and chemicals from coal. Optimizing the distribution of products from these processes requires understanding the detailed mechanisms and kinetics of the underlying chemical reactions. During the past few years, Gavalas and his students developed a characterization of coal in terms of functional groups rather than individual molecules. The reactions involved in pyrolysis, hydropyrolysis, and liquefaction can be described in terms of reactions of the constituent functional groups. However, this description is inherently complicated because of the large number of elementary reactions proceeding at elevated temperatures. To attain a simplified, yet meaningful kinetic description, Gavalas's group is currently conducting experiments with simple mixtures of compounds simulating coal. Kinetic modeling in a simplified setup and measuring certain crucial rate parameters may well lead to an improved understanding of coal pyrolysis and liquefaction.

DNA Research

DNA is the hereditary information tape present in each cell of a complex organism. The information tape is subdivided into several chromosomes; each chromosome contains many thousands of the units of hereditary information, called genes.

The research programs of Professor Norman Davidson and Assistant Professors Judith Campbell and Carl Parker are devoted to understanding how DNA has the two following basic properties: (1) It contains the information for making the thousands of complex molecules and ordered structures of multicellular organisms, as well as the instructions for expressing this information in appropriate tissues and at the correct time in a developing organism. (2) DNA is the hereditary material; when a cell divides, its DNA replicates to give two identical copies, one for each daughter cell.

Davidson and his students seek to understand how, although each cell contains the identical information tape with many thousands of genes, only certain parts of the tape are used (expressed) in the cells of one particular tissue or at one particular time of development, and other genes are expressed in other tissues at different times of development. One excellent model system is that of the development of muscle tissue. When a precursor cell differentiates to form a muscle cell, a number of specific genes are simultaneously turned on to produce the specialized proteins found in muscle cells.

Davidson and his coworkers have been studying these genes for the fruit fly, Drosophila. They have found it has six different genes coding for actin, one of the major proteins of muscle fibers. These six genes, which are located in different regions on the chromosomes, are very similar in their sequences that code for the proteins. However, the genes are very different in sequence in their adjacent regions, which suggests these regions are important in the control mechanism. The Davidson group and others have shown that each actin gene is expressed at a different time and place in development. For example, one is expressed in the jumping muscle of the adult, yet another one in the body wall crawling muscle of the larva.

The major constituents of muscle fibers are actin filaments and myosin filaments. A particularly difficult gene to study is that for the myosin heavy chain, a major protein of the latter filament, because of its large size. However, this gene has been isolated and characterized in the Davidson laboratory. It was a great surprise to discover that Drosophila has only one gene coding for myosin heavy chains in contrast to the six genes coding for actin. This gene has the unusual property of being copied into different length RNA molecules in the developing larvae and in the adults. Present evidence indicates that these different RNA molecules code for the same protein. Thus, Drosophila uses different strategies for controlling the production of the several complex constituents of its different kinds of muscle tissue. Once the structures of the genes involved have been determined, it will be possible to begin to discover which molecular mechanisms control their expression.

Campbell and her students investigate the mechanisms of DNA replication in the simple eukaryote, *Saccharomyces* *cerevisiae*. This yeast system can be analyzed by the same genetic and molecular biological approaches that have been successful for bacteria and, it is believed, will illuminate many of the features of replication of the genetic material in complex eukaryotes, such as Drosophila and man.

The main tool used in such studies is the *in vitro* replication system. By suitable disruption of yeast cells, it is possible to prepare an extract that can efficiently and faithfully replicate added double-stranded circular DNA molecules. Campbell and her coworkers have shown that their system initiates replication correctly on short sequences within the larger DNA molecules. The enzymes and proteins that initiate DNA replication at these short sequences act only once during each cell cycle, but at a critical time, such that orderly replication of the chromosomes is insured. Now that an *in vitro* replication system is developed, it will be possible to isolate the enzymes and other proteins that carry out DNA replication and to study their mechanism of action.

To do so an *in vitro* complementation assay will be used. If a particular protein (gene product) is part of the DNA replication machinery, then extracts prepared from cells carrying a temperature sensitive defect in that protein will be defective in DNA synthesis *in vitro* at high temperature. The wild type protein corresponding to the temperature-sensitive gene product can be purified from wild type cells by searching for those components of wild type extracts that can restore DNA synthesizing ability to the mutant extract at high temperature. Using this approach, Campbell and her coworkers have identified and purified a protein — known as the Cdc8 protein — that is essential for replication.

In order for a gene in the DNA information tape to be expressed it must be transcribed into an RNA molecule. Selective control of transcription probably involves tissue specific regulatory molecules — probably proteins and/or RNA — acting on specific short target sequences in the DNA around the gene. Carl Parker and his students are interested in discovering these regulatory molecules and target DNA sequences. They are thus undertaking to duplicate selective transcription *in vitro*, using cloned DNA for a particular gene and fractionated cell extracts as a source of the regulatory molecules. Parker has carried out the first successful development of an *in vitro* system for Drosophila transcription. He and his coworkers have chosen the Drosophila histone genes as one of the very best test systems for these studies because they have been well characterized structurally and the start and stop points for transcription in the living cells have been determined. They are expressed in all dividing cells. Parker and coworkers have prepared an extract from Drosophila cells that for the first time manifests both correct starting and stopping points for copying histone gene DNA into RNA. By studying transcription *in vitro* of histone genes in which various regions suspected of being control regions have been systematically deleted, they have begun to identify the actual control regions. The important initial results show that a main part of the control regions for histone genes lies in the same relative location as do the control regions for bacterial genes; however, these regulatory sequences extend over a greater distance than is the case for bacterial genes.

Promising initial results have been obtained for systems for expression of the Drosophila actin and heat shock genes. These genes may be more interesting and involve more complex controls than do the histone genes. Expression of the actin genes is regulated both developmentally and in a tissue specific manner; on the other hand, expression of the heat shock genes is induced by elevated temperatures in all tissues without regard to developmental stage. Furthermore, Parker has, for the first time, developed a system in which yeast genes that are copied by the particular polymerase known as RNA polymerase III are faithfully transcribed. Because of its simplicity, the yeast system offers great promise for a complete analysis of the molecular components important for gene expression.

Chemical Catalysis

For a number of years, a group of chemistry professors and their students have gathered weekly to discuss developments related to catalysis. Catalysts will increasingly be needed in developing new energy resources, in increasing industrial productivity, and in protecting environmental quality. This is so because of growing shortages of raw materials and of sources of clean, efficient energy. As chemical catalysis has become more and more prominent in the division's research activities, the catalysis group has formalized its activities. This is a brief overview of the work of some of its members.

Chevron Professor Henry Weinberg and his group study surface processes at a molecular level by a variety of modern techniques, including high-resolution electron energy loss spectroscopy, photoelectron spectroscopies, molecular beam scattering, and low-energy electron diffraction. With these techniques they can study the elementary steps in heterogeneously catalyzed surface reactions: (1) adsorption of the reactants, (2) the chemical reaction occurring on the surface, and (3) desorption of the products of the reaction. Current work emphasizes the reactions of hydrocarbon molecules, carbon monoxide, and hydrogen with transition metal surfaces.

A completely different approach to the study of catalytic reactions involving the synthesis of what are known as catalytic intermediates is being pursued in the laboratories of Professor Robert Grubbs. For many catalyzed chemical reactions that occur in solution, it is suspected that the catalyst forms an actual chemical compound for a brief interval with the reacting materials. Students in the Grubbs group synthesize these fairly unstable compounds and determine their structures by a variety of techniques; the new compounds are shown to be identical to the ones seen fleetingly in chemical reactions. This kind of information about catalytic intermediates can be used to work out the details of a chemical reaction, and Grubbs is doing this for such important processes as the polymerization of unsaturated hydrocarbons, for example, ethylene and propylene and the so-called olefin metathesis reaction, in which unsaturated hydrocarbons are rapidly converted to more useful chemicals.

Another important chemical process under investigation in the catalysis group is the splitting of water into its constituent gases — hydrogen and oxygen. Hydrogen has a wide variety of uses, from purely chemical to use as a fuel in homes, automobiles, and airplanes. The eventual depletion of our fossil fuel supply makes hydrogen attractive as an alternative energy source for the future, and the oceans of the world represent an inexhaustible supply if we can develop an efficient way to obtain it from water. One promising technique involves a cluster of metal atoms acting as a catalyst, trapping solar energy and using it to split the water. Beckman Professor Harry Gray and his students are designing and synthesizing a number of metal cluster compounds in their effort to develop durable and highly efficient photocatalysts. Their original work with rhodium compounds has been extended to include materials made from rhenium, iridium, platinum, molybdenum, and tungsten. The eventual role of metal clusters in hydrogen production is uncertain, but the compounds currently being investigated are sturdier than the original ones. It is possible that more clusters can be found that will absorb sunlight and produce hydrogen. Such a development can be significant in our search for new energy sources in the future.

Other synthetic chemistry related to general problems in catalysis is being done in Professor John Bercaw's group. The emphasis in this work is on making organometallic compounds with unusual chemical reactivity. The metal atoms in these compounds are titanium, zirconium, or hafnium, metals whose chemistry is not yet well developed. One of these compounds, containing zirconium, reacts with carbon monoxide and hydrogen to form compounds that are the precursors of synthetic fuels. It is not yet clear how the hydrogen combines with the carbon monoxide, so further experiments under way are designed to determine in detail the mechanism of these reactions. Other experiments involving catalysts for different reactions of small molecules give new insight into precisely how complex chemical reactions occur, step by step. Such a detailed understanding of these types of reactions is necessary if we are ever to be able to design new catalytic materials from first principles.

Basic to such a fundamental knowledge of chemical reactions is a knowledge of the energy content of individual bonds in a molecule. Professor Jack Beauchamp and his students carry out detailed studies of small molecules and ions in the gas phase, using a wide variety of modern techniques such as ion cyclotron resonance spectroscopy, photoionization mass spectrometry, and laser photochemistry. These techniques allow them to study the kinetics of isolated reactions — reactions unperturbed by the presence of solvent molecules, for example — and thus determine the fundamental parameters of the reactions. These in turn can lead to the calculation of individual bond energies, energies impossible to measure in other ways. Additionally, members of the group are attempting to characterize the energetics of organometallic reactions in sufficient detail to explain the course of processes such as reductive elimination reactions, olefin metathesis, and dehydrogenation of hydrocarbons. Finally, various techniques are used to study the formation and reaction of free radicals and excited intermediates on surfaces, as well as reactions between adsorbed layers and the underlying surface itself. All these kinds of work promise results of wide applicability in synthetic chemistry, catalyst design, process chemistry, and electronic devices.

Work in Professor Fred Anson's laboratory includes fundamental studies in electrochemical catalysis. Some electrochemical reactions are extraordinarily slow, so there is a need for catalysts that can speed them up sufficiently to make them useful. In recent years the Anson group has developed several methods for attaching transition metal complexes to the surfaces of electrodes in solution, and these modified electrodes have been used to catalyze electron transfer reactions. A specific reaction of very great importance is the reduction of oxygen to water at an electrode. This reaction requires four electrons per oxygen molecule to go to completion; unfortunately, the reaction often does not go to completion, with the result that the full energy content of the oxygen molecule is not released. Such a failure is often the cause of low performance in fuel cells, potentially one of the more promising energy sources of the future. A catalyst to promote the reduction of oxygen will have broad applicability; Anson and his students study catalyst molecules that can be attached to inert electrode surfaces and provide the transfer of the full four electrons to the oxygen molecule. Further work to improve the lifetimes and performance of these catalysts and their ease of attachment is under way.

Complementing these experimental studies of catalysis, the theoretical analysis of catalytic problems is being undertaken by Professor William Goddard and his students. They currently study reaction mechanisms for both heterogeneous and homogeneous catalytic reactions. These theoretical studies examine the details of how bonds are broken, moved, and formed during the reactions — processes that are almost impossible to follow experimentally. A major emphasis in this work is to extract qualitative principles that can be used to predict how the reactions would be modified by various changes in the system. Catalysts could then be designed to achieve specific objectives.

The work of two other professors in the catalysis group, Assistant Professors Kenneth Janda and Terrence Collins, was described in the 1979-80 President's Report.

Division of Engineering and Applied Science

Roy W. Gould, Chairman

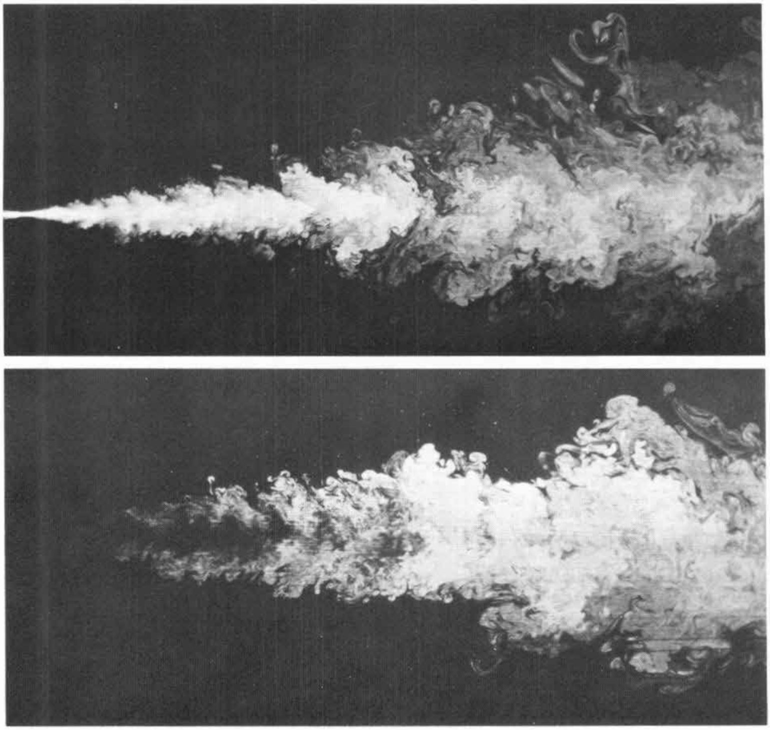
In 1980-81 the Division of Engineering and Applied Science faced some problems that are reflections of national trends — engineers in high demand, undergraduate enrollment in engineering rising to meet that demand, but fewer engineering students pursuing graduate study so that the number of Ph.D.s granted has dropped substantially in the past five years.

The situation at Caltech is a little different. Undergraduate engineering enrollment at Caltech has mirrored the national trend. The number of undergraduate students studying some field of engineering or applied science in 1972 was 172; by 1980 this number had increased to 305. This influx of undergraduate students means that classes are larger and that the instructional laboratories are crowded.

Our graduate enrollment, however, has not mirrored the national trend. We have consistently had a large pool of well qualified applicants for graduate study, and the number of students accepted is only limited by the size of the faculty and the availability of resources. In the period between 1972 and 1980 our graduate enrollment rose from 257 to 317. There has been no discernible decrease in the quality of graduate students.

It has become very difficult to recruit new faculty members in engineering because of the nationwide shortage of top Ph.D. graduates and because of the intense competition from industry — and industry can offer larger salaries than universities. Caltech has the added disadvantage of high priced housing in and around Pasadena.

The acquisition of outstanding young faculty in engineering and applied science at Caltech proceeds slowly, but the research activities of the division continue to prosper. I am pleased to present a few highlights from last year's research results.



Work in progress in aeronautics may alter our understanding of turbulent flow, an area of research in which ideas have been changing during the last ten years. Depicted here are probe mechanisms of entrainment and mixing by turbulent jet, using laser-induced fluorescence techniques. The top photo reveals the concentration of jet fluid on the jet's plane of symmetry; the bottom shows the chemical reaction product.

Entrainment and Chemical Reactions of Turbulent Jets

A solution to the riddle of entrainment by turbulent flow — and the subsequent mixing of the entrained fluids in a turbulent environment — would constitute a major scientific advance in the understanding of fluid dynamics and turbulence. It would have a significant technological impact on the way power plants, jet engines, internal combustion engines, and high power chemical lasers are built, and it would affect the way we control pollutants.

Most present day analyses of the phenomena of entrainment and mixing assume that turbulent transport can be modeled as a gradient diffusion transport process, with an effective diffusion coefficient, called "eddy diffusivity." The validity of these models is now in doubt largely because of experimental investigations begun in the last few years in the department of aeronautics at Caltech.

In a recent research effort, the mechanisms of entrainment and mixing by turbulent jets have been investigated directly, using laser-induced fluorescence techniques. The top photograph shows the concentration of jet fluid (on the plane of symmetry of the jet) as it is mixed and diluted by the entrained reservoir fluid. Note the sharp fronts, separating monotonically decreasing concentrations. The bottom photograph shows the product of the chemical reaction that is formed when one part of jet fluid has mixed with at least 25 parts of reservoir fluid. The absence of any significant chemical reaction product for a large number of jet diameters is consistent with the new thinking about the dynamics of free turbulent shear flows.

These investigations, performed by Paul E. Dimotakis, associate professor of aeronautics and applied physics, in collaboration with James E. Broadwell, senior research associate in aeronautics, are supported by the Air Force Office of Scientific Research, and the Energy and Environmental Research Corporation (on behalf of the Environmental Protection Agency). They are part of a larger activity in the department of aeronautics to further our understanding of turbulent flow.

Active Control of Laminar Turbulence Transition

Another new idea about turbulent flows is that they are not completely unstructured, or random, but are partly coherent, or structured and organized, at least at the largest scale of the flow. One consequence of this profound change in thinking is that partial control of turbulence may be possible. Not only is this prospect an exciting one from a fundamental point of view, but the gains that might be realized through modification and control of turbulence in numerous applied problems are so great as to be difficult to estimate.

Recent research in aeronautics by Hans W. Liepmann, Powell Professor of Fluid Mechanics and Thermodynamics, and graduate student Daniel Nosenchuck has made a beginning by attacking the problem of transition from laminar to turbulent flow. In the important case of the boundary layer, transition involves a wave-like, periodic vortex motion that grows exponentially when the frequency or wavelength lies within a certain narrow range of values. A technique was developed to introduce such waves artificially in a laminar flow of water by periodic heating of a thin surface strip, making use of the sensitivity of the fluid viscosity to temperature. It was conjectured — and then demonstrated — that these unstable waves could be canceled, for all practical purposes, by using a suitably phased second strip heater downstream of the first one. A later phase of the research demonstrated that the same instability waves — occurring naturally as a response to noise in the flow — could be detected and drastically reduced in amplitude by using a single strip heater controlled by a closed feedback loop. The natural transition was delayed substantially.

This experiment marks the first time that active control has been successfully used in any problem related to turbulence. Future reseach is planned to show how the technique can be improved and extended. This research is supported by the Office of Naval Research.

Kármán Vortex Streets

The well known phenomena of Aeolian tones and the singing of telegraph wires are caused by the regular shedding of vortices alternately from the opposite sides of a cylinder standing in a wind. When the cylinder is a skyscraper, the eddies may be strong enough to blow people off their feet. The fluctuating forces on the structure can be large enough to destroy it, as in the famous collapse of the Tacoma Narrows bridge. If the speed of the wind is not too large so that the flow remains laminar, the vortices arrange themselves into a uniform staggered double row, or vortex street, which can extend far downstream behind the cylinder. This flow pattern is not restricted to engineering type flows; satellite photographs have shown vortex streets in the wakes of islands in a prevailing wind.

Theodore von Kármán, whose name is associated with this flow, was the first to carry out a mathematical study of the phenomena and to propose an explanation of the remarkable stability of the flow configuration. His calculations assumed that the vortices were very small and predicted that the street would be stable only if the spacing ratio of width to longitudinal separation had the value 0.281. Experimental observations have shown that the spacing ratio may have values between 0.2 to 0.4 and changes as the street evolves. Also later work showed that von Kármán's calculations were only true if the disturbances were very small and that the street with spacing ratio 0.281 would in fact be unstable if the disturbances were of finite amplitude. This conflict between theory and experiment has been one of the challenging problems of fluid mechanics research on the basic fundamentals of flow past bodies.

A new theoretical study of the Kármán vortex street has been carried out by Philip Saffman, professor of applied mathematics, and graduate student James Schatzman. They assumed that the vortices were of finite size and calculated the equilibrium shape of the vortices and the properties of the street. By utilizing the conservation of momentum and energy, it proved possible to relate the structure and evolution of the street to the drag of the body and the rate of shedding of the vortices, so that the size, speed, and separation of the vortices in the street could be predicted from knowledge of the flow near the body. The results agree well with experiment. Further, the stability of the street of finite vortices was calculated, and it was shown that finite core size makes the street stable for a range of spacing ratios about the Kármán value of 0.281, the width of the range being proportional to the size of the vortices. The puzzle of the street stability now seems to have been resolved. The theoretical study required extensive computations, which were carried out on a CDC Cyber 203 supercomputer.

Earthquake Measurement on an International Scale

Earthquakes know no national boundaries. It is therefore important that engineers and scientists worldwide cooperate in the study of this international phenomenon.

One of the most seismically active countries is the People's Republic of China, yet the number of instruments deployed in that country to measure damaging earthquake ground motion is relatively small. Caltech is leading a project that will place nearly 50 additional engineering instruments in China. The cooperative project also involves the University of Southern California and the United States Geological Survey.

Wilfred D. Iwan, professor of applied mechanics, is directing this National Science Foundation-sponsored project, which will (1) expand the coverage of strong-motion instruments in China to help assure that records will be obtained from any major earthquake within the country, (2) establish a network of instruments that can be rapidly deployed in the case of a credible earthquake prediction or for aftershock measurements, and (3) make coherent measurements of strong ground motion over a fairly small geographical area in order to better understand the spatial variation of such motion.

To meet these objectives, a unique fixed-mobile instrumentation network has been developed. Some of the instruments will be deployed as stand-alone stations in regions of highest probability of seismic activity; however, the majority will be deployed as a dense array in a seismically active region near Beijing. This array has been designed so that the instruments can be rapidly redeployed. With the entire system in place by July 1983, it is anticipated that much needed data will be provided on the nature of the ground motion in the near field of very large earthquakes. These data are needed to gain further confidence in the design of major structures and critical facilities in earthquake-prone regions of the world.

Harbor Oscillations Induced by Tsunamis

A tsunami — an earthquake-generated sea wave — can travel large distances across the ocean (with wave speeds of about 700 kilometers per hour) and impinge upon the coast, creating catastrophic damage. These waves are very difficult to observe in the open ocean; the wave heights there might be one meter or less and the wave lengths could be about 200 kilometers. As they approach the shore, the height increases significantly.

Fredric Raichlen, professor of civil engineering, and his co-workers work on the generation, the propagation, and the coastal effects of tsunamis. Most recently graduate student Thierry Lepelletier and Raichlen have investigated the excitation of harbors or bays by tsunamis. A harbor or bay acts dynamically, as do many mechanical systems, and responds with amplified wave heights when excited at certain frequencies and attenuated wave heights when excited at others. In fact, in some harbors this resonance can be extremely serious with far-reaching consequences to the mooring of large ships and damage to harbor facilities. The tsunami is another form of excitation, and the potential enhancement of its amplitudes — because of the shape of the harbor or bay or the variation of the depth — can significantly influence coastal flooding and damage.

In his Ph.D. thesis Lepelletier developed a numerical model to determine the response of arbitrary-shaped harbors to large transient long waves. Laboratory experiments were conducted concurrently to test the long wave model and the various conditions for which a simple linear theoretical model could be applied as opposed to the more complex nonlinear approach. Various types of energy dissipation associated with long waves propagating through a harbor entrance and traveling in a harbor were evaluated. Thus, one major result of Lepelletier's research was to establish with confidence the effect of breakwaters at a harbor entrance on the response of the harbor to a tsunami.

These results provide a means of designing protective schemes for harbors that might be exposed to tsunami threat. In addition, the numerical method developed in this research program can be applied to the excitation of a harbor with significant depth and width variations and associated dissipative effects to other types of long wave excitation whether the waves are transient or steady.

Hybrid Catalysts

Chemical contaminants are eliminated most often from domestic and industrial wastewaters by oxidation to species with fewer problems. With the exception of molecular oxygen, which is obtained readily from air, oxidants such as chlorine, ozone, and hydrogen peroxide are costly and inherently hazardous. Alternatively, oxidation of pollutants by molecular oxygen tends to be a slow process in the absence of catalytic agents.

Selective oxidation of air and wastewater contaminants by oxygen with the aid of transition metal catalysts represents a new alternative to the conventional treatment method. Michael R. Hoffmann, associate professor of environmental engineering science, and his students are synthesizing and testing these new metal-organic catalysts for selected oxidation processes. Catalytic systems developed by them promote the rapid oxidation of a wide range of air and water pollutants. These catalysts have been designed to activate molecular oxygen into a favorable electronic configuration and symmetry state for the transfer of electrons from reductant to oxidant.

Hybrid catalysts have been developed by chemically bonding specific metal-organic complexes to inert solid surfaces such as silica gel,polystyrene, polyacrylamide, activated carbon, and alumina. These solid-supported catalysts have been designed to be used in continuous flow treatment systems with fixed-bed or fluidized-bed reactors. The rapid elimination of H_2S and SO_2 gases, two primary air pollutants, has been achieved with hybrid catalysts developed at Caltech. Odor-producing pollutants such as phenols, indoles, and thiols are rapidly eliminated by oxygen in the presence of these new catalysts. In addition to their development, the dynamic and mechanistic behavior of these systems is being characterized in order to optimize their performance under a wide range of conditions.

Far-Infrared Imaging Antenna Arrays

Most current far-infrared imaging systems depend on a single detector with scanned optics. For many applications, this approach is too slow. For example, far-infrared waves are used to measure the plasma density and magnetic field in fusion plasmas in tokamaks, where events occur in microseconds. Dean Neikirk, a graduate student, and David Rutledge, assistant professor of electrical engineering, have developed a far-infrared imaging array using evaporated microscopic silver bow-tie antennas on quartz substrates. The image is coupled to the array through a lens placed on the back side of the substrate. This approach takes advantage of the fact that antennas on substrates are sensitive mainly to radiation from the substrate side. The arrays have demonstrated diffraction-limited images on a microsecond time scale at wavelengths of 1.2 millimeters and 120 micrometers. These arrays should allow plasma density and magnetic field maps to be made with a resolution of one millimeter at intervals of one microsecond.

Integrated Magnetics

In the conversion of electrical energy from one form to another, such as direct to alternating current conversion (switching dc-to-ac inversion) or for efficient conversion to direct current of another voltage and current (switching dc-to-dc conversion), the magnetic components represent the dominant part in terms of the size, weight, and loss contribution. Scaling laws in the sizing of inductors and transformers indicate that their energy storage and power capability grow as the fourth power of linear dimension, while their weight, size, and loss grow only as the third power. Therefore, a single higher power magnetic unit is more efficient and smaller than several lower power magnetic components.

Modern switching converters often have a multitude of magnetic components (inductors and transformers) to provide smoothing and dc isolation functions. Recently a new integrated magnetics approach has been pioneered by the power electronics research group, which integrates previously separate inductors and transformers into a single higher power magnetic structure with multiple windings. The key benefit is better utilization of the core material, significantly boosting the conversion efficiency and decreasing the size and weight of the converters. This new approach was spawned by the development of some new converter topologies, with unique features that allowed the integration of several inductors and transformers into a single magnetic circuit with multiple windings. Improved efficiencies and reduced size and weight are attractive for many applications: solar (dc) to utility line (ac) power conversion, variable speed dc or ac motor drives for electric vehicles, switching power supplies, and uninterruptible power supplies. The power electronics group led by R.D. Middlebrook, professor of electrical engineering, and Slobodan Cuk, assistant professor of electrical engineering, is currently developing theoretical and practical aspects of the integrated magnetics approach.

White Noise

Flashing a checkerboard pattern of light into the eye evokes electrical potentials on the surface of the human scalp. The functions of the populations of brain cells that are the neural generators of these events can be studied by applying a new system analysis approach.

A single impulse, or flash, is sufficient to characterize a linear system, but a nonlinear system such as the human brain requires a much more complex stimulus for its complete characterization; typically various forms of random signals are used.

Previous attempts to apply nonlinear analysis to the functions of the visual system have used light stimuli with a brightness varying randomly in time, principally because the original theoretical work was developed for this kind of system input. However, this stimulus looks like a faintly twinkling light, and it produces a very weak response that is hopelessly overwhelmed by the ongoing activity of the rest of the brain.

Professor Derek Fender and his research group have tried to identify a more powerful random stimulus so that the characteristics (kernels) of the visual system could be determined with greater certainty. They use a checkerboard pattern flashed with low probability every 4 msec. This constitutes a Poisson sequence, and not only is it a subjectively strong stimulus, but it is also powerful analytically, and permits the system kernels to be easily computed. The researchers were able, for the first time, to reliably measure second and third order effects. Furthermore, the stimulus revealed that the visual activity of the midbrain, located deep in the head, could be measured at the scalp. These results are important because they point toward a non-invasive method for characterizing the functional mechanisms of the neural structures at many points along the visual pathway.

Division of Geological and Planetary Sciences

Barclay Kamb, Chairman

A significant step in building the division's resource geology program was taken in 1981 with the addition of Robert W. Clayton to the faculty as assistant professor of exploration geophysics. Clayton brings a powerful teaching and research capability in exploration seismology, which, combined with the long-established strengths of our Seismological Laboratory, gives the division an advantageous position in the training of exploration geophysicists and in the development of fundamental new analytical and interpretive seismic techniques for practical application. The work in this field is being enhanced by the addition of a new VAX computer system especially suited to the processing and evaluation of seismic reflection data. The computer acquisition was made possible by industrial support of the resource geology program.

These steps revive the division's commitment to exploration seismology, which was for many years pursued by Professor (now emeritus) C. Hewitt Dix. In honor of Professor Dix and in recognition of his important contributions to the development of exploration seismology and his long and devoted service as a teacher of geophysics, the division and its alumni raised an endowment fund of $38,000 to establish the C. Hewitt Dix Lectureship in Geophysics, which aims to provide a public forum for recognition of the progress of exploration geophysics. Dix was also honored nationally by award of the Maurice Ewing Medal of the Society of Exploration Geophysicists.

Clayton's research is devoted to improving our ability to determine the detailed structure of the earth's crust from state-of-the-art seismic reflection data, whose quality and quantity have increased dramatically in recent years. The inversion problem of deducing subsurface structure from such data separates in a natural way into two parts, the separation being based on the two distinct types of information contained in the data — travel times and wave amplitudes.

The travel times depend on an integral of the seismic-wave velocity along each wave path, and therefore contain information primarily for determining average velocities and slow, broadly distributed variations. In contrast, the amplitudes depend mainly on rapid local variations in velocity. Inversion of travel-time data is basically a transmission or tomographic problem, which Clayton analyzes by a downward-continuation procedure to produce an image of the velocity-vs.-depth function. He approaches the amplitude problem by means of scattering theory, and has developed an inversion procedure based on the Born approximation. The two inversions interact with one another: the amplitude inversion requires that the general background velocity be known, which comes from the travel-time inversion; and the travel-time inversion depends on the location of the reflectors, which are given by the amplitude inversion. Clayton is currently working to develop methods to handle this interaction and carry out the inversions simultaneously. He is also working on inversion methods that can estimate laterally varying velocity functions. Once these things can be done reliably in practice, it will be possible to deduce subsurface structure (in terms of the distribution of different rock types at depth) by detailed plots of seismic velocity as a function of depth and lateral position, effectively combining in an internally consistent way the types of information that are at present derived separately from seismic reflection and refraction work and from well logging.

A new dimension of teaching and research in geobiology, a field pioneered by Professor Heinz Lowenstam, was added in 1981 with the appointment of Joseph L. Kirschvink as assistant professor. Kirschvink's special interests are in the application of highly sensitive magnetic measurements to paleomagnetic stratigraphy and to the role of magnetic minerals in organisms. In particular he is studying the use of magnetite by certain organisms in detection of the earth's magnetic field and in navigation. He is also developing a paleomagnetic record for stratigraphic sequences spanning the Cambrian-Precambrian boundary in many parts of the world, as a means of unraveling the sequence of events that took place near the time of this most profound break in earth history. The paleomagnetic-stratigraphy work carries on a tradition established by Professor Eugene Shoemaker.

The results of the Voyager encounters with Saturn provided some of the most exciting research developments in the division during the past year. They included observations of the atmospheric motions and dynamics, the helium-hydrogen ratio and its relation to the fractionation of these gasses by phase separation deep in the interior of the planet, the dynamics of

The Precambrian-Cambrian boundary working group gathered at Ulikhan-Suligur on the Aldan River in eastern Siberia, July 1981. This locality has been proposed as an international stratotype section for the Precambrian-Cambrian boundary.

density waves in Saturn's ring system, the composition and photochemistry of satellite Titan's atmosphere, and the surface development of the icy satellites of both Jupiter and Saturn through the action of ice flow in their interiors. Professor Andrew Ingersoll, Associate Professor David Stevenson, DuBridge Professor Peter Goldreich, Assistant Professor Yuk Yung, Professor Eugene Shoemaker, and their students and colleagues were very much involved in these developments.

Other research highlights of particular note are Professor Hiroo Kanamori's discovery of a monopole source mechanism for the earthquake that accompanied the Mt. St. Helens blast, the demonstration by Professor Clarence Allen and Assistant Professor Kerry Sieh of recent activity of the Red River Fault of southern China, and Professor Samuel Epstein's discovery that the deuterium-to-hydrogen ratio in meteorites is four times larger than the terrestrial value, which has important implications for cosmochemistry. It is also noteworthy that Peter Goldreich was named California Scientist of the Year by the California Museum of Science and Industry.

Division of the Humanities and Social Sciences

Roger Noll, Chairman

Caltech's most important asset is the people associated with its academic programs: the faculty who undertake research and who teach, the students who are here to learn but who teach the faculty more than the latter are always comfortable to admit, and the alumni who carry on the institution's academic tradition throughout society. With this in mind, the highest priority of the division has been to attract outstanding new faculty. Consequently this report will focus less on programs than on some of the people who make them work.

New Faculty

The division has been especially fortunate in attracting some excellent new faculty during 1980 and 1981. One is Jerome J. McGann, the Dreyfuss Professor of the Humanities. McGann's principal field of research has been 19th-century Romantic literature, and he is regarded as the leading Byron scholar of this century. He is midway through the publication of his eight-volume edition, *Lord Byron: The Complete Poetical Works*. These books contain what are now regarded as the authentic versions of the texts and associated materials of all of Byron's work. In addition, the notes and commentaries discuss the texts and contexts of the poems, especially the relationship of the poetry to Byron's life and the history of the times in which he wrote. The third volume, published in 1981, reports major new findings about Byron's poetry in the period 1812-15. Many of the poems from this period are political allegories that were heavily camouflaged to avoid reprisals from the rather oppressive political system of the time. McGann's research has deepened the political meaning of several poems that were known to be allegorical, and he has discovered heretofore unknown political roots of others.

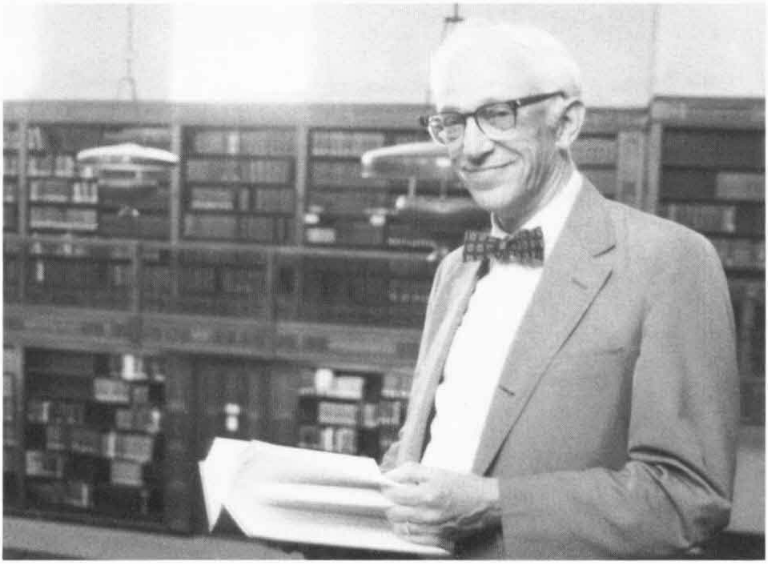
McGann is also at work on constructing a comprehensive theory of the historical method in literary criticism. His forthcoming book, *Romanticism and Its Ideologies*, describes this method and applies it to the literature of the early 19th century. Another forthcoming book, *Textual Criticism and Its Histories*, explores the same theoretical and methodological issues in the general field of textual studies.

Another new member of the division is Professor of Political Science Gerald H. Kramer, whose research spans a variety of theoretical and empirical topics about electoral processes. One of his principal contributions is to establish the foundation for the theory of political dynamics: how the winning policy positions of candidates can be expected to change over time. Another contribution is the seminal study on the effects of macroeconomic conditions, or the overall performance of the economy, on American elections.

Recently Kramer has turned his attention to a major puzzle in the research findings about American elections. Kramer and others have found a strong relationship between voting returns and the state of the economy. However, surveys that ask about voting intentions and personal economic conditions find much weaker correlations. Kramer's recent work solves this puzzle. In a given year most differences among people in personal economic circumstances are due to relatively permanent life-style factors that are largely unrelated to government economic policies. Thus, differences in personal circumstances will be largely uncorrelated with individual vote intentions, even if everyone votes according to whether administration policies have made them better off economically. In analyzing a survey, a failure to account for this will lead to an underestimate of the strength of the relationship between economic circumstances and voting behavior. Kramer corrects the error, and resolves the controversy.

Joining the faculty in 1980 was Martin Ridge, professor of history. Ridge represents an important first for Caltech, for he also holds the position of senior research associate at the Huntington Library. This is the first joint appointment between Caltech and the Huntington, one of the world's great research libraries, and is an important step in building close ties between the two institutions.

Ridge's field of research is 19th-century American history. He is the author of numerous books and papers, including the historical biography of Ignatius Donnelly, a Progressive-era politician. He has also published widely in the history of the American West. His most recent work deals with bilingualism in the United States — and especially in the Southwest with its large Hispanic population. As editor and contributor, Ridge



Caltech's Professor of History Martin Ridge, shown here at the Huntington Library, where he is also senior research associate, holds the first joint appointment between the two institutions. Ridge's research concentrates on 19th-century American history.

sums up *The New Bilingualism: An American Dilemma* by pointing out the genuine conundrums in the debate over bilingualism and biculturalism. The root of the problem is that an open, free society can lead to a biculturally based separatism that hinders the assimilation and economic advancement of immigrants. Ridge traces the history of how America has coped with this dilemma, and concludes that we are now at a crossroads: The debate about bilingualism and the development of law establishing the rights of non-English-speaking Americans have forced a choice between a Canadian model of bilingualism and a Mexican model of adopting one language but a diverse culture in a society that includes many ethnic and linguistic groups.

After serving as visiting professor in 1980-81, Alan Schwartz was appointed professor of law and social science in 1981. A specialist in commercial and consumer law, Schwartz also holds a professorship at the University of Southern California Law Center. One of his major contributions has been to analyze the economic consequences of different rules used by courts to compensate for breach of contract. More recently, in conjunction with Louis L. Wilde, associate professor of economics, Schwartz has focused on the relationship between the efficiency of markets for consumer goods and the quality of the information held by consumers.

One recent avenue of research by this pair is product warranties. Recent legislation and judicial decisions assume that firms offer insufficient warranty coverage at too high a price because of failures of the market; e.g., consumers have difficulty relating product characteristics to the details of the warranty, and firms write warranties that are difficult to compare. Recently some common warranty terms have been banned, and the Magnuson-Moss Warranty Act imposes extensive disclosure requirements. The issue for research is whether these actions improve the performance of the firms issuing the warranties. Schwartz and Wilde have constructed a theoretical model of a market for consumer products that can break down and in which warranties are available that promise to replace defective goods. The model establishes the conditions under which warranties are viable — e.g., when someone will want a warranty at a competitive price. The policy implications of this work are significant, for they will provide guidelines for deciding when consumers will prefer the absence of warranties — and when their absence is because of a failure in the market.

Several junior faculty have been added to the division in recent years. Edward J. Green, appointed assistant professor of economics in 1981, is an economic theorist with special interests in the application of game theory in economics and in the relationship between the structural characteristics of markets and their efficiency. One of his major contributions is in the theory of repeated games. A highly useful game theoretic concept is the "prisoner's dilemma," which refers to a perversity in certain specialized but plausible noncooperative games. In some games the best outcome for all players is a cooperative one; however, if the players are cooperating, each has an incentive to "cheat"; acting alone, each player could reap greater gains by abandoning the cooperative solution, assuming everyone else continues to cooperate. Economic theory predicts that in this situation all players will abandon cooperation, and thereby achieve a result that makes everyone worse off. This particular game form has been applied to numerous practical problems — from understanding pollution problems to describing the business behavior of sports leagues. Theorists have long recognized that, if the game is repeated indefinitely rather than played only once, the cooperative solution may be obtained. Green's important contribution was to characterize precisely when the cooperative outcome will occur, and to relate this characterization to economic theory.

His most recent work is on detecting the presence of collusion in markets. By combining statistical decision theory and game theory in analyzing the interaction among members of a cartel, Green has produced two important advances: a characterization of the conditions under which cartels become unstable and then restabilize, and a statistical method that people outside the cartel can use to determine whether price fluctuations are natural phenomena or evidence of the periodic rise and fall of collusive behavior.

Also arriving in 1981 was James Lee, assistant professor of history. Lee's principal research interest has been the expansion of China into its southern frontiers over the last 2,000 years. The work focuses on the Chinese migration, acculturation, and assimilation that integrated the southern provinces into the Chinese sociopolitical system. In researching his work, Lee was the first westerner in 40 years to have access to the wealth of demographic and political records in mainland China. By applying modern methods of historical analysis, including social scientific methods and theories, Lee has produced the seminal work on the development of the Chinese nation under Han domination from balkanized, disconnected principalities.

On arriving at Caltech, Lee made a major contribution to the Institute by negotiating an agreement with Beijing University whereby Caltech will soon acquire the best Chinese-language history library in the West. This will be a valuable research resource for Chinese historians and will serve the significant number of Chinese-speaking students attending Caltech.

Another 1981 addition to the Caltech faculty is Quang H. Vuong, assistant professor of economics. His primary research interest is in econometrics — the development and application of statistical methods in social science. His major research contribution is the development of methods for estimating the parameters in systems of simultaneous equations in which some of the variables are qualitative. An example of a qualitative variable is a vote: A person votes yes or no, rather than expressing the degree of approval. Another example is the response to a "multiple-choice" survey questionnaire, in which a person must check which of several responses best characterizes his or her position on an issue. Still another example is a rank ordering, such as when a college admissions committee ranks the desirability of applicants on a waiting list who will then be admitted in that order if vacancies develop.

Vuong's work deals with the problem of estimating the probability that a person or organization will pick a particular qualitative response in a setting in which the decisionmaker is making several related decisions simultaneously. In addition to developing the appropriate statistical methods for attacking such problems, Vuong has successfully applied his methods to studying pricing and investment decisions of French and West German manufacturing firms.

Also arriving in 1981 was Mary Martha Ward, assistant professor of art history. Professor Ward is the first permanent professorial faculty appointment in this field — an area experiencing increased student interest in recent years. Her recent research has been on the paintings of the French Impressionist Camille Pissarro, an important figure in the history of art because he was the only member of the older generation of painters who embraced the Neo-Impressionist technique and subscribed to the Symbolist-oriented aesthetics by which the technique was interpreted in the 1880s. Thus, the study of his paintings during his transition from Impressionist to Neo-Impressionist provides a unique possibility for studying the differences in the approach within the context of the style and skills of the same artist. In studying Pissarro's personal correspondence, Ward discovered that his stylistic innovations during the transition period were a direct response to the criticisms of Impressionism by such people as Zola, Huysmans, and Fénéon. Pissarro was consciously responding to the major criteria then used for evaluating paintings: the unity and completeness of a painting in making a pictorial statement, the sense of primitiveness and simplicity in the painting that demonstrated the naiveté and sincerity of the artist, and the requirement that paintings, like industrializing society and burgeoning science, reflect a form of progress over the work of the past.

Ward's findings about Pissarro's self-conscious transition from one artistic school to another provide new insights into the aesthetic theory of Neo-Impressionism. Moreover, once developed, Ward's detailed description of Pissarro's transition permits her to establish a more precise chronology of his paintings and, in fact, to date definitely many of them for the first time.

Mellon Instructors

One of the most valuable programs in the division is a regular flow of postdoctoral instructors in the humanities. Five two-year instructorships have been created by the Andrew Mellon Foundation. They are currently held by a distinguished group of recent recipients of doctoral degrees, and have become nationally known as an outstanding way to begin an academic career. The current Mellon Instructors are Barbara S. Freedman and David Sundelson, literature scholars who are especially interested in psychology-based critical studies of Elizabethan literature; Walter Kamphoefner, a historian who studies European migration to the United States in the 19th century; Susan A. Keefe, a student of medieval religious history; and Theodore M. Porter, a historian of science with special interest in the development of statistics.

Some Additional Contributions

Two important promotions within the division took place in 1981. Rodman W. Paul, Edward Harkness Professor of History, became professor emeritus, and Lance E. Davis, professor of economics, became the Mary Stillman Harkness Professor of Social Science.

Rodman Paul has long been a major asset to Caltech. One of the best teachers at the Institute, he closed out his educational career by winning the annual teaching award from the undergraduates. Professor Paul is also one of the outstanding scholars of his generation in the history of the West. The author of eight books and over 100 articles and reviews, Paul's greatest contribution was in the history of mining as a major force in developing the Western frontier. One of his books, *Mining Frontiers of the Far West*, was the subject of an episode of the television series "History of American Civilization." Another, *California Gold*, was the winner of a book award from the American Historical Association.

Paul's great scholarly contribution was, in the words of the eminent historian, the late Ray Billington, "to rescue the story of Western mining from the hands of fact-worshipping antiquarians, irresponsible popularizers, retired mining engineers, and imaginative tall-tale-tellers to reveal its true importance as a molding force in the evolution of the American social order." Paul's history of the West is not one of gunfights, vigilantes, and wild rushes, which were of slight importance, but of entrepreneurs, investors, inventors, and builders who established mines, permanent towns, and the infrastructure to support them. Paul demonstrates that the history of the West is cohesive, not a collection of unconnected tales of bravado. The cohesion was provided by the miners, who were the migratory workers of the era and the developers of the transportation and communications systems that linked the mining camps and made possible more diversified, permanent development.

Lance Davis is one of the handful of innovative economic historians who introduced the use of modern techniques of economics, both theoretical and statistical, to the study of history. In his eloquent and, by example, mistitled paper, "And It Will Never Be Literature," Davis makes the definitive statement of how economic history should be done: the scientific, usually quantitative, testing of theories of long-term economic developments. Davis has successfully applied his methods to a variety of topics, including the development of capital markets in the United States in the 19th century and the interactions between government and business that produce changes in the ground rules by which the American economy operates.

In collaboration with Robert A. Huttenback, chancellor of the University of California at Santa Barbara and formerly a Caltech faculty member, Davis is completing a research project of major importance. The topic is the economic effects of the British Empire in the late 19th century. The research effort included several major activities. One is the budgetary history of Britain, other advanced industrialized countries, the British colonies, other colonies, and independent, less developed nations. Davis and Huttenback used this information to undertake a comparative study of the ways in which Britain and her Empire differed fiscally from other countries. A second project is the financial history of a large number of important British corporations and an analysis of their stockholders. The purpose: to determine whether companies with strong Empire interests fared better or worse than companies oriented toward the domestic market or trade with the developed countries, and to detect patterns of differences in ownership between Imperial companies and other British industries. Still another project is the voting history of members of the British Parliament on matters relating to economic policy and Empire. The object is to identify the political interests that favored — and opposed — government support for an ever-larger Empire.

The findings of the study are surprising, and at variance with conventional wisdom. First, including the costs of maintaining an Imperial presence, the Empire was not profitable; Britain would have earned a higher return by investing the Empire funds domestically or in more advanced nations. Second, the countries of the Empire were made substantially better off financially, if not politically, by membership in the British sphere, largely through government subsidies and extensive unprofitable investments. Third, in Britain some groups profited handsomely from the Empire — primarily, the wealthy upper class — at the expense of small businessmen and other members of the middle class. The major economic effect of the Empire was to drain British resources and to accomplish a redistribution of income within Britain in favor of the wealthy.

The Weingart Programs

Owing to the generosity of the Weingart Foundation, two new programs were created in 1981. One was the Weingart Symposia, an annual series of conferences in humanities. The first Weingart Conference in March 1981 centered on the theme "Family and Property in Traditional Europe." The conference participants included leading medieval historians from Britain, France, and the United States. The theme was the role of the family in shaping the social, economic, and political institutions of medieval Europe.

The second new activity is the Weingart Program for the Study of Institutional Performance. A program of research and education focused on the factors affecting the performance of social and political institutions, it will create new graduate fellowships for students intending to undertake dissertation research on American political institutions, positive political theory, or economic, political, and social history.

Division of Physics, Mathematics and Astronomy

Rochus E. Vogt, Chairman

The year 1981 marked the 50th anniversary of the W. K. Kellogg Radiation Laboratory in the Division of Physics, Mathematics and Astronomy. The Laboratory has played a distinguished role in the history of the division, and the scientific achievements of its faculty and students have greatly contributed to Caltech's image all over the world.

In 1931, W. K. Kellogg's philanthropy and the vision of Caltech's R. A. Millikan and C. C. Lauritsen established a laboratory that proved to be one of the inspired investments in American science. Almost instantly, the Kellogg Laboratory became a thriving intellectual center for a group of faculty and students that shared its facilities. Kellogg not only established itself as a leading laboratory for nuclear physics and astrophysics, but also became the advocate and godfather of many other of Caltech's distinguished research efforts, such as elementary particle physics, relativistic astrophysics, and nuclear geophysics. In addition, it supported a variety of other fledgling programs during their establishment on campus. Kellogg's excellence as a center of research is enhanced by its success as a training center and intellectual home for numerous visitors, postdoctoral fellows, graduate students, and undergraduates.

Kellogg's 50th anniversary milestone was observed with a two-day symposium that celebrated the laboratory's scientific achievements, provided a historical perspective, featured the dedication of Kellogg's new particle accelerator, and took a look at the future.

The division is proud of Kellogg's history, it values the Laboratory's present contributions, and it looks forward to future achievements. Kellogg is a success story which reflects well what this division is all about, and we dedicate the major portion of this report to the Laboratory, as it presented itself in the two days of the 50th anniversary symposium under the motto: "Fun and Physics at the California Institute of Technology."

The report concludes with a brief news summary of the division.

50 Years of the W. K. Kellogg Radiation Laboratory

The 50th anniversary symposium of the W. K. Kellogg Radiation Laboratory was partly a scientific conference and partly a reunion of the Kellogg alumni, an extended group that includes scientists from around the world who have been visitors in Kellogg and a large number of postdoctoral fellows, as well as the former graduate students who earned their Ph.D. degrees in the Laboratory.

By a happy coincidence, the 50th anniversary year of the Laboratory included the 70th birthday of Professor William A. Fowler, who has been with Kellogg since its inception. And it may well be that the most memorable conference session was the one held in the Athenaeum on the first evening, "Willy's Birthday Party." Especially notable among Willy's birthday presents was the first copy of a *Festschrift* volume in his honor, containing 23 chapters, each written by one of his former students or coworkers. The two exciting days of science and celebration were brought to a close, following the last of the formal sessions, with a traditional Kellogg Party in Dabney Lounge.

Kellogg History

In the first of these sessions, Professor Charles Holbrow of Colgate University, one of Kellogg's "extended alumni," entertained the audience with the inside story (gleaned from the Caltech Archives) of Millikan's solicitation of funds from W. K. Kellogg, leading to the establishment of the W. K. Kellogg Radiation Laboratory at Caltech. Although that series of events was officially the beginning of the 50-year period, the story really began five years earlier. In 1926 Charles Christian Lauritsen, a Danish immigrant, was designing radio receivers in St. Louis. In a public lecture there, Robert Millikan conveyed the excitement of science, and Charlie, with his wife Sigrid and son Tommy, followed Caltech's Pied Piper to Pasadena. Charlie became Millikan's graduate student and in 1929, at the age of 37, wrote his thesis on what is now called field emission — the emission of electrons from metals acted on by strong electric fields.

Lauritsen and Millikan realized that these results in basic science could be applied to designing an x-ray tube of much higher voltage than any then available. That idea and Dr. Seeley G. Mudd's study of the efficacy of these "super voltage" x rays in cancer therapy led to W. K. Kellogg's involvement with Caltech.

From Richard Crane (the first graduate student in Kellogg and now professor emeritus at the University of Michigan), the audience learned that even though the daylight hours were filled with the clinical irradiations of patients, the nights were devoted to studies in basic science. For example, John Read and Lauritsen studied the energy dependence of the scattering of high energy x rays from the electrons, and when Cockcroft and Walton discovered the transmutation of nuclei at energies below the Coulomb barrier, as predicted by Gamow, Lauritsen and Crane immediately converted one of the x-ray tubes into a positive ion accelerator. With this accelerator they were the first to produce "artificial" radioactivity using ion beams and to observe positron-electron annihilation radiation. Thus began the experimental study of nuclear reactions in the Kellogg Laboratory that has continued up to the present time.

This hectic pace — x-ray therapy during the day and nuclear physics at night — continued into the late 1930s. However, in 1939, basic research in the Kellogg Laboratory was set aside until the close of World War II. For the two-year period 1939-41, Charlie and Tommy Lauritsen and Willy Fowler worked on the development of the proximity fuse at the Department of Terrestrial Magnetism in Washington, D.C. Then, as the United States entered the war, they returned to Caltech to establish the rocket ordnance project; a consequence of this effort was the founding of the China Lake Naval Weapons Laboratory. After the war, with funding from the Office of Naval Research (ONR), the Laboratory returned to the study of nuclei. So many excited states of nuclei were observed with the new Van de Graaff accelerators and the new high resolution spectrometers, developed in Kellogg, that Fowler, William Hornyak, and Tommy Lauritsen began the first systematic compilations of the properties of nuclear states. This led to the nearly 20 years of collaboration between Tommy Lauritsen and Fay Ajzenberg-Selove (University of Pennsylvania), who wrote a series of such compilations. She presented the third of the talks on the history of Kellogg research, using examples from Laboratory publications to show how the program since the war had evolved from one involving mostly nuclear physics to application of nuclear physics to problems in astrophysics, geophysics, and technology.

Kellogg Seeding New Efforts

Just after the war Charlie Lauritsen began a project to develop an electron synchrotron with ONR funding. When R. F. Bacher came to Caltech in 1948 to become the chairman of the Division of Physics, Mathematics and Astronomy, he took on the leadership of the project, greatly extended it in scope, and turned it into the major facility that was the beginning of Caltech's program in experimental high energy physics.

In the middle 1960s interest in the end products of nuclear burning made it desirable to achieve greater precision in the mass spectrometric analysis of meteorites. With support from Kellogg's ONR grant, Professor G. J. Wasserburg and D. A. Papanastassiou developed the first of the Lunatic Spectrometers, which 15 years later continue to lead in high precision mass spectrometric measurements. The scientific bonds between the two groups are even stronger now than at the beginning; students move freely between the two labs, ideas and apparatus are exchanged, and lunar and meteoritic samples cycle between the Kellogg accelerators and the Lunatic Spectrometers.

In the late 1960s, National Science Foundation funding supported the development of a superconducting linear accelerator jointly by Kellogg and Professor Jim Mercereau's low temperature physics group. Several new accelerating structures were developed, were analyzed theoretically, and became the standard designs for a new generation of linear accelerators. In 1973, when Kellogg decided not to extend its accelerators to higher energies, the collaboration shifted, and Mercereau's group is now supplying the State University of New York at Stony Brook with the finished modules of a superconducting linear accelerator.

Also in the middle 1960s Fowler and Sir Fred Hoyle had become especially interested in supermassive star models of the newly discovered quasi-stellar sources. Kip Thorne came back to Caltech, where he had been an undergraduate, to supply the necessary expertise in general relativity. Professor Thorne has gone on to lead a distinguished effort in theoretical and experimental relativity at the Institute.

Nuclear Astrophysics

In Kellogg's own basic program since World War II, the greatest change occurred because the dominant interest in nuclear physics shifted gradually into a preoccupation with the means by which nuclei are created and stellar processes are energized. Although this transition began earlier, the watershed in this change can be dated from the writing in the mid-1950s of the review article, "Synthesis of the Elements in Stars," by Margaret and Geoffrey Burbidge, Willy Fowler, and Fred Hoyle. Between this time and the mid-1960s, the Laboratory's experimental and theoretical programs were devoted to sorting out the details of energy generation by nuclear reactions in main sequence stars. During this period the data obtained by Professor Ralph Kavanagh and his students, and the ideas of John Bahcall (now at the Institute for Advanced Study, Princeton) contributed to the start of neutrino astronomy by Ray Davis of the Brookhaven National Laboratory.

In the last fifteen years both measurements and theories have moved on to the study of the later stages of stellar evolution. Important work on the helium burning portion of energy production in red giant stars was carried out by Professor Charles Barnes and his collaborators, and they have made a good beginning on the many reactions that occur as a star becomes a supernova. It is here that the debris of the stellar explosion is dispersed, later to be incorporated into new stars, planets, and meteorites. The detailed experimental study of meteorites by Professors Gerald Wasserburg and Donald Burnett has thus become an important source of data that decide the fate of the theorists' models of exploding stars. Professor Ward Whaling has added further essential data through his laboratory measurements of atomic transition rates, which have helped establish reliable stellar elemental abundances. Through this interplay of meteoritic observations, laboratory measurement, and the developing theory of nucleosynthesis, scientists have just begun to see dimly into a window that has opened on the origin of our sun and solar system.

Thus, in the history of Kellogg, a beginning in applied science encouraged the birth of basic research in nuclear physics, which in turn was applied in astrophysics. In the present program this application to other endeavors has continued, facilitating basic research efforts.

Nuclear Physics, Astrophysics, Cosmology

The speakers for the first three sessions of the scientific program were chosen from among the former graduate students, postdoctoral fellows, and visitors in Kellogg. In the second session, which was devoted to research in nuclear physics, four former students from the early 1960s, Peter Parker (Yale University), Andrew Bacher (Indiana University), Robert Stokstad (Lawrence Berkeley Laboratory), and Eric Adelberger (University of Washington), demonstrated the range of their collective interests, including light ion cluster transfer reactions, scattering of intermediate energy probes (electrons, pions, and protons) by nuclei, collisions of heavy nuclei at bombarding energies from MeV to many GeV, and weak interaction studies in nuclear and atomic systems. The training and education of young men and women in the Laboratory have been among its most important contributions, and the speakers provided ample justification of the pride felt in Kellogg for the accomplishments of its graduates.

Another role played by the Laboratory has been to help entice scientists from other fields into astrophysics and nuclear astrophysics. In his speech at the dedication of the new accelerator laboratory, Professor Edwin Salpeter (Cornell University) told of his own growth of interest in astrophysics as a visitor in Kellogg. The four talks in the session on astrophysics and cosmology were given by Robert Wagoner (Stanford University), Fred Hoyle (Manchester University), Stan Woosley (University of California, Santa Cruz), and Salpeter, all of whom had come to Caltech as postdoctoral fellows. These talks reflected the diverse interests characterizing the field — the big bang, a reply in favor of steady-state theory, nuclear reactions in exploding stars, and the structure of galaxies and galactic clusters. One saw the vitality of this field, not only from the diversity of the subjects covered but also from the heated debates over the details.

Education

The students and Laboratory visitors who returned for the celebration (and those who did not make it this time) represent a wide range of current specialities. A number now are particle physicists, some do space physics, and some have gone as far afield as glaciology or computer science. The belief that a broad exposure to science is beneficial both to the student and the Laboratory can be traced back to the days of Charlie Lauritsen, who made sure that all of the students received the broadest education, involving not only research and course work, but also the technical underpinnings of experimental science. He also made sure that even leisure hours were filled with opportunities to learn physics and to see at close range how scientists really go about doing science. Seminars were conducted in which Charlie and the students worked their way through new books (e.g., Compton and Allison and Rutherford, Chadwick and Ellis); these sessions became the Kellogg seminars (then on Friday evenings), and were followed by a chance to unwind at the Lauritsens' home — the origin of the Kellogg parties. The various Kellogg musical groups date from this period; many of those returning for the celebration were again pressed into service performing in the impromptu band and chorus. These traditions have continued and evolved; for example, there is a yearly seminar weekend at the Capra Ranch for the members of the Laboratory and their families. (Who will forget Willy Fowler holding forth on why the Laboratory needs another cross-section measurement as a sleepy toddler trails her security blanket through the crowded living room in search of a parent?)

Caltech undergraduates have become a vital part of the Laboratory in the last decade. Since 1970 they have won a large share of Caltech's research prizes, published important research papers, and in most ways become indistinguishable from the other Laboratory researchers. One of the first of these unusual undergraduates was Steve Koonin (B.S. 1972), who after graduate school (Ph.D., MIT, 1975) returned to Kellogg where he is now a professor of theoretical physics.

An effort is made in Kellogg to continue the early Laboratory philosophy that everyone is an essential part of the whole effort, although individual research interests may be quite diverse. All new ideas are worthy of consideration — the only criterion being: Is it good science? For this reason, the research program continues to evolve as new scientific opportunities appear, and those who share in this evolution are marked by that spirit and carry it away with them when they leave.

New Accelerator

The last afternoon began with the audience gathered in a new underground laboratory annex, just east of the original Kellogg building, to dedicate a new electrostatic accelerator. Present to take part in this observation were representatives of the National Science Foundation, W. K. Kellogg Foundation, Caltech Trustees, National Science Board, National Academy of Sciences, American Physical Society, and Office of Naval Research, a long-time friend and early supporter of Kellogg research. In 1979, responding to a Kellogg proposal organized by Charles Barnes, the National Science Foundation made a grant to purchase a new high current, high stability accelerator. Caltech contributed to the accelerator purchase, and provided the major portion of the funding for a heavily shielded, underground laboratory for the accelerator. A grant from the W. K. Kellogg Foundation aided in the construction of the laboratory. Installation of the new accelerator began in October 1981, in time for the dedication ceremony during the 50th anniversary meetings and festivities.

A new particle accelerator was dedicated by William Fowler, Institute Professor of Physics, shown here with Professor of Physics Charles Barnes (right), at the 50th anniversary celebration of the Kellogg Radiation Laboratory. A new gravitational wave detector, with a sensitivity of 10^{-15} centimeters, has also been completed.

The greatly improved characteristics of this accelerator will make possible a wide range of new basic and applied research projects. Among the planned fundamental nuclear physics projects is the search for fractionally charged particles that will require many of the novel features of the accelerator, especially its high stability, high transmission, and very low residual gas pressure. Another project involves the search for parity violation in nuclei and in collisions between nuclear particles, which are the only ways to study the characteristics of charged and neutral weak currents in purely hadronic interactions. At present, several such experiments are being pursued by the Kellogg staff, but thus far they have had to be carried out in other university or national laboratories. The large currents and high stability of the new accelerator will make it possible to "repatriate" these basic research projects to Caltech.

In Kellogg's specialty of nuclear astrophysics, many crucially important reaction cross sections remain to be measured or remeasured at higher precision, in order to test current theoretical models of stellar evolution and nucleosynthesis. The intense, stable beams of the new accelerator will allow significant improvements in the measurements of many stellar nuclear reactions and allow others, such as those on unstable targets, to be performed for the first time.

In a different direction, several new and useful techniques have been developed in the Laboratory for elemental and isotopic analysis of materials, often by nondestructive techniques. Many light elements can be measured quantitatively at the part-per-million level because of highly specific nuclear reactions leading to easily detectable final products. Other less specific analytic techniques (like elastic scattering or the production of characteristic x rays by ion bombardment) are also capable of elemental detection and identification at very low concentrations. These analytical techniques have been applied in Kellogg to problems such as solid state physics, archeology, fish migration, and the structure and constitution of semiconductors and metal alloys. Most of these techniques, developed with the older accelerators, will be improved by the characteristics of the new accelerator.

An important mass-spectrometric analysis method will employ the accelerator to eliminate troublesome molecular-ion interferences and to measure the mass and charge of each detected ion. One of the main applications of this tool is to the dating of samples; both much smaller and more ancient samples can be tested. With its transmission, high stability, and bakeable accelerator tubes, which will reduce contamination, the new accelerator will make it possible to improve sensitivity of this analytical technique.

Future Directions

The dedication ceremony was brought to a noisy close when Professor Fowler christened the new accelerator with a bottle of champagne. The conference then moved back to Ramo Auditorium for the final session, entitled "The Beginning of the Next Fifty Years," in which a number of speakers gave examples of present research interests and possible future directions for the Laboratory's program. The topics covered exhibited the range of interests in the Laboratory — from earthquake prediction in southern California to a search for free fractionally charged particles. The weaving of such diverse topics into a coherent program within the Laboratory is a tribute to the spirit of cooperation and the overall enthusiasm that can be traced directly to the influence of Charles Lauritsen.

The talk by Assistant Professor Bob McKeown outlined an extension of Kellogg's existing experimental nuclear program into the area of pion physics. These experiments will require the use of facilities at other laboratories, primarily the Los Alamos Meson Physics Facility (LAMPF). Although the actual experimental measurements will be performed at LAMPF, the development and construction of particle detectors, and the data analysis, will be carried out largely in Kellogg. Caltech students will become involved with all aspects of this work, both on campus and at Los Alamos. Touching on very recent developments, McKeown described his work with graduate student Jeffrey Ungar in which pion reactions were used to search for an exotic light nucleus made up only of neutrons. He also outlined Kellogg's role in a planned investigation of "neutrino oscillations," whereby these elusive particles of astrophysical importance are suspected of quietly changing their identity as they move from the sun to the earth.

Research Fellow (and Kellogg Ph.D.) Barbara Cooper described one of the first experiments for which the new accelerator will be used — the search for fractionally charged particles or quarks. The fact that the electrically charged particles making up all ordinary matter have the same magnitude of charge as the electron was demonstrated many years ago by Millikan. However, quantum chromodynamics, the modern theory of matter, is based in part on the idea of quarks, and it has been argued that just a few of these particles of fractional charge may be "loose" in nature in a way in which their fractional charge can be observed. Tantalizing but unconfirmed results from Stanford suggest that free quarks may in fact exist. Cooper, McKeown, Barnes, and graduate students Richard Milner and Raymond Rau plan to use the new accelerator as a high-sensitivity instrument to separate out any fractional charges from normal matter.

On the theoretical side, Professor Koonin gave an exposition of new techniques promising much improvement in our knowledge of atomic nuclei. A reliable theoretical description of nuclear structure and reactions is essential for a thorough understanding of nuclear behavior and for accurate estimates of important, but experimentally inaccessible, nuclear properties. Because exact solutions to the motion of many-body systems like the nucleus are currently impossible, some Kellogg research in nuclear theory is focused on developing new conceptual and practical methods for dealing with many-body systems. Among them is the time dependent Hartree-Fock method, in which each nucleon is assumed to move under the average influence of the others. In a series of calculations, Koonin and collaborators showed this method to be a good description of the average properties of the collisions of large nuclei. "Semi-classical" methods for treating many-body systems are also of high current interest. Here, the simpler and more familiar classical description is used, with some modifications, to approximate the full quantum mechanical behavior. Semi-classical calculations by Koonin and Research Fellow K. R. Sandya Devi have been used to describe charge-exchange atomic collisions important in plasma physics applications, while graduate student Roy Williams has investigated the nuclear shell model. Also under study are "Monte Carlo" computer techniques used with Feynman's path-integral method to provide detailed descriptions of the properties of small nuclei.

Professor Wasserburg's talk reviewed his group's discovery of anomalous patterns among the Mg isotopes in Al-rich "inclusions" in the Allende meteorite. From this important result, the exciting hypothesis was made that the "anomalies" are due to ^{26}Al production in the dissemination from a nearby supernova explosion, which also triggered the solar-system formation from the pre-solar nebula. Allende then condensed out of the mix on a time scale comparable to the million-year lifetime of ^{26}Al, with inclusions of aluminum minerals enriched in ^{26}Al that subsequently decayed to ^{26}Mg, *in situ*. This fossil footprint is presumed to have been essentially unmodified when the meteorite fell in northern Mexico on 8 February 1969 (where fragments were personally retrieved by Wasserburg). The quantitative analysis of Allende in Wasserburg's lab, the Lunatic Asylum, is being mined for clues to solar-system formation. Data from Allende are currently stimulating theoretical work in Kellogg to explain various observed anomalies, while investigations by Professor Kavanagh and graduate student Tom Skelton aim to clarify by experiment the role of ^{26}Al in nucleosynthesis.

In the final talk of the session Professor Tom Tombrello discussed a variety of scientific questions in both basic and applied nuclear science. One phenomenon, sputtering, is a by-product of any nuclear reaction experiment initiated by ion beams, in which target atoms get violently jostled back and forth by the passing ion. When these disturbed atoms lie near the target surface, they may be knocked off entirely. A program of investigation into this process is a natural direction for Laboratory research because of the connection between techniques used in sputtering and the Kellogg experience in accelerator-based physics.

Because most planets and satellites are bathed in magnetospheric or solar wind ion fluxes, sputtering occurs naturally in the solar system. Experimental and theoretical work in Kellogg and elsewhere, in conjunction with results obtained from the Voyager spacecraft, revealed the role of sputtering as an erosive agent of importance on the satellites of Jupiter. Recent investigations in the Laboratory by Senior Research Associate Peter Haff and Research Fellow Charles Watson have also shown how planetary atmospheres can be depleted by this mechanism; much of the original Martian atmosphere may have been lost by solar wind sputtering. Pursuit of the planetary aspects of sputtering has been especially rewarding through close collaboration between the Caltech campus and the Jet Propulsion Laboratory.

Besides its connections with planetary science, sputtering may also be linked to the questions of star and solar-system formation. Scientists have argued that charged particle bombardment of tiny mineral grains in space may be a source of some of the strange patterns of isotopes discovered by Wasserburg and collaborators in meteoritic samples, patterns which in the main are thought to reflect the nuclear history of solar-system material prior to formation of the planets. Experimental work in Kellogg and the Lunatic Asylum, however, has demonstrated that isotopic compositions can be changed significantly by sputtering, and explanatory theories have evolved. Whether or not sputtering of interstellar grains in supernova shock waves is responsible for any of the observed meteoritic isotope anomalies remains under investigation.

Sputtering is also a standard technique for producing the ions that are raised to high velocity in particle accelerators. Normally, copious negative ion production is desired, and sputter sources are designed accordingly. The accelerator search in Kellogg for fractionally charged particles, however, has been made several orders of magnitude more sensitive by redesigning the sputter source to minimize normal ion production while retaining high yields of any fractionally charged particles present.

Tombrello also discussed how in pursuing leads exposed by student investigations, the Laboratory has been led to new applications of sputtering. Using ion beams from the tandem accelerator, a novel atomic erosion process operative only at high energy has been explored. This high energy sputtering process rapidly and selectively erodes many dielectric materials, but leaves metals untouched. Thus, construction of three-dimensional composite structures such as microcircuit components may be possible.

An interesting surface-related phenomenon is the bonding of thin films to a host substrate using ion beams. Thus, under irradiation, gold layers can be bonded tightly to normally unreceptive materials like teflon and ferrite. The very rapid disturbance of electron configurations at the metal-substrate interface apparently allows the formation of atom-atom bonds that are difficult or impossible to attain conventionally. Applications to electronic and computer-related devices are being developed.

Another very different research venture described in Tombrello's talk was started in 1976 by Visiting Associate Mark Shapiro and Senior Research Fellow Jon Melvin. This research on earthquake prediction was based on standard detection and data handling techniques in nuclear physics and was prompted by Caltech's location near the San Andreas Fault. Previous research in Russia, Japan, and China has indicated that changes in the content of the radioactive gas radon in well water often are precursors of earthquake activity. The Kellogg group has built and deployed (in southern California) nine microprocessor-controlled units to measure the decay products of radon. These devices are remotely sited and communicate their data to the Laboratory over ordinary voice-quality telephone lines.

Beginning late in June 1979, highly anomalous short-term fluctuations in the radon level were recorded by two monitors near Pasadena. In October of that year several moderate earthquakes occurred in southern California; important baseline and calibration data were obtained during this period. In August 1981, following a period of relative quiescence, two radon monitors near the San Andreas Fault began to show anomalous changes. At the present time, the meaning of the precursory signals is not clear, but such anomalous episodes must be considered as opportunities to learn more about tectonic processes along the San Andreas Fault. In this spirit Professor Koonin has contributed his theoretical abilities to an analysis of radon emission. One hopes that the application of diverse Kellogg talents to this important problem will help eventually to produce accurate assessments of the seismic risk to southern California.

As the two-day celebration ended, the enthusiasm of all the participants made it clear that the Kellogg Laboratory is well launched into its next 50 years. Although it is not clear what changes will occur in the research done in the Laboratory before 2031, one must expect that if the past is any guide at all, it will be performed with the same sense of excitement that has always been a Laboratory tradition.

Other News of the Division

Students

The revision of the physics undergraduate program initiated in 1979 has been completed. Caltech sophomores are now able to choose, in fulfillment of their Institute requirements, Ph 2, a course primarily designed for students who may seek no further training in physics, or Ph 12, for those who plan to continue studies of physics. In addition, a new course, Ph 98, Quantum Physics, is being inaugurated in 1981-82 under Professor Koonin. This, together with Ph 12, Quantum and Statistical Mechanics, initiated by Koonin in 1980-81, establishes a two-year sequence designed to offer an exceptionally thorough exposure to modern physics for students intending further work in physics and related options. Rounding out these new offerings is Ph 10, Frontiers in Physics, a seminar course, offered in 1981-82 by Professor Tombrello, to introduce undergraduates to research in physics.

The new system for the Ph.D. written candidacy exam, started in 1979-80, is now in steady state operation. Graduate students must demonstrate proficiency in five subjects: quantum mechanics; mathematical methods of physics; electricity, magnetism, and classical mechanics; applications of quantum mechanics; and applications of classical mechanics. Instead of the old system, where all subjects were offered together once a year, the students may now take each subject independently and at a time of their choosing. It is hoped that the new system will reduce trauma, provide more flexibility, and most importantly, allow students to begin serious research earlier. To help students prepare for the applications sections in particular, several new graduate courses (Ph 135, 136, 229) have been introduced.

Research Faculty

The physics, mathematics and astronomy faculty completed a major review of the role of the research faculty in the academic program and has adopted a set of "Policies and Procedures" for its own operations. These deliberations were subsequently extended by the other division faculties and have led to an Institute policy on research faculty that was adopted to supplement the existing policies on the professorial staff.

These measures formally acknowledge the important role played by the research faculty in the Institute's academic life. In particular, the contributions of the senior research faculty are crucial to, and reflect the sophistication and demands of, some of our major research programs that need full-time senior researchers.

Astronomical Observatories

The transients introduced by the dissolution of the Hale Observatories and their reconstitution as separate administrative entities under control of Caltech (Palomar Observatory, Big Bear Solar Observatory) and the Carnegie Institution of Washington (CIW) (Mt. Wilson and Las Campanas Observatories) have damped out, and the joint use agreement of Caltech and CIW is working well. We have been fortunate to secure the services of outstanding scientists as directors of the full set of Caltech astronomical observatories: Professors Gerry Neugebauer for the Palomar Observatory, Tony Readhead for the Owens Valley Radio Observatory, and Hal Zirin for the Big Bear Solar Observatory.

Professor Bev Oke completed a new, state-of-the-art spectrometer for the 200-inch Hale Telescope at Palomar. This superb instrument uses a novel optical design, very high efficiency optical coatings, and both blue- and red-sensitive charged coupled devices (CCDs) to achieve a sensitivity two to four times higher than that achieved with similar older devices here and elsewhere.

Caltech and Berkeley radio astronomers made an important breakthrough in radio interferometry using the new mm-wavelength telescopes at Owens Valley (Caltech) and Hat Creek (UC Berkeley). Operating at the unprecedented short wavelength of 3 mm over a 300-mile baseline, they detected a compact feature in the nucleus of the powerful radio galaxy NGC 1275. Long baseline millimeter interferometry thus has been shown to be feasible as an important tool for probing the nuclei of active galaxies and quasars.

New Campus Facilities

Gravitational Wave Laboratory

Construction of an L-shaped laboratory building (bordering Central Engineering Services) to house the new 40-m x 40-m laser interferometer gravitational wave detector, under development by Professor Ronald Drever and Assistant Professor Stanley Whitcomb, has been completed. The large vacuum system necessary for the laser interferometer to achieve its desired sensitivity (10^{-15} centimeters!) has been installed. Current efforts concentrate on suspension, seismic isolation, and servo-control of the three test masses that define the geometry of the interferometer.

Astronomical Data Processing Facility

An unused vault between the Robinson and Arms laboratories, formerly known as the "morgue," has been transformed into a splendid new facility housing the computing and data processing systems used in optical and radio astronomy, including the VLBI Mark II and Block II processors operated jointly by the campus and JPL, and two VAX computers, one of which will form the nucleus of the astronomical image-processing facility under development.

Jet Propulsion Laboratory

Staffed and managed by the California Institute of Technology under operating and facilities contracts with the National Aeronautics and Space Administration.

Bruce C. Murray, Director

Some truly astounding discoveries of the Saturn system by Voyager 2 made 1981 a memorable year for JPL and the National Aeronautics and Space Administration's space-exploration program. The flight team, the Deep Space Network, and mission-support personnel carried out a near-perfect encounter while Voyager 2 was sorting out the discoveries of Voyager 1, which had rewritten the basic textbooks on the Saturnian system. Voyager 2 will go on to a 1986 encounter with Uranus and a 1989 encounter with Neptune.

As NASA's lead center for planetary exploration, JPL continued preparations for the Galileo mission to orbit and send a probe into the atmosphere of Jupiter. The Laboratory also launched an Earth-orbiting satellite in October, the Solar Mesosphere Explorer. Also under way are the Infrared Astronomical Satellite and the International Solar Polar Mission.

Two experiments from the Laboratory flew on the space shuttle *Columbia.* They were the Shuttle Imaging Radar-A and a Shuttle Multispectral Infrared Radiometer.

The last year was, however, a time of considerable uncertainty for NASA's planetary program and for JPL, due to restrictions on the NASA budget. To help keep the Laboratory a viable, working institution, a major effort has been mounted to seek substantial additional research work from the Department of Defense.

Energy and energy-conversion technology were also major endeavors during 1981. Solar thermal power conversion studies for the Department of Energy (DOE) went ahead at JPL and at the Edwards Test Station at Edwards, California. The Laboratory also is lead center for the DOE's Solar Photovoltaic Program, aimed at a cost-effective civilian solar-cell technology.

With dedication and resolve, JPL looks forward to a future of steady contributions to the nation, in space exploration, Earth-orbital missions, and national defense and energy-development programs.

Space Exploration

Voyager

Voyager 2 encountered the ringed planet Saturn in 1981 and contributed much to our knowledge of Saturn's atmosphere, magnetosphere, rings, and the ever-growing number of known satellites.

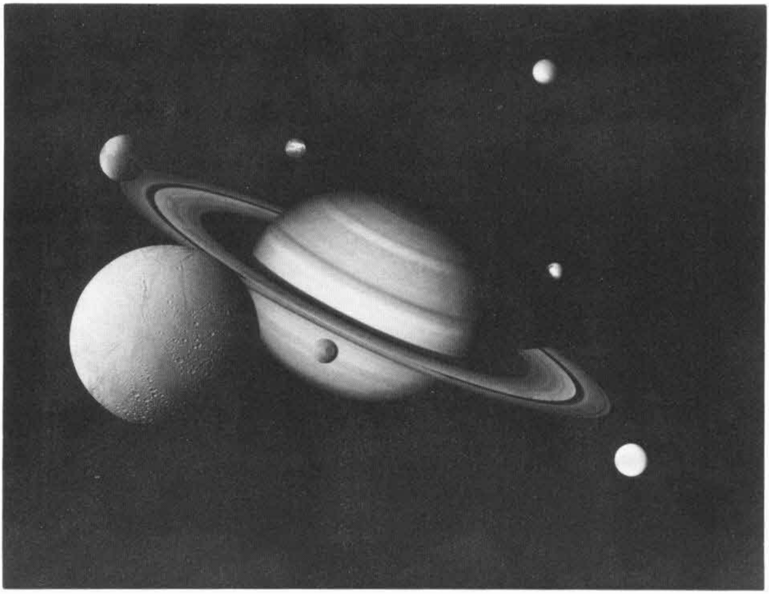
During Voyager 2's passage, the magnetosphere apparently underwent a rapid expansion and was about 70 percent larger at the time of outbound magnetopause crossings than at the time of inbound crossings. The observations may be consistent with effects of an extended magnetic tail of Jupiter; the Jovian magnetotail was detected by Voyager 2 several months before the Saturn encounter.

With the better detail available in Voyager 2 photos, Saturn's atmosphere now appears to have a number of important similarities to Jupiter's. For example, long-lived oval spots, convective clouds, and tilted stream-flows noted in Saturn's atmosphere are reminiscent of similar features on Jupiter. The more muted cloud colors of Saturn, compared with Jupiter's, are now thought to be a consequence of colder temperatures and stronger cloud mixing at Saturn, rather than an obscuration by an overlying haze.

Stellar occultations by the rings and much-higher-resolution imaging improved definition of ring features by orders of magnitude. The thousands of ringlets noted in Voyager 2 data are now seen to be the result of radial variations in the spatial density of ring particles. Much of the fine-scale structure is constantly changing as gravitational interaction with some of the inner satellites of Saturn generates density waves that spiral outward.

Voyager 2 provided photos of all 17 satellites, 11 at better resolution than was obtained by Voyager 1. Charged-particle shadowing observed by Voyager 2 indicated the presence of an 18th satellite, in about the same orbit as Mimas; further analysis of photos may reveal even more tiny satellites in the incredibly complex Saturn system.

Phoebe, Saturn's outermost satellite, is roughly spherical, has a very dark surface, and rotates about once in nine hours. Iapetus's dark leading hemisphere is uniformly blanketed with dark material that reflects only one-tenth the light reflected by material on its trailing hemisphere.



Voyagers 1 and 2 photographed Saturn, its rings, and all 17 known satellites during their encounters with the planet. This montage of individual photographs includes all major satellites known before the Voyager launches in 1977. Not included are Hyperion and Phoebe, and the eight small satellites discovered in 1980. The satellites shown are (clockwise from upper right): Titan (photo by Voyager 1), Iapetus (by Voyager 2), Tethys (by Voyager 2), Mimas (by Voyager 1), Enceladus (by Voyager 2), Dione (by Voyager 1), and Rhea (by Voyager 1). The 17 known Saturnian satellites represent a broad spectrum of bodies, which include small snowballs; a dark, asteroidal body; icy objects subjected to meteoroidal bombardment; some that have undergone substantial surface changes caused by internal geologic processes; and one giant with a massive atmosphere — Titan. Voyager 1's closest approach to Saturn occurred November 12, 1980; Voyager 2's closest approach was August 25, 1981.

Hyperion is very irregular in shape and has a darker than average surface among Saturnian satellites. The canyon on Tethys, first seen by Voyager 1, is now known to extend three-fourths of Tethys's circumference, and an enormous crater more than 350 kilometers in diameter exists on one face of Tethys. Areas of the surface of Enceladus are still undergoing change. Tidal interaction with Dione seems the most likely source of energy for the changes on Enceladus's surface, but current theoretical estimates indicate that its orbital eccentricity is too low to provide the requisite amounts of energy.

NASA has declared the Voyager mission a success, Voyagers 1 and 2 having accomplished all their planned objectives at Jupiter and Saturn. The scientific data gleaned from the four encounters exceeded expectations in both volume and significance.

A new mission has been declared for the spacecraft — the Voyager Uranus Interstellar Mission. Voyager 2 is on course for an encounter with Uranus in January 1986 and with Neptune in August 1989. Voyager 2 is en route out of the solar system on a course 35 degrees north of the ecliptic.

Galileo

Galileo is a NASA flight project planned to orbit the planet Jupiter and send an instrumented probe into the planet's atmosphere. It will be launched in 1985 aboard the space shuttle.

1981 was an event-filled year for Project Galileo. A delta-vega (for delta-V, Earth gravity assist) trajectory, in which Galileo must fly beyond the orbit of Mars, then return to Earth for its final boost to Jupiter, was chosen for the spacecraft, delaying its arrival at Jupiter until late 1989 or early 1990. The choice, dictated by the need to use NASA's inertial upper-stage booster, will decrease the number of orbits of Jupiter during the 20-month lifetime at the planet. Some redesign of the orbiter was undertaken to rejoin the probe and orbiter after the separation dictated by the conditions of a possible 1984 launch, and to adapt the spacecraft to the 1985 mission.

Systems design for the probe and orbiter were completed and critical design reviews were held in November. In addition, science and mission requirements were established and documented for the new 1985 mission.

The orbiter completed all but one subsystem critical-design review. Engineering-model hardware was completed and tested. Fabrication and flight hardware was begun on nearly all subsystems and some has been completed.

Infrared Astronomical Satellite

The Infrared Astronomical Satellite (IRAS) will carry a cryogenically cooled, 57-centimeter-aperture infrared telescope into a 900-kilometer, near-polar orbit. The international satellite will survey the sky at infrared wavelengths not observable from Earth's surface to produce an infrared sky map and a catalog that may contain several hundred thousand new infrared sources.

IRAS will contribute to the understanding of such astronomical phenomena as the origin, constitution, and replenishment of interstellar and circumstellar matter and how molecular clouds and stars are formed. IRAS will also give insight into the problem of energy balance in ionized hydrogen regions, normal galaxies, extragalactic sources, and quasistellar objects. IRAS should permit scientists to study infrared objects throughout the Milky Way.

JPL is project manager and performs the design and operation of science-data-analysis facilities. Ames Research Center developed the telescope system, the spacecraft was built in the Netherlands, and the mission-control facilities are in England.

Scientists from the United States, the United Kingdom, and the Netherlands will gather at JPL to interpret the data. The IRAS spacecraft is to be launched in late 1982 or early 1983 on a Delta launch vehicle from NASA's Western Test Range at Vandenberg Air Force Base, California.

International Solar Polar Mission

The International Solar Polar Mission (ISPM) authorized in fiscal year 1979 by Congress continues as a cooperative program between the European Space Agency (ESA) and NASA. However, as a result of decisions by NASA in late 1981 to delete the NASA spacecraft, ISPM has been reduced from a two-spacecraft mission to a single-spacecraft mission. The planned launch has been delayed from April 1985 to May 1986.

JPL will retain responsibility for managing the development of five of the scientific instruments to be flown on the ESA spacecraft. Additionally, JPL is responsible for mission design, tracking, flight operations and data records preparation and distribution.

Solar Mesosphere Explorer

The Solar Mesosphere Explorer was launched on October 6, 1981, at 4:27 a.m. (PDT), from the Western Test Range. The mission objectives are to determine the nature and magnitude of changes in mesospheric ozone densities that are the result of changes in the solar ultraviolet flux, and to determine the relationship between solar flux, ozone, and the temperature, between ozone and water vapor, between ozone and nitrogen dioxide, and between solar proton events and ozone. The four limb-scanning science instruments are collecting ozone data using both the leading and trailing limbs. The solar irradiance is being measured by the fifth instrument.

The spacecraft was developed, assembled, and tested by the Ball Aerospace Systems Division, Boulder, Colorado. The science instruments were developed, assembled, and tested by the University of Colorado's Laboratory for Atmospheric and Space Physics. University students there are the principal members of the Mission Operations Team.

Shuttle Imaging Radar-A

JPL flew the Shuttle Imaging Radar-A (SIR-A) on the second shuttle flight in November 1981. The instrument was part of the first scientific payload on the shuttle.

The SIR-A objective was to acquire radar images over a variety of geologic regions to assess the capability of spaceborne imaging radar sensors for geologic mapping. Images were acquired over a variety of regions around the world with a total coverage of ten million square kilometers. Analysis of the data over some regions is providing additional information on the surface and near-surface structure that is not available in the most recent geologic maps.

Shuttle Multispectral Infrared Radiometer
The Shuttle Multispectral Infrared Radiometer (SMIRR) also flew on the second flight of *Columbia,* November 12-14, 1981. The JPL-designed-and-built instrument obtained about 1.4 million ten-channel spectra of the land surface in a 100-mile-wide strip directly beneath the spacecraft.

The experiment was designed to obtain data in narrow spectral bands in the 0.5-2.35 micrometer region for unique identification of Earth surface materials for geologic mapping purposes. The results are important for the design of future high-spectral-resolution imaging systems and demonstration of the value of narrow-band spectroscopy from orbit.

Mission Support

The major Deep Space Network (DSN) operational support provided in 1981 was for the Voyager 2 encounter with Saturn. The network provided command and telemetry data for the entire 116-day period. High-quality radiometric data, including very long baseline interferometry data, were generated for three trajectory-correction maneuvers during the encounter period.

The network obtained about 12,000 high-quality pictures of Saturn, its rings, and satellites from a distance of about one billion miles from Earth. During the encounter, 99.7 percent of the planned photos were received (with only a small number degraded by weather) and delivered to the scientific investigators.

Differential or delta-VLBI was tested for spacecraft navigation on Voyager 2 beginning in April 1981. The technique uses antennas at all three DSN sites, alternately observing the spacecraft and a natural radio source to precisely determine spacecraft angular position. The Voyager demonstration surpassed the original accuracy goal. Delta VLBI will now be used regularly to support Voyager 2 navigation to Uranus and beyond.

The Deep Space Network continues to support all the operational spacecraft, including Pioneers 6 through 11 and the Pioneer Venus orbiter, as well as Viking Lander 1 (renamed the Thomas A. Mutch Memorial Station) and Helios 1.

In addition, the Networks Consolidation Program is merging several ground stations managed by Goddard Space Flight Center into the Deep Space Network. The consolidated network will assume support for several highly elliptical, Earth-orbiting spacecraft formerly supported by GSFC, in addition to continued support to JPL's traditional deep-space missions.

Space Science and Applications

Telecommunication Science
A number of significant radio-astronomy experiments were

supported by the DSN during the past year. Observations of the energetic galactic object SS-433 continued, and of the twin quasar 0957+561A,B. The multiple quasar images are believed to be caused by a nearby galaxy refocusing rays from a single quasar. The K-band maser amplifier, used as the low-noise amplifier in a microwave spectroscope, led to the discovery of two new water-vapor maser sources and six new ammonia sources.

Radar observations of the asteroid Apollo, which passed within 8.4 million kilometers of Earth in November 1980, resulted in 1981 in estimating the radius of the tiny body at 600 meters and its rotation period at three hours.

Radar observations of Saturn's rings were made during the past year with the ring plane only 6 degrees from being edge-on. The normalized radar cross section did not drop appreciably with angle. The result, coupled with earlier data and computer scattering simulations conducted during 1981, shows that the ring particles must be larger than the wavelength — on the order of a meter or larger.

The JPL Geodynamics Program has continued its extensive vector baseline determination at a number of sites in southern California. Baseline changes are expected to shed some light on earthquake mechanisms. The primary instrumentation involves radio interferometry at microwave frequencies. The Laboratory has continued to upgrade the instruments and has completed the design of an operational unit.

Photochemistry of Venus and Earth

Some interesting comparisons with the Earth's atmospheric photochemistry have come to light as a result of laboratory and modeling studies of the Venus atmosphere.

A long-standing puzzle to planetary aeronomers is the question of why CO_2 in the Venus atmosphere is not significantly decomposed to CO and O_2 by the action of sunlight. Evidence now suggests that trace constituents in the Venus atmosphere play a fundamental role in this regard. Further, the mechanisms by which the processes operate bear a close resemblance to those of trace species in the terrestrial atmosphere.

Discovery of Apollo Asteroid 1981 VA

A new Apollo asteroid was discovered by JPL astronomers on November 3-4, 1981, using the 1.2 meter Palomar Schmidt telescope. The discovery was made during the course of an ongoing survey of high-inclination asteroids.

Utilitarian Projects

JPL continued research, systems management, and other technical innovative activities in defense systems, solar energy, utility systems, energy conservation, transportation, coal, and biomedical technology.

Autonomous Spacecraft Project

Work continued on a new project for the Air Force Space Division to achieve, by the end of the decade, a high degree of defense satellite autonomy (independence from ground stations). The implementation of certain autonomy features on planetary spacecraft, necessitated by the long two-way communication times, had resulted in the development of a unique set of JPL skills with direct application to this national defense need.

Future efforts will include compilation of JPL's autonomy experience into a document for Air Force/industrial use, and design, development, and demonstration of a prototype fault-tolerant, computer-based spacecraft subsystem capable of implementing ground-based routine maintenance and fault-correction functions on future defense satellites.

Mobile Automated Field Instrumentation System (MAFIS)

The Mobile Automated Field Instrumentation System is under development by JPL for the U.S. Army. MAFIS is a transportable instrumentation system that will enable simulated battlefield test exercises to be monitored and evaluated.

A system preliminary design review was completed in 1981 and a request for proposals was issued to industry late in the year to produce 200 univeral field elements and a command and control center; the position location network will be produced by JPL. A three-month test was conducted during 1981 of a medium-frequency, differential-phase measurement method for position location.

Another major accomplishment during the year was completion of design and development of an engineering model of a helicopter laser platform. A test was conducted at Fort Hood in May to demonstrate the feasibility of using the platform as part of an air-to-ground engagement simulation system.

Salton Sea Solar Pond Experiment

A design study for salt-gradient solar pond electric power plants in the California Salton Sea has shown the concept to be technically, environmentally, and economically feasible. A five-megawatt proof-of-concept experiment is being designed for installation in the mid-1980s. A salt-gradient solar pond is a body of water that stratifies heavy brine to the bottom and low-salinity water on the surface. A controlled non-convecting center zone prevents lower brines from mixing with the surface. Large quantities of thermal energy are captured and stored in the lower brines, where working temperatures of 80°C have been demonstrated.

Solar Thermal Power Systems

The Solar Thermal Power Systems Project is developing parabolic dish modules for producing electricity. An 11-meter-diameter dish produces 20-25 kilowatts of electricity using a receiver/heat engine/alternator power-conversion assembly (PCA) at the focus of the dish. The Stirling cycle PCA mounted on an 11-meter JPL solar test bed concentrator fed about 20 kilowatts of electricity into the Southern California Edison Company's grid.

Automated Cervical-Cancer Screening
JPL, in collaboration with UCLA pathologists, has completed a four-year feasibility study of automated analysis of the Pap-smear specimen. A computerized microscope system found and measured 10,000 cells and classified each as either normal or abnormal. The results were compared with the pathologist's diagnosis to demonstrate the accuracy of the system, and a cost-benefit analysis indicates that significant cost savings are possible with automation. JPL will begin development of a clinical prototype in 1982 that will employ a unique JPL-developed multiple-microprocessor computer system to attain processing speeds of up to 1,000 cells a minute.

Photovoltaics
A fledgling photovoltaic industry has been established, stimulated to a large extent by the success of the DOE-sponsored Flat-plate Solar Array Project (formerly the Low-cost Solar Array Project). For seven years, technology advancements, sponsored by the project, have increased module reliability and permitted module manufacturing costs to be reduced sufficiently so the photovoltaics are cost-effective for small, remote applications. The technology achievements covering all aspects of module manufacturing, from raw materials through modules, are continuing to show promise that in the future photovoltaics can be practical for residential and other large-scale uses.

Land Mobile Satellite System
JPL and the Boeing Company performed a configuration study of a land mobile satellite system spacecraft based on a preliminary system designed by JPL. The spacecraft, in geostationary orbit, will be capable of relaying radio messages to hundreds of thousands of land mobile units throughout the continental United States. Its intended application ranges from emergency medical cases to disaster relief, from law enforcement to truck dispatch. It would also provide two-way mobile telephone channels for commercial use in rural areas not adequately served by terrestrial systems.

Tunable Lasers for Remote-Sensing Applications
A scanning, narrow-spectral-bandwidth, ultraviolet xenon-chloride (XeCl) excimer oscillator-amplifier laser system was developed. The system was used to detect hydroxyl radicals produced by laser-excited fluorescence. The laser system is one-third the size of, and much less complex than, conventional

dye-laser sources now being used for atmospheric measurements of species such as hydroxyl radicals, ozone, sulfur dioxide, and nitric oxide.

Sensor Cooling
During the past few years there has been a considerable growth in the use of spaceborne sensors that require cooling to maintain them at cryogenic temperatures.

The major problem in achieving cryogenic temperatures with passive radiator systems is in thermally isolating the system from the spacecraft and the external environment. A 68cm x 40cm thermal engineering model has been developed and tested. A novel arrangement of highly specular and reflective lightweight radiation shields surrounds and actively isolates the cold, black radiating plate from the hot spacecraft environment.

The test results and an analytical model indicate that the advanced radiator can be 50 percent smaller and lighter, have up to 50 times greater cooling capacity, and can achieve temperatures of 30° or 40° lower than conventional passive coolers.

Detector Arrays for Infrared Imaging
Development of solid-state infrared detector arrays may provide a new capability for future planetary and terrestrial missions. Infrared imaging offers the possibility of detecting and discriminating between the constituents of planetary atmospheres and mapping the locations of geologic structures. Such imaging is of great interest for both planetary and Earth-resource missions.

An array of 128 indium antimonide photodiodes has been coupled to a silicon multiplexer, capitalizing on hybrid fabrication techniques and resulting in very low readout noise. The device achieves the inherent, high sensitivity of the diodes in an array format compatible with high-resolution imaging. It operates at temperatures from 55 to 80 Kelvin and at readout rates up to 1 million samples per second. The line-array imager will be placed in a spectrometer for use at the 200-inch Hale Telescope.

New Electromechanical Actuators
A new class of general-purpose electromechanical actuators has been developed for the Galileo spacecraft. The actuators are called dual drives. They provide two independent electromechanical drive trains that combine at a common output shaft. Both trains are continuously engaged and are independently operable.

Discretionary Research Funds
The memorandum of understanding between NASA and Caltech provides for two discretionary funds — a JPL Director's Discretionary Fund supplied entirely by NASA, and the Caltech President's Fund to which NASA contributes half on a matching

basis. The key objectives of the funds are to support innovative efforts and encourage collaborative work between JPL staff and the faculty and students of Caltech and other universities.

This year the Director's Discretionary Fund and the President's Fund each initiated 15 tasks. Other schools involved besides Caltech were the University of Arizona, University of Rochester, Duke University, Pennsylvania State University, University of Minnesota, Harvard Medical School, and the Berkeley, Los Angeles, and Riverside campuses of the University of California.

Environmental Quality Laboratory

Norman H. Brooks, Director

As EQL started its second decade, the interest of the federal government in sponsoring environmental and energy policy research was at a low ebb compared to the high enthusiasm at the beginning of the '70s. However, society must continue to seek solutions to the vexing problems of balance: How much should government regulate polluting activities in order to protect the environment? What actions should government take to ensure adequate future supplies of critical resources? What priorities do government programs for environmental protection and resource management have when tax money is scarce at all levels of government?

While political objectives may shift sharply every few years, university research organizations like EQL must continue to pursue some long-term research and educational objectives that will help government and industry achieve well-reasoned balances. It is not EQL's role, of course, to advocate what *should* be done, but only to do research on policy alternatives and their various implications, and, in addition, to provide research opportunities as part of the training of selected predoctoral students and postdoctoral fellows in disciplines related to these problems.

EQL has been able to withstand the downturn of government support because of generous increases in private gifts, coupled with moderate reductions in program and staff. For 1980-81, the actual dollar rate of expenditure was nearly the same as 1972-73, but inflation has cut the size of the program and staff that can be supported to less than half of what it was then. A top priority for EQL is to obtain more stable sources of funds for the future (such as from an endowment).

For 1980-81, EQL's support was distributed as follows: gifts for general support from individuals and corporations (Texaco, General Motors, and General Electric), 14 percent; gifts for specific research program areas (Andrew W. Mellon Foundation, Exxon, Atlantic Richfield, Union Oil, Bechtel), 40 percent; Caltech funds, 4 percent; and government-sponsored research, 42 percent (federal government, 14 percent; state government, 24 percent; and local government, 4 percent).

By the end of the year, the research staff included eight full-time researchers working with twelve professors, ten graduate students, and two consultants, all doing part-time EQL work. The full-time support staff consists of six people, down from eight a year earlier. Three new postdoctoral researchers joined our ranks during the year — a chemist, an engineer, and an economist. No new professors were hired in areas directly related to EQL , but an assistant professor in applied economics is currently being sought.

In the following sections, selected current research projects are described. The focus of EQL's research continues to be multi-disciplinary policy-oriented studies in four closely related program areas: air resources, water resources, hazardous substances, and energy. A publication list is available on request.

The Environmental Quality Laboratory's multi-disciplinary studies help determine policy alternatives in several areas, including air resources. Here graduate student Andrew Gray installs an air sampling station for atmospheric carbon particles on the roof of a Los Angeles building, part of a network of stations throughout the area, for a research project headed by Assistant Professor Glen Cass.

Atmospheric Carbon Particles — How Do You Control Soot?

Some combustion sources, especially diesel engines, emit tiny carbon particles that are believed to be responsible for a significant fraction of atmospheric visibility degradation. Assistant Professor Glen Cass, with graduate student H. Andrew Gray, is continuing research on measurement and control of these particles, with major support from the California Air Resources Board starting in fiscal year 1982.

His earlier work indicated the need for obtaining better data on existing atmospheric concentrations and size distributions of carbon-containing particles before possible control strategies could be properly analyzed. The next step was the installation early in 1982 of a special sampling network of ten stations throughout the Los Angeles basin to collect these particles for analysis of quantity, sizes, and chemical composition. The sampling instruments and enclosures (see photo) were designed, built, and installed by Cass, Gray, and the personnel of the shops in the Keck Laboratory. Data from the monitoring network will be used to verify air-quality modeling calculations relating atmospheric carbon particle concentrations to the emission sources responsible for this pollution problem.

Modeling of Photochemical Air Pollutants — Smog Concocted by a Computer

Urban air pollution is a problem that is both pervasive and difficult to control. Professor John Seinfeld and senior research engineers Gregory McRae and James Tilden have developed advanced computer-modeling techniques for accurately predicting the formation and transport of photochemical oxidants. These tools are now being used by government agencies in the design of emission controls for smoggy regions like Los Angeles. Graduate student Armistead Russell has extended the basic photochemical model to study the production of particulate nitrates, as part of a research project with McRae, Seinfeld, and Cass. These nitrate-containing pollutants impair visibility and are an important component of acid rain. Last year further research refined the analysis of atmospheric photochemistry and dispersion of pollutants from large point sources (like power plants), and utilized JPL's image-processing techniques for compactly displaying computer results in the form of smog maps that change as the day progresses.

Marketable Permits to Emit Air Pollutants — Licenses to Pollute?

Regulating air pollution is commonly achieved by setting control standards for each emissions source. To reduce abatement cost and red tape, several alternatives to this approach have been studied. Under a research contract from the California Air Resources Board, Professor Roger Noll, Cass, and research economist Robert Hahn have designed a workable scheme of marketable permits to emit air pollutants, using sulfur oxides in the Los Angeles basin as a model. Under this plan a market would be organized so that rights to emit one or several pollutants can be bought and sold.

This approach is attractive because it provides flexibility and creates incentives for individual plant managers to implement control measures that are cost-effective for both the plant and society as a whole. Plants will have an incentive to control emissions whenever the cost of control is less than the price of a permit. To date EQL has provided useful information on the expected price of permits, and current work is dealing with special problems of implementation, such as how the transition could be made from the present standards-based regulation to the new marketable-permits approach.

Energy Developments and Water Use in the Upper Colorado River Basin — Is There Enough Water?

Since energy projects consume water, future development of such projects is a matter of special concern in water-short areas, like the upper basin of the Colorado River (lying in parts of Utah, Wyoming, Colorado, and New Mexico). Senior research engineer Morton Isaacson has critically evaluated the water needed per unit of energy produced for various types of developments including coal-fired electric power plants, coal export by slurry pipeline, coal gasification, and oil-shale processing. He considered two sets of values for use: one for normal good practice, and the other for the lowest practical use rates based on extensive measures for conservation and recycling.

Using various possible energy development scenarios, he was able to predict total water needs and compare them to the other demands and the naturally variable supply to meet these demands. On the average the upper basin states have an additional 1.8 million acre-feet (MAF) available for development. If 1.0 MAF is allocated to energy projects and it is consumed at normal use factors, it would be sufficient to support production of seven quads per year (equivalent to nearly four million barrels of oil per day or about one-tenth of current U.S. consumption). With more stringent measures for conservation and reuse of water, up to about 20 quads could be produced, but no additional water would be available for non-energy uses. In both cases, additional water transport and storage works would be needed, along with some adjustment or transfer of water rights, including provisions for allocating occasional shortages. Required water deliveries to the lower basin states of California, Arizona, and Nevada could be maintained in all but a very few percent of the years. Thus, despite many statements to the contrary, there is, *hydrologically* speaking, enough water to support a significant increase in the energy-processing industries in the upper Colorado River basin.

In a new study (starting in 1981-82), Professor James Quirk and Katsuaki Terasawa, an economist at JPL, will start examining the economics of the oil-shale industry, in particular the problems of cost estimation in this new industry and regional socio-economic dislocations due to industrialization of remote rural areas.

Deep-Ocean Disposal of Sewage Sludge — Does It Really Disappear?

As a continuation of many years of research on ocean discharges of wastewater and digested sewage sludge, Professor Brooks and Senior Research Associate Robert Koh have undertaken a planning study for a possible research and demonstration project involving pipeline discharge of digested sewage sludge into the ocean at about 1000-foot depth at a distance of seven miles off the Orange County coast. (The sponsors of the planning study are the Orange County Sanitation Districts and the National Oceanic and Atmospheric Administration.)

The federal government is reconsidering its ban on ocean dumping or discharge of sludge. Coastal agencies (like the Orange County Sanitation Districts) are finding land disposal increasingly expensive and possibly hazardous to the quality of groundwater. If this Orange County sludge-discharge experiment proceeds, it will allow scientists from several institutions to participate in a well-planned study of the fates and effects of pollutants in the deep ocean. The results will allow engineers and regulators to design suitable control technologies if the ocean discharge ban is lifted.

Trace Contaminants in the Environment — How Hazardous Are They and What Are the Tradeoffs?

Under a three-year grant from the Andrew W. Mellon Foundation, EQL researchers have been studying the science, engineering, and social science of a variety of problems related to our overall control of the dispersion of hazardous substances in the air and water environment. Very small amounts of numerous toxic chemicals dispersed in the environment (which a decade ago were often believed to be insignificant) are now suspected of being important carcinogens. Controls for trace contaminants must almost always be imposed at the source, or point of use (e.g., not downstream in a large municipal sewer system).

The environmental engineers at Caltech are learning more about problems such as the distribution and behavior of these pollutants in surface water, groundwater, the ocean, the atmosphere, and indoor air. On the other hand, R. Talbot Page, senior research associate in economics, is examining the broader issue of regulatory strategies. There are about 74,000 chemicals now in commercial use, and 500 to 1000 more are being added each year. The current strategy of the Environmental Protection Agency (as required by the Toxic Substances Control Act) is essentially an exhaustive one-by-one analysis and decision-making process, which is clearly incapable of handling the flood of new chemicals, in addition to the existing ones. Consequently, although the law appears stringent, there is no way it can be administered to provide the intended environmental protection. Page and his associates are examining alternative approaches to regulation that emphasize the control of overall risk, taking into account the fact that the risk itself is uncertain for most chemicals.

Caltech Libraries

Johanna E. Tallman, Director

Caltech Libraries continued their expansion of resources, services, and equipment in 1981. Nearly 900 searches of on-line bibliographic data bases were provided for a wide variety of users, an increase of 60 percent over the previous year. A new word processor was used to maintain such lists as reserve books, wants, new books, and updates of the Caltech serials list. The library system has 15 terminals, including the word processor, printers, and a micro-computer.

Microform equipment was upgraded, and there are now 34 microform readers, printers, projectors, and a duplicator. Microform holdings now total 405,000 items, representing 230,390 bibliographic units.

Special efforts were made to speed up the cataloging of books from the Dewey to the Library of Congress system. This project provided the opportunity to evaluate the books to be reclassified for retention, discard, or transfer to another collection. Putting the records in machine readable form for future on-line catalog and circulation uses, the recataloging provided better and more compatible classification numbers and updated subject headings.

Cumulative indexes to *Science Citation Index, Social Sciences Citation Index,* and *INSPEC* (covering physics, computing, electric, and electronics literature) were obtained through special funds. These made searching for specific references more efficient for both staff and users.

A recently acquired set of microfiche brought together 100,000 pages of the descriptive catalogs and trade lists from 2,000 publishers in 18 British and European countries, providing current and accurate bibliographic and cost information. The libraries already have a similar set for American publishers.

The total number of hard-copy volumes in the Caltech Libraries for which the catalog department maintains statistics is 355,921, with another 31,549 volumes in microform. The number of periodical titles currently received is 5,457, and the number of bound periodicals totals 144,182, plus 8,242 volumes in microform.

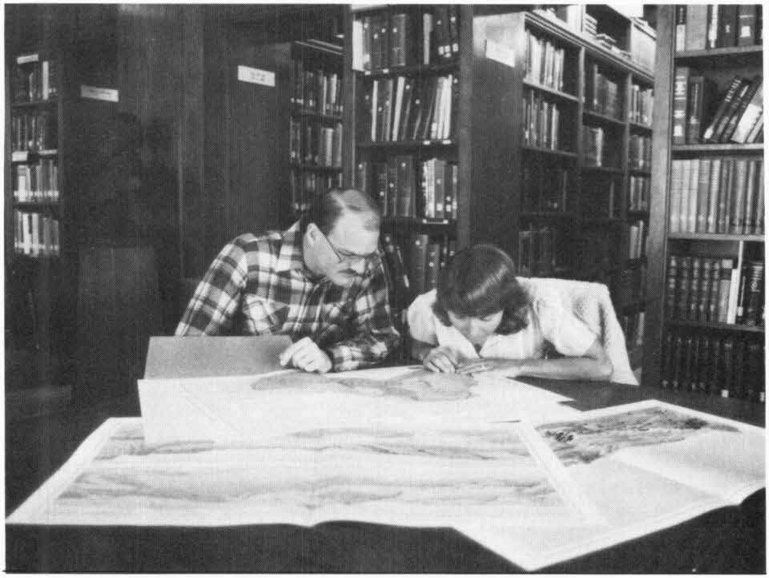
January 1981 saw the implementation of the second edition of the Anglo-American Cataloging Rules. These rules were compiled by representatives of the national libraries of the English-speaking world in an effort to standardize the forms of personal and corporate names as used in library catalogs. The changes in AACR have a major effect not only on catalog use by the libraries' public but also on the catalogs' maintenance by libraries' staff. In addition, the catalog department did bibliographic operations on 13,406 items, a 40 percent increase over the previous year.

The serials cataloging department has continued to catalog all of our serial holdings with complete sets of cataloging information. Since October 1975 the staff has cataloged 8,747 titles, resulting in a catalog of approximately 30,000 cards. This department also indexes current conference proceedings published in journals received by Caltech libraries. As these proceedings become cited in the literature, our quick access through this catalog proves to be a great timesaver in locating the published sources.

A total of $690,520 was spent on books, periodical subscriptions, continuations, and binding for the libraries that the Millikan Library staff services, an increase of 12.5 percent. Of this amount, 62.6 percent was for periodicals, 17.7 percent for books, 13.2 percent for continuations, and only 6.5 percent for binding. This reflects the high cost of periodicals, consuming more and more of available funds. In 1972-73 the percentages were: 49.8 for periodicals, 30.2 for books, 9.4 for continuations, and 10.6 for binding.

Our requests to other libraries to borrow material increased 34 percent, to 3,576, reflecting both a lack of resources in-house and a greater variety of publications requested by our diverse faculty. Requests from other libraries to borrow from Caltech totaled 13,154, with 59.4 percent coming from Industrial Associates company libraries, and 20.7 percent from JPL. We were able to supply 78.5 percent.

Along with insufficient acquisition funds, the libraries are suffering from lack of space. The Millikan Library is currently reabsorbing the material stored during the last decade in Gates basement. The release of the third floor in the next few years will be insufficient to accommodate growth, since the usable floor space is actually quite small. Other campus libraries are also bulging.



Departmental libraries throughout campus contain a large portion of the system's 356,000 volumes and 144,000 bound periodicals, plus current periodicals and additional material on microform. Many of these libraries also house specialized collections, such as Geological and Planetary Sciences, which provides access to a large collection of maps.

The Archives staff has combined the "History of Caltech" project and the oral history program by interviewing persons whose Caltech connections go back many years. They included Earl Mendenhall, member of the class of 1918; Harvey House, class of 1919; and Herbert Hahn, trustee emeritus. President emeritus Lee A. DuBridge and former humanities head Hallett Smith were also interviewed. The Archives collections are also exceeding available space as additional valuable materials are received.

Industrial Relations Center

Victor V. Veysey, Director

Since its establishment in 1939, the Industrial Relations Center has pursued several objectives:
1. Instructing Caltech students in business economics and management, with particular emphasis on making the best use of human resources;
2. Providing continuing educational and developmental opportunities for those who advance through the ranks of management, with special emphasis on technical professionals and high technology companies;
3. Creating educational forums where business leaders and executives can examine their roles and missions within their organizations and in American society;
4. Discovering new knowledge of, and insights into, management of human resources through research, studies, and surveys; and
5. Collecting in the Management Library the best reference materials for users on and off campus.

Management of Technical Professionals

Managing scientists, engineers, and other technical professionals is of great interest to the Center because many Caltech graduates are in jobs at important management or executive levels. An intensive technical background supplemented by a commitment to getting things done provides a strong basis for success in management, provided sensitivities and skills in human relationships are also developed. The Center offers opportunities for Caltech students to develop managerial competence.

For engineers who are encountering the difficult and perplexing problems of management, the Center has developed its engineering management program in cooperation with a dozen companies that employ large numbers of engineers. Completion of the program requires 120 hours of instruction in designated study areas, and the Center awards a certificate for satisfactory achievement. In the two years this program has been in operation, nearly a dozen engineers have received the certificate while continuing their regular work, and a number of others will soon complete the program.

Improvement of Productivity

Management and labor in America will be concerned with the improvement of productivity for the next decade. Fortuitously, the Center identified this problem six years ago and established a productivity improvement group to explore, through case studies, practices and programs that have enhanced productivity as measured in net profits. Through this group, the Center has presented 21 conferences on campus to ever increasing audiences of managers.

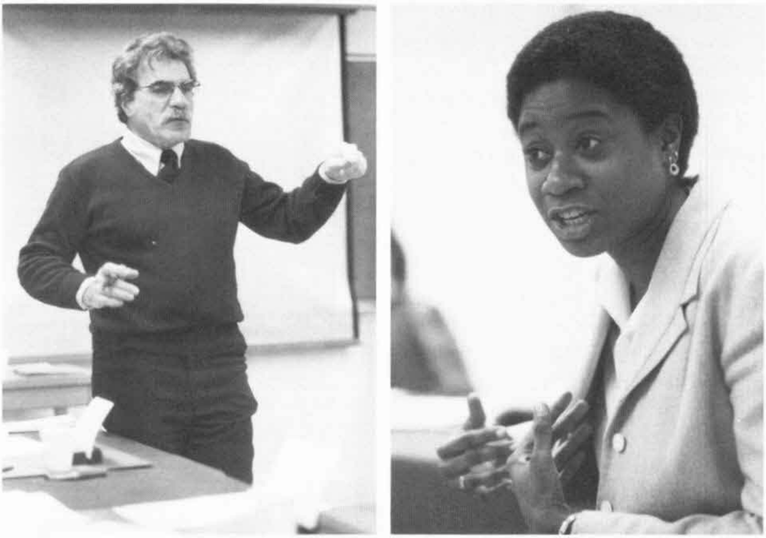
While some declining productivity is a result of national policies on money and taxation, and of national shortfalls in areas such as savings, investment in new plant, and research and development, there is reason to believe that much can be done through skillful management, more effective incentives, and better understanding of the needs and aspirations of employees.

The Center is planning to expand its productivity efforts by integrating library resources with the productivity improvement group, and by adding research and study, as well as specific seminars, and publications. These new functions, operating as a productivity section within the Industrial Relations Center, will be responsive to the national concerns of industry.

Because attention is now focused on the remarkable success Japanese industry is achieving in improving productivity, the Center has planned research, studies, seminars, and publications on this topic. Tentative conclusions include the possibility of adopting some Japanese management techniques in the United States, and the impossibility of adopting others because of great cultural dissimilarities.

Management Development

Concerns about declining levels of productivity make it clear that the management of American business and industry will bear the major burden of reversing trends that have been long in the making. Indeed, the effective management of human resources is generally believed to hold the potential for a major share of the needed productivity turn-around. New and untrained employees entering the labor markets in large numbers, more specialized work, and new attitudes and expectations of employees all have contributed to demands for managers with greater abilities and sensitivities.



One of the seminars in the IRC's Management Development Program was the two-day workshop "Handling People Problems Face to Face" led by Joe Barnes, left, from the Atlantic Richfield Company.

In recent years the Center has also stressed management development in the manifold requirements of federal and state laws and regulations governing employee relations, the use of computer technology by management, and the concerns of middle and top level management.

The Center has developed four different types of management development programs:

1. Seminars offered to qualified managers from a cross-section of business and industry, e.g., vocal communications, Equal Employment Opportunity law, interpersonal skills, and data base management.
2. Larger conferences on current problems, for example a conference on combining the best of Japanese and U.S. management, the popular Peter Drucker-Reed Powell top management seminar, and the annual conference on employee assistance programs.
3. Ongoing groups of professionals with a common concern, which meet periodically, such as The Executive Forum, Managerial Compensation, Executive Development, and a newly established group — Equal Employment Opportunity/ Affirmative Action.
4. Programs for specific industry groups, including Building Owners and Managers Association, Steel Service Center Institute, and in-company management development programs.

During 1981 Valerie Hood joined the Center to direct the programs in management development. Under her supervision, new offerings are being readied, additional seminar instructors have been recruited, and a catalog developed.

Research and Studies

Understanding employee attitudes is essential to solving the productivity problem. The techniques for measuring employee opinions were a pioneering project of the Center starting in 1944, and they are being used with growing frequency both by the Center and by others to strengthen management in its efforts to achieve higher productivity.

In addition to conducting several polls of employee opinions, during 1981 the Center researched and developed an "instant poll" technique, which will make possible rapid and low-cost polling of employee opinions to meet the need for current measurement of employee reactions to policies, practices and events affecting work relationships. With added study, it may become possible to identify the factors conducive to high motivation and, consequently, enhanced productivity.

Isabella Kierkowska, Mary MacKintosh, and Giles Hall have, with help from all the staff, updated and revised the Center's "Manual for Making Employee Opinion Polls."

The Management Library

Research, service to management, and dissemination of information are all dependent on the knowledge and experience accumulated in the Management Library. This feature has attracted serious scholars from many nations to pursue advanced projects. This year the library acquired computer terminal data base access. Through DIALOG, *New York Times*, and other data bases, hundreds of thousands of articles can be reviewed, thus speeding research and information searches.

Faculty

Changes in the Faculty, 1980-81 *

ADMINISTRATIVE OFFICERS

J. F. Benton, Executive Officer for the Humanities
M. H. Cohen, Executive Officer for Astronomy
G. C. Fox, Executive Officer for Physics
H. C. Martel, Executive Officer for Electrical Engineering
J. J. Morgan, Acting Dean of Graduate Studies
G. Neugebauer, Director, Palomar Observatory
T. G. Phillips, Associate Director, Owens Valley Radio Observatory
A. C. S. Readhead, Director, Owens Valley Radio Observatory
E. M. Shoemaker, Distinguished Visiting Scientist at the Jet Propulsion Laboratory

PROMOTIONS

To Professor Emeritus

J. F. Bonner, Professor of Biology, Emeritus
L. Davis, Jr., Professor of Theoretical Physics, Emeritus
M. Hall, Jr., IBM Professor of Mathematics, Emeritus
G. W. Housner, Carl F Braun Professor of Engineering, Emeritus
D. E. Hudson, Professor of Mechanical Engineering and Applied Mechanics, Emeritus
P. A. Lagerstrom, Professor of Applied Mathematics, Emeritus
R. W. Paul, Edward S. Harkness Professor of History, Emeritus
W. D. Rannie, Robert H. Goddard Professor of Jet Propulsion and Professor of Mechanical Engineering, Emeritus
J. Todd, Professor of Mathematics, Emeritus
R. L. Walker, Professor of Physics, Emeritus

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*This report covers the period from October 1, 1980, through December 31, 1981.

To Named Professorship
L. E. Davis, Mary Stillman Harkness Professor of Social Science
P. Goldreich, Lee A. DuBridge Professor of Astrophysics and Planetary Physics
H. B. Gray, Arnold O. Beckman Professor of Chemistry
F. E. Marble, Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering
W. L. W. Sargent, Ira S. Bowen Professor of Astronomy
M. Schmidt, Institute Professor of Astronomy
H. P. Taylor, Robert P. Sharp Professor of Geology
W. H. Weinberg, Chevron Professor of Chemical Engineering Related to Energy; Professor of Chemical Engineering and Chemical Physics

To Professor
A. S. Kechris, Professor of Mathematics
S. E. Koonin, Professor of Physics
A. C. S. Readhead, Professor of Radio Astronomy

To Associate Professor
J. P. Brockes, Associate Professor of Biology
P. E. Dimotakis, Associate Professor of Aeronautics and Applied Physics
R. C. Flagan, Associate Professor of Environmental Engineering Science
E. Lazarides, Associate Professor of Biology
J. B. Minster, Associate Professor of Geophysics

To Assistant Professor
K. C. Janda, Assistant Professor of Chemistry

To Senior Research Associate
R. J. Britten, Distinguished Carnegie Senior Research Associate in Biology
R. A. Mewaldt, Senior Research Associate in Physics
B. T. Soifer, Senior Research Associate in Physics

To Senior Research Fellow
J. W. Bieber, Senior Research Fellow in Physics
V. A. Gerard, Senior Research Fellow in Environmental Engineering Science
C. R. Masson, Senior Research Fellow in Radio Astronomy
C. A. Swarts, Senior Research Fellow in Applied Physics

NEW APPOINTMENTS
Named Professor
J. J. McGann, Doris and Henry Dreyfuss Professor of the Humanities

Professors
G. H. Kramer, Professor of Political Science
B. Simon, Professor of Mathematics and Theoretical Physics

Assistant Professors
J. L. Beck, Assistant Professor of Civil Engineering
R. E. Bryant, Assistant Professor of Computer Science
R. W. Clayton, Assistant Professor of Exploration Geophysics
E. J. Green, Assistant Professor of Economics
M. B. Kennedy, Assistant Professor of Biology

J. L. Kirschvink, Assistant Professor of Geobiology
J. Lee, Assistant Professor of History
J. M. LoSecco, Assistant Professor of Physics
R. D. McKeown, Assistant Professor of Physics
C. S. Parker, Assistant Professor of Chemical Biology
B. Smith, Assistant Professor of Mathematics
Q. H. Vuong, Assistant Professor of Economics
M. M. Ward, Assistant Professor of Art History
B. J. Wold, Assistant Professor of Biology

Instructors
W. L. Craig, Bateman Research Instructor in Mathematics
M. Gitik, Bateman Research Instructor in Mathematics
J. L. Hafner, Bateman Research Instructor in Mathematics
P. L. Jay, Instructor in Literature
W. D. Kamphoefner, Mellon Postdoctoral Instructor in History
S. A. Keefe, Mellon Postdoctoral Instructor in History
M. J. McGuinness, Instructor in Applied Mathematics
T. M. Porter, Mellon Postdoctoral Instructor in History
J. W. Walker, Bateman Research Instructor in Mathematics

Senior Research Fellows
C. W. Readhead, Senior Research Fellow in Biology
I. Vicente-Sandoval, Senior Research Fellow in Biology
S. Zweben, Senior Research Fellow in Applied Physics

Faculty Associate
I.-J. Sackmann, Faculty Associate in Physics

Sherman Fairchild Distinguished Scholars
Philip W. Anderson, Consulting Director of Physics Research, Bell Laboratories; Joseph Henry Professor of Physics, Princeton University
Garrett Birkhoff, Putnam Professor of Pure and Applied Mathematics, Harvard University
Donald J. Brown, Professor of Economics, Staff Member, Cowles Foundation for Research in Economics, Yale University
George F. Carrier, T. Jefferson Coolidge Professor of Applied Mathematics, Harvard University
Robert G. Coleman, Research Geologist, U.S. Geological Survey
James Franklin Crow, Professor of Genetics and Medical Genetics, The University of Wisconsin
Malcolm L. H. Green, Professor of Inorganic Chemistry, Balliol College, University of Oxford
Marcus Grisaru, Professor of Physics, Brandeis University
James A. Ibers, Professor of Chemistry, Northwestern University
Hiroshi Inose, Professor of Electronic Engineering, University of Tokyo
Vladimir I. Keilis-Borok, Professor, Institute of the Physics of the Earth, Academy of Sciences, Moscow; Head, Department of Method of Interpretation
Kenneth I. Kellermann, Staff Member, National Radio Astronomy Observatory, Green Bank
John J. Lambe, Principal Staff Scientist, Ford Motor Company, Dearborn
Christopher McKee, Professor of Physics and Astronomy, University of California

Bohdan Paczynski, Professor, Copernicus Institute of Astronomy, Polish Academy of Sciences
Israel Pecht, Jacques Mimran Professor of Chemical Immunology, The Weizmann Institute of Science
Obaid Siddiqi, Professor and Head, Molecular Biology Unit, Tata Institute of Fundamental Research
Gilbert Strang, Professor of Mathematics, Massachusetts Institute of Technology
Lynn R. Sykes, Professor of Geology, Columbia University; Head of Seismology Group, Lamont-Doherty Geological Observatory
Gerard 't Hooft, Professor, Institute for Theoretical Physics, Utrecht

Visiting Professors
C. D. Aliprantis (Mathematics) Professor of Mathematics, Indiana University-Purdue University at Indianapolis
D. Gorenstein (Mathematics) Professor of Mathematics, Rutgers University
T. E. Madey (Chemical Engineering) Deputy Chief and Physicist, Surface Science Division, National Bureau of Standards
S. Meshkov (Physics) Physicist, National Bureau of Standards
S. Ramo (Management Science) Director, TRW Inc.; Chairman of the Board, The TRW-Fujitsu Company
C. H. Sibley (Biology) Associate Professor of Biology, University of Washington
V. L. Telegdi (Physics) Enrico Fermi Distinguished Service Professor, The University of Chicago
A. Varma (Chemical Engineering) Professor of Chemical Engineering, University of Notre Dame
J. K. Watson (Electrical Engineering) Professor of Electrical Engineering, University of Florida

Visiting Associate Professors
T. V. Johnson (Planetary Science) Group Supervisor, Optical Astronomy Group, Planetary Atmospheres Section, Jet Propulsion Laboratory
D. L. Norton (Geology) Associate Professor of Geology, University of Arizona
S. W. Salant (Economics) Industry Analysis, Bureau of Economics, Federal Trade Commission
S. D. Smith (Mathematics) Associate Professor of Mathematics, The University of Chicago
J. B. Minster (Geophysics) Program Manager, Theoretical Geophysics, Systems Science and Software, Inc.

Visiting Assistant Professors
J. E. Avron (Theoretical Physics) Assistant Professor of Mathematics, Princeton University
A. J. Martin (Computer Science) Research Scientist, Philips Research Laboratories, Eindhoven, the Netherlands
A. L. Walton (Economics) Senior Economist, Jet Propulsion Laboratory

The 743 faculty members, including professorial, research, and visiting faculty, garnered honors this year that included a Nobel Prize, four new memberships in the National Academy of Sciences (for a total of 48), and one in the National Academy of Engineering (making 27).

TERMINATIONS
R. E. Forsythe, Assistant Professor of Economics
G. P. Garmire, Professor of Physics
L. Hesselink, Senior Research Fellow in Fluid Mechanics
R. A. Kirkham, Lecturer in Debate
R. J. Konopka, Assistant Professor of Biology
M. D. Manson, Senior Research Fellow in Biology
K. C. McNally, Senior Research Fellow in Geophysics
R. L. Messner, Senior Research Fellow in Physics
G. J. Milne, Assistant Professor of Computer Science
J. B. Minster, Associate Professor of Geophysics
R. P. Morton, Bateman Research Instructor in Mathematics
C. J. Pings, Professor of Chemical Engineering and Chemical Physics; Vice Provost and Dean of Graduate Studies
S. H. Pravdo, Senior Research Fellow in Physics
N. J. Proudfoot, Senior Research Fellow in Biology
M. V. Reddy, Senior Research Fellow in Biology
S. Reuben-Karady, Lecturer in Russian
A. C. Rose, Instructor in American History
A. R. Schep, Instructor in Mathematics
D. L. Smith, Associate Professor of Applied Physics
W. A. Squires, Bateman Research Instructor in Mathematics

DEATHS
M. Delbrück, Board of Trustees Professor of Biology, Emeritus
P. J. Young, Assistant Professor of Astronomy

Honors and Awards

J. L. Beauchamp was elected to membership in the National Academy of Sciences.

R. D. Blandford was a recipient of a Sloan Foundation Fellowship.

F. Boehm received the Alexander von Humboldt Foundation Award, which provided for a six-month stay at the University of Munich and the Laue-Langevin Institute at Grenoble.

L. Breger was awarded the Franz Alexander Essay Prize for 1980 by the Southern California Psychoanalytic Institute for his essay, "Some Metaphorical Types Met with in Psychoanalytic Theory."

W. B. Bridges was elected to membership in the National Academy of Sciences. He also received an annual teaching award from ASCIT for EE 60, Communication System Fundamentals.

N. H. Brooks was elected to membership in the National Academy of Sciences.

M. Cohen was awarded a Guggenheim Fellowship for 1980-81.

F. E. C. Culick received the Pendray Aerospace Literature Award from the American Institute of Aeronautics and Astronautics for numerous outstanding contributions to the technical literature of combustion instability in solid rocket motors.

P. B. Dervan received an annual teaching award from ASCIT for Ch 41, Chemistry of Covalent Compounds.

C. H. Dix was elected to honorary membership in the Seismological Society of America, for attainment in seismology or related sciences.

P. E. Duwez was awarded the Heyn Medal for 1981 by the Deutsche Gesellschaft für Metalkunde in recognition of his achievements in the field of metallurgy, especially in connection with metallic glasses. He also received the 1982 William Hume-Rothery Award, which is given annually to an outstanding scientific leader in recognition of scholarly contributions to the science of alloys.

C. Eshleman was one of the recipients of the Witter Benner grant-in-aid award from the Poetry Society of America for co-authoring "The Complete Poetry of Aimé Césaire."

D. A. Evans was the recipient of the 1982 American Chemical Society's award for creative work in synthetic organic chemistry.

D. H. Fender received the Alexander von Humboldt Foundation Award, which provided funds for a six-month stay at the Department of Zoology, Johannes-Gutenberg Universität, Mainz, West Germany.

J. A. Ferejohn was the recipient of a Guggenheim Fellowship Award for his comparative study of legislators and their constituencies.

B. Fornberg was the recipient of a Guggenheim Fellowship Award for research on computational methods in fluid mechanics.

W. A. Fowler received a Doctorat Honoris Causa de l'Université de Liège and a Doctorat Honoris Causa de l'Observatoire de Paris-Meudon.

J. N. Franklin received an annual teaching award from ASCIT for AMa 181, Mathematical Programming and Game Theory.

P. Goldreich was one of three men to be named California Scientist of the Year by the Los Angeles-based California State Museum of Science and Industry.

E. Herbolzheimer was the recipient of an ARCO Outstanding Junior Faculty Award for outstanding contributions to education.

L. E. Hood received the 1981 Bridges Award of the Achievement Rewards for College Scientists for communication of science to the general public. He was also selected as the Camille and Henry Dreyfus Lecturer, Pomona College; the Kinyoun Lecturer, National Institutes of Health; the Smith Kline and French Lecturer, Vanderbilt University; the Dan Campbell Lecturer, Midwinter Conference of Immunologists, Asilomar; the Michael Heidelberger Lecturer, Columbia University; the Doisy Lecturer, University of Illinois-Urbana; the Philip E. Newmark Lecturer, University of Kansas; and the Shaffer Lecturer, Washington University School of Medicine.

A. P. Ingersoll received the Exceptional Scientific Achievement Medal of NASA.

P. C. Jennings was elected a Fellow of the American Association for the Advancement of Science for his fundamental developments in earthquake engineering and their applications to tall buildings, power plants, and offshore structures.

D. J. Kevles was the recipient of a Guggenheim Fellowship Award for his work on a history of eugenics and human genetics in the United States and Britain from the 1890s to the present. He was also recipient of an NEH Fellowship for academic year 1981-82.

M. Konishi was elected a Fellow of the American Association for the Advancement of Science.

J. LaBelle was awarded a grant from the Arnold L. and Lois S. Graves Awards Committee for calendar year 1983 for the purpose of completing a book on women and mirrors in literature.

E. Lazarides received a Dreyfus Teacher-Scholar Award from the Camille and Henry Dreyfus Foundation, and was selected for the R. R. Bensley Award and Lecture by the American Association of Anatomy.

V. A. Lindholm received an annual teaching award from ASCIT for L 141, Elementary Russian. She was also appointed to the Danforth Associate Program for demonstrating major commitments to undergraduate teaching.

C. A. Mead was co-recipient of the eighth Achievement Award of *Electronics* magazine for his work in structuring the methodology of the design of very-large-scale integrated (VLSI) circuits.

B. C. Murray received the NASA Distinguished Service Medal.

R. W. Oliver was appointed to the Danforth Associate Program for demonstrating major commitments to undergraduate teaching.

C. S. Parker was awarded the Dreyfus Grant for Newly Appointed Young Faculty in Chemistry. This award is for research purposes during his first year as a new member of the faculty.

R. W. Paul received an annual teaching award from ASCIT for H 6, American Life and Thought.

G. W. Pigman III was voted support by the Arnold L. and Lois S. Graves Awards Committee in 1981 for his study of Renaissance interpretations of Virgil.

C. J. Pings was elected to membership in the National Academy of Engineering for his leadership in development of knowledge on properties of liquids and for his educational leadership as a teacher and administrator.

C. R. Plott was the recipient of a Guggenheim Fellowship Award for developing experimental methods in political economy research.

J.-P. Revel presented the second Burton Baker Memorial Lecture at the University of Michigan at Ann Arbor.

J. D. Roberts received the Pauling Award from the Puget Sound and Oregon Sections of the American Chemical Society for outstanding contributions to chemistry of a character that has merited national and international recognition.

R. A. Rosenstone was a recipient of an NEH Fellowship for academic year 1981-82.

W. L. W. Sargent was elected a Fellow of the Royal Society of Great Britain for his achievements in observational astronomy, particularly with respect to studies of Seyfert Galaxies and quasars.

M. Schmidt was awarded the Gold Medal of the Royal Astronomical Society and was elected correspondent of the Koninklijke Nederlandse Akademie van Wetenschappen.

E. M. Searle was a recipient of an NEH Fellowship for academic year 1981-82.

K. E. Sieh received the E. B. Burwell Award of the Geological Society of America.

B. Simon was awarded the 1981 Academy Medal of the International Academy of Quantum Molecular Science for fundamental contributions to the theory of the stability of many-electron systems and applications of the complex-scaling method to molecular scattering and resonance phenomena.

A. Smith was one of the recipients of the Witter Benner grant-in-aid award from the Poetry Society of America for co-authoring "The Complete Poetry of Aimé Césaire."

R. W. Sperry was the co-winner of the 1981 Nobel Prize in Medicine or Physiology for his discoveries concerning "functional specialization of the cerebral hemispheres." He also received the Golden Plate Award of the American Academy of Achievement.

E. C. Stone was recipient of the NASA Exceptional Scientific Achievement Medal, the NASA Distinguished Service Medal, and The American Education Award of the American Association of School Administrators.

F. Strumwasser was elected a Fellow of the American Association for the Advancement of Science.

H. P. Taylor was elected to membership in the National Academy of Sciences.

K. S. Thorne received the Doctorat Honoris Causa Degree from the University of Moscow.

V. A. Vanoni received honorary membership in the American Society of Civil Engineers. This is the highest distinction given by the ASCE.

R. Vogt was recipient of the NASA Exceptional Scientific Achievement Medal, and the Professional Achievement Award from The University of Chicago Alumni Association.

G. J. Wasserburg was awarded the Arthur L. Day Prize and Lectureship by the National Academy of Sciences for his work in the use of isotopes in studying geophysical problems of the solar system.

W. H. Weinberg was the recipient of the 1981 Allan P. Colburn Award of the American Institute of Chemical Engineers for his creative work in the area of surface structure and reaction kinetics.

S. Wolfram was awarded a MacArthur Fellowship.

G. Zweig was awarded a MacArthur Fellowship.

Statistics

MEMBERS OF THE FACULTY	75-76[1]	76-77[1]	77-78[1]	78-79[1]	79-80[2]	80-81[3]
Administration	6	3	3	3	5	3
Emerti	42	39	39	37	40	52
Professors	187	197	190	195	195	192
Associate Professors	33	28	26	31	35	31
Assistant Professors	32	33	34	34	34	43
Instructors	7	10	10	16	15	12
Lecturers	8	10	6	11	11	13
Staff Members of Observatories	12	11	10	10	—	—
Senior Research Associates	2	2	2	2	2	30
Senior Research Fellows	42	44	45	50	50	29
Research Fellows	182	209	208	202	204	194
Research Associates[4]	21	20	21	20	23	—
Faculty Associate	—	—	—	—	—	1
Associate	—	—	—	—	—	1
Fairchild Scholars	28	24	31	22	25	20
Visiting Professors, Associate and Assistant Professors	13	18	30	37	39	14
Visiting Associates	80	110	106	88	96	103
Physical Education Staff	5	5	5	4	5	5
	700	763	766	762	779	743
Tenured Faculty	213	216	204	209	211	210

[1]July 1-June 30
[2]July 1, 1979-September 30, 1980
[3]September 30, 1981
[4]The title "Research Associates" was terminated in 1981.

NOTE: Total number of Fairchild Scholars is shown for each year. Total number of visiting professorial members is shown through 1980-81.

Student Affairs

James J. Morgan, Vice President for Student Affairs

Renamed "Placement and Career Planning Services," the old Placement Office was added to Student Affairs in the fall of 1980. Its longtime director, William F. Nash, Jr., retired, and in the spring of 1981 Sally J. Asmundson came from UC Riverside to be director. Linda K. Berkshire, director of financial aid, left Caltech to take another position; former assistant director Ruth J. Wilson became director in October. In November, Ann Draper joined the staff as assistant director. Student Counseling Services also welcomed a new director; Dr. Bruce Kahl replaced Dr. Sigrid McPherson. Chris Wood, assistant to the dean of students, became assistant dean in July 1981.

With these changes in personnel and with the dedicated assistance of the continuing staff, Student Affairs has had another successful year supporting Caltech students.

Admissions

Including achievement test scores, the overall level of test scores remained substantially the same in 1980-81. The quality of the class that entered in September 1981 as measured by both ability and academic achievement is comparable to that of the previous several years. Applications totaled 1,518 (the third largest number on record, exceeded only by the years 1958 and 1960), offers to admission totaled 387, and 217 freshmen were enrolled (including 35 women, the highest number Caltech has achieved).

Upperclass Admissions

A special transfer program, a 3-2 dual degree program, and regular competition based on Caltech-designed examinations provide upperclass admissions.

In 1981, two students were admitted under the special transfer program, which affiliated Caltech with 12 local public community colleges.

The 3-2 dual degree program joins Caltech to nine liberal arts colleges (Bowdoin, Bryn Mawr, Grinnell, Occidental, Ohio Wesleyan University, Pomona, Reed, Wesleyan University, and Whitman). Students who attend these schools for three years and then transfer into the junior year at Caltech receive two bachelor's degrees at graduation — one from the liberal arts college and one from Caltech. This year, 17 students (a record number) were admitted — and 16 enrolled.

In the regular upperclass admissions competition, 103 students applied, 78 took the transfer examinations, 17 were offered admission, and 15 accepted.

Upperclass admissions totaled 33 (compared with the same number in 1980 and 26 in 1979). Among the new students were three women.

In 1980-81 the admissions office had several programs to reach more women secondary school students — to raise both the number of applicants Caltech received from women and the number of women accepting admission. On a spring "pre-frosh weekend," women who had been offered admission to Caltech were invited to Pasadena to meet students and faculty and to inspect the student houses and the campus before making their decision. A mailing program in the fall of 1981 sent out two lively recruitment pieces — a poster calendar that went to physics teachers all over the United States featuring three Caltech women students, and a brochure entitled, *What's a nice girl like you doing in a place like this?* Efforts were also made to visit an increased number of all-women secondary schools.

Secondary School Relations and Special Student Programs

The director of secondary school relations and special projects has been active in recruiting minorities by making contacts with potential Caltech students, science teachers, and school counselors through high school visits (in 12 states) and through mailings to minority students on various lists (e.g., 400 letters to minority students on the PSAT list).

The Saturday school for secondary students continued with classes in the various fields of math and science taught by Caltech undergraduate and graduate students; an average of 280 students per Saturday turned up in 1980-81. The seven-week summer session for high school students in astronomy, physics/calculus, physics/trigonometry, chemistry, and biology was attended by 350 students.

The lecture series for secondary school students, held on seven Wednesday afternoons throughout the school year, drew an average of 150 students to each talk. Their teachers and other interested people also attended. The varied fare presented in 1980-81 included "Planetary Rings" by DuBridge Professor Peter Goldreich, "Solarchemistry" by Beckman Professor Harry Gray, "Engineering Solutions to Urban Air Pollution Problems" by Assistant Professor Glen Cass, "Radon Monitoring for Earthquake Prediction in Southern California" by Professor Thomas Tombrello, "Studies on the Neural Basis of Learning in the Rat" by Senior Research Fellow Dorwin Birt, "DNA Replication" by Assistant Professor Judith Campbell, and "Gems, Science, and Technology" by Associate Professor George Rossman.

The Undergraduate Deans

The dean of students and the assistant dean, who oversee the personal and academic well-being of the undergraduates, had many students visit their office for discussions about all aspects of undergraduate life. The deans try to check individual academic progress during the year and to help students who are having problems. They also help arrange leaves of absence when appropriate and encourage students to look realistically at their programs and career goals.

Freshman Camp on Catalina Island introduced 217 new students, including 35 women — the highest number ever — to the life of Caltech. Also joining the undergraduate student body of 844 were two from the special transfer program, 16 from the 3-2 dual degree program, and 15 regular transfer students.

The deans are always considering suggestions for ways to improve the undergraduate life at the Institute. For example, they administer an emergency loan fund for students, and financial support is available for projects of interest to undergraduates. This year these incuded a special student house dinner, a women's annex party, several athletic team banquets, and a house ski trip to Mammoth. Several attractive fellowships and scholarships are administered through their office; this year two Caltech students received Watson Fellowships to spend the year engaging in independent study and travel. One student is in Micronesia and the other in Southeast Asia.

During the spring and summer, preparations were made by the dean's office staff for the incoming class of freshmen and transfers. They were again welcomed at Catalina Island in an orientation program designed to introduce them to Caltech.

Registrar

At commencement in June 1981, of the 206 students who received bachelor's degrees, 111, or 54 percent, graduated with honor. (Graduation with honor is awarded by the faculty to students who have achieved a high scholastic standing [an overall grade point average of at least 3.2] or who have carried out creative research of high quality.) Master's degrees were awarded to 136 students; one engineer's degree was awarded; and Ph.D.s were awarded to 129 doctoral candidates.

The registrar reports that the time has come to face realistically that in the relatively near future his office must reduce or eliminate its dependence on the Booth Computing Center. During the year the staff looked at various possibilities and hope soon to be able to define and implement an independent computing service meeting the needs not only of the registrar's office but also of the rest of Student Affairs.

Registration statistics for first term 1980-81 follow. "Not classified" refers to freshmen, who make their choice of options at the end of their freshman year. The numbers in the tables indicate the number of students in the various categories who have selected that particular option.

1980-81 Registration

Options	*Fr*	*So*	*Jr*	*Sr*	*Total Under-grads*	*Total Grads*	*Totals*
Aeronautics						43	43
Applied Math		2	1	5	8	28	36
Applied Mechanics						17	17
Applied Physics		16	24	13	53	52	105
Civil Engineering						30	30
Computer Science						23	23
Electrical Engineering		34	21	17	72	56	128
Engineering and Applied Science		50	55	67	172		172
Engineering Science						9	9
Environmental Engineering Science						19	19
Materials Science						3	3
Mechanical Engineering						39	39
Total Engineering and Applied Science		102	101	102	305	319	624
Astronomy		4	6	1	11	20	31
Biology		19	11	14	44	67	111
Chemical Engineering		17	14	19	50	66	116
Chemistry		18	12	15	45	171	216
Geology		5	5	11	21	67	88
Math		11	12	11	34	17	51
Physics		46	34	41	121	119	240
Total Science		120	94	112	326	527	853
Economics			1	1	2		2
Literature			1		1		1
Social Science						19	19
Total Humanities and Social Science			2	1	3	19	22
Not Classified	206	4			210		210
TOTALS:	206	226	197	215	844	865	1,709

Undergraduate Women Distribution

		AMa	*APh*	*Ay*	*Bi*	*ChE*	*Ch*	*EE*	*Eng*	*Ge*	*Ma*	*Ph*	*Total*
Fr	34												34
So	1				6	5	4	1	11	2	1	6	37
Jr			1		7	3	2	1	5	1	3	6	29
Sr					5	1	3	1	5	1	1	1	18
Total	35		1		18	9	9	3	21	4	5	13	118

Graduate Women Distribution

Ae	*AMa*	*APh*	*Bi*	*ChE*	*Ch*	*CE*	*CS*	*EE*	*ES*	*Env*	*Ge*	*Ma*	*Me*	*Ph*	*SS*	*Total*
2	1	1	14	5	27	2	4	4	1	5	20	1	4	6	1	98

Financial Aid

The office of financial aid administers and coordinates a variety of funds from endowments and from federal, state, corporate, foundation, and private sources. Eligibility for most of the funds is contingent on need or a combination of need and merit; some funds are awarded for merit alone.

Sixty-five percent of the undergraduates applied for need-based assistance for 1980-81. The director and her staff analyze information on family income and assets to determine each student's need. Each family provides documentation of the information supplied in the basic application; this requirement helps ensure equitable awarding of limited funds.

The faculty scholarships and financial aid committee choose the Carnation and Caltech Prize Scholars and the Summer Undergraduate Research Fellows (SURF participants) on the basis of applications, recommendations, and, for prizes, grades.

In 1980-81 some sort of financial award was received by 629 students — 77 percent of the undergraduate student body. The fund distribution is as follows:

Undergraduate Financial Aid 1980-81

Gift Aid	
Caltech scholarships & grants	$1,071,742
Federal grants	290,717
Cal Grants & other state grants	402,898
Outside scholarships	274,400
	$2,039,757
Loans	
National Direct Student Loans	$ 367,213
Caltech loans	183,437
Federal Insured Student Loan/ Guaranteed Student Loans	677,955
	$1,228,605
Employment	
College work-study	164,222
Other campus employment	48,000
	$ 212,222
Merit Awards	
Caltech and Carnation Prizes	72,905
Summer Undergraduate Research Fellowships	108,000
	$ 180,905
TOTAL	$3,661,489

The increase in FISL/GSL borrowing of approximately $400,000 more than in 1979-80 is a reflection of the middle income student assistance act of 1978. 1981-82 will be the last year of general eligibility for such funds.

The number of students requiring assistance, and the amount required by each student, grows as the cost of a Caltech education continues to rise dramatically. The basic student budget averaged $8,800 in 1980-81.

Master of Student Houses

The master of student houses is a faculty member appointed to minister to the needs and well-being of undergraduate students, to promote harmony in the student houses, to counsel resident associates, and to provide moral and financial support for house social programs.

The room improvement fund, now in its third year, enabled 135 students to paint, panel, carpet, build shelves, and generally improve their ambiance. Two new off-campus houses were added, making a total of 24 separate off-campus facilities. Furnishings for these houses were supplied by the room improvement fund.

The master contributed to various student organizations — the chess club, Caltech amateur radio club, model United Nations, film workshop, ice skating club, and others. A substantial donation is made each year to the annual musical (*Candide* in 1981) and house social events including theater parties, special dinners, and pie night. Friday morning coffee and donuts (23 dozen every Friday that classes are in session) are enjoyed by hundreds of undergraduates. In 1980-81 the master's office held three (one each term) tea parties. Students responded overwhelmingly to an invitation to eat fancy pastries and drink tea. In February the master hosted a campus-wide celebration of the Chinese New Year with an outdoor picnic supper, dragon dancers, Chinese orchestra and dance troupe, and animals.

The Faculty Fellow program was launched in an effort to encourage interaction between faculty and students. Each house picked two or three professors to become faculty fellows and invited them to dine in the house as often as their schedules allowed. The tutors program went into its fourth year continuing to assist students requesting help with their studies. A food service committee was organized for the purpose of ensuring the quality of food offered on board contract.

Sunney I. Chan, professor of chemical physics and biophysical chemistry, followed the tradition established by former masters by moving his family into Steele House where he and Mrs. Chan regularly entertain students at dinner, Sunday morning classical music brunches, holiday parties, and other informal meetings.

Health Center

The Archibald Young Health Center was built in 1957. At that time, because the emphasis was on providing treatment of physical problems, the staff consisted of three part-time physicians, consultants in radiology, one part-time consulting psychiatrist, and RNs, whose duties included operating a 10-bed infirmary.

Changes in medical attitudes dictated an equal emphasis on providing treatment for emotional problems — with a resulting increase in the size of the counseling staff. However, the accommodations for the equivalent of 2½ full-time professionals were woefully inadequate.

Plans to remedy the situation were approved in the spring, and construction was started in summer and finished in time for the start of the 1981-82 school year. The counseling staff now has a suite of offices, completely redecorated and effectively soundproofed, a separate entrance, and their own waiting room. Medical services, now located in the north wing of the health center, gained a laboratory, medical conference room, and a revitalized hydrotherapy room. All parties are delighted with the new arrangement.

Student Counseling Services

Distribution of service hours changed from last year, though the bulk of the 1,706 total clinical hours was still spent on individual psychotherapy; this total represents an increase of 28 hours over the previous year. More students were seen on a short-term basis than last year, reflecting an internal push for increased availability and efficiency of services. Of the students utilizing services 61 were undergraduates (7 percent of the undergraduate population) and 65 graduates (8 percent of the graduate population). Twenty-five more individuals from other groups (spouses, faculty, staff, ex-students) sought our services for various purposes; five couples were seen in treatment as well.

Women represented 33 percent of the clinic population, an increase of 8 percent over last year, probably explicable on the basis of an increase in the number of female spouses seeking help. Certainly women in the Caltech community are still seeking help in proportionately much greater numbers than men.

Beyond direct provision of therapeutic services, staff was involved in the organization and operation of the peer counseling program, a preventive medicine model outreach plan for spotting students with potential or beginning psychological crises and managing them in an appropriate fashion. 1980-81 was the fourth year for this project, which was thought by students and staff involved to be successful in meeting its basic goals.

Medical Services

Medical services treated about the same number of patients as in previous years for a wide variety of illnesses and injuries, provided health, preventive, and self-care information and physical examinations, counseled on gynecological problems including contraception, and disseminated birth control and nutrition information and guidance.

The campus interaction program provided an opportunity for all staff members to be involved in the promotion of health awareness and Health Center services. The staff also contributed a series of weekly articles to the *California Tech* on health subjects under the title of "The Body Shop."

First aid and training in cardiopulmonary resuscitation classes offered at the Health Center by nursing staff members and certified Red Cross instructors were well attended.

Performing Arts

Offerings for students interested in the performing arts at Caltech have expanded. A theater arts program involving approximately 200 students and staff presented both spring and fall offerings, including experimental workshop scenes, a children's masquerade, a dance showcase with student choreography, and *Our Town*, student produced, directed, and acted. The Caltech musical, *Candide*, played to sellout houses, including one performance signed for the deaf. An active film workshop resulted in two student films.

The glee clubs, men's and women's, continued their good work. The traditional holiday concert, Festival of Light, was, as always, sold out, and the spring concert, held in conjunction with Seminar Day, provided a fitting climax to a gleeful year.

The interpretive music class continued, as did flamenco and classical guitar classes for interested students, and the Caltech-Occidental Symphony provided opportunities for instrumentalists. A new chamber music group has a membership of 40 students, and the wind ensemble and jazz band produced their second annual Bandorama. The Caltech Jazz Band won the Outstanding Band Award at the Orange Coast College Jazz Festival in April 1981.

Athletics, Physical Education, and Recreation

Undergraduate participation in the organized aspects of the athletic program increased more than 10 percent over the previous year. Over 400 undergrads received instruction in the 17 different classes offered. Competition in the eight intramural sports also attracted more than 400 undergraduates, and over 200 participated in the 13 intercollegiate sports.

Participation in competitive sports by women continued to increase at both the intercollegiate and club levels. Undergraduate women participated in intercollegiate cross country, fencing, and swimming and joined graduate students to form club teams in soccer, volleyball, and water polo.

The pressures on the existing indoor facilities and swimming pool continued to increase during the year. Preliminary plans and a cost estimate for expansion of these facilities have been prepared, and fund raising plans are being developed.

Placement and Career Planning Services

More than 165 separate companies visited the campus, many sending representatives from several divisions, and graduates accepted positions with 65 different companies. About 50 percent of those earning bachelor's and master's degrees continued their education, and about 30 percent of both groups had accepted an employment offer by July 1, 1981. The average monthly salary for positions accepted by B.S. graduates was $1,979 and for M.S. graduates, $2,213. Of the Ph.D. graduates about 35 percent accepted positions in industry with an average monthly salary of $2,579, and about 53 percent accepted positions with academic institutions.

The office also provided services for continuing students and alumni. Over 250 positions for experienced personnel were listed, and 144 alumni participated in the referral service. Part-time positions, both on and off campus, were listed, and 450 students obtained them; of these, 181 were funded through a federal work-study grant.

Plans are made to continue to provide services to both students and alumni seeking immediate employment, and, in addition, to develop services and programs related to the career planning needs of students and alumni. Specific projects include the development of brochures such as *The Resume and Cover Letter, Job Search Strategies, Applying to Graduate School, Preparing for Medical School, Finding a Summer Job,* and *Interview Techniques*. Other projects include increased efforts to solicit summer employment opportunities, development of a networking system for alumni seeking employment, increased employer contact through a concerted outreach program, presentation of career seminars, increased individual help for students on career exploration, resume preparation and interview techniques, and expansion of the materials in the career information library.

Graduate Studies

James J. Morgan, Acting Dean of Graduate Studies

Graduate Studies, reporting for the academic year 1980-81, includes admissions to graduate study for 1981-82. The academic year 1980-81 was one of continued growth, and the second largest number in Caltech's history accepted admission to graduate studies for 1980-81.

Admissions for 1981-82

The number of graduate applications for 1981-82 was an all time high, 8 percent greater than for the previous year. Applications were up by 7 percent in the sciences, up by 8 percent in engineering, and by 14 percent in the social science option.

This year 24 percent of applicants were offered admission, the same percentage as last year, with 46 percent of these offers being accepted compared to 42 percent accepted last year. The total of 263 accepting admission was second only to the 267 accepting admission in 1979-80, which was the largest number accepting in Caltech's history.

Student Support

Fellowships and traineeships of all types continue the slow decline noted in these reports over the last several years. One encouraging aspect is the number of recipients of NSF Fellowships who continue to choose Caltech for their graduate study.

Assistantships are the primary source of graduate student stipends. Teaching assistantships have increased only slightly during the past few years. Increases in graduate research assistantships continued during 1980-81, but decreases did occur in a few areas of study.

Many of the 860 graduate students enrolled in 1980-81 were able to participate in research groups studying science in the making — such as Professor of Physics Ed Stone's students, who observed evidence, provided by Voyager's cosmic ray instrument, for the presence of sulfur and oxygen nuclei from volcanoes on Jupiter's satellite Io.

Federal college work-study funds again were available in substantial amounts during 1980-81, but have decreased significantly for 1981-82.

Enrollment for 1980-81

The graduate enrollment of 860 for 1980-81 was 4 percent less than the 898 enrolled in 1979-80, the latter enrollment having been the highest in Caltech history. This temporary downward trend has already been reversed, with the enrollment for 1981-82 having been 897.

For 1980-81, the percentage of foreign students was 29 percent, up from the five-year average of 26 percent. The distribution was 21 percent in the sciences and 44 percent in engineering.

The total number of graduate degrees awarded in June 1981 was 266, down slightly from the 297 awarded in June 1980. However, Ph.D. degrees awarded in 1981 totaled 129 compared to 125 awarded in 1980, with the previous maximum being 127 in 1972. The average residence time was 4.8 years for those receiving Ph.D. degrees in 1981, compared to 4.9 years in 1980.

Summary

Interest in graduate study at Caltech is high. The quality of applicants and students admitted continues to be excellent. In the next few years, graduate enrollment may continue to increase one or two percent a year.

Institute Relations

Dwain N. Fullerton, Vice President for Institute Relations

Institute Relations set two long-term goals during 1981: to make the Institute better known in California and the nation, and to increase gift support from private sources.

A significant part of the year was spent in selecting new directors of development and of public relations. Both positions were filled by June 1981.

Alumni Association

The Caltech Alumni Association serves the Institute and its 14,000 graduates. Under the leadership of its 1981 president, Philip L. Reynolds, the Association assisted undergraduate and graduate students with scholarships and provided financial support for Freshman Camp, Interhouse, athletics, and the Graduate Student Council, among other activities. Seminar Day 1981 attracted 1,800 alumni and friends. The speakers included Professors James Bonner, biology; J. Kent Clark, literature; Robert D. Middlebrook, electrical engineering; Anthony Readhead, radio astronomy; alumna Susan Kieffer from the U.S. Geological Survey; and astronomer Sir Fred Hoyle.

In November 1981, alumni from the Kellogg Laboratory gathered for an Association-sponsored event to celebrate three milestones — the dedication of a new particle accelerator, the 50th anniversary of the Laboratory, and Professor Willy Fowler's 70th birthday.

Chapter meetings, 20 in all, were held across the country and as far away as Tokyo. Professor Robert Sharp, geology, met with the Salt Lake City group at its first annual gathering; Provost J. D. Roberts reported on the state of the Institute to alumni in Boston and Philadelphia. The class of 1931 gathered in

June to commemorate its 50th reunion, and at the Alumni House class reunions were held for every fifth-year class through 1976. Continuing the Association's travel programs, Professor Sharp and Dr. Daniel Dzurisin led two groups of alumni through the Hawaii Volcanoes National Park.

Alumni have also provided information about Caltech to high school counselors and given assistance to students interested in applying for admission. This program helps increase the number of qualified students who apply and widens the geographical base of the Caltech student body.

The Associates

The members of The Associates of the California Institute of Technology, founded in 1926 by Robert A. Millikan and a distinguished company of southern California business and community leaders, are special Caltech benefactors. Invaluable to Dr. Millikan in the thirties and forties, this group provided moral and financial support as he set the Institute on the course that brought it to eminence in science and engineering. Despite 50 years of change in education and society, The Associates today play the same key role as their predecessors. Financial support from members now provides unrestricted funds, a critical element underlying many of the Institute's most exciting advances. In an era of uncertainty, aid of this kind is one of the school's most important assets.

President Hannah G. Bradley led The Associates in an outstanding year of growth and activities. Membership reached 860 with the addition of 62 new Associates. The group contributed $1,113,204 in unrestricted gifts during 1981.

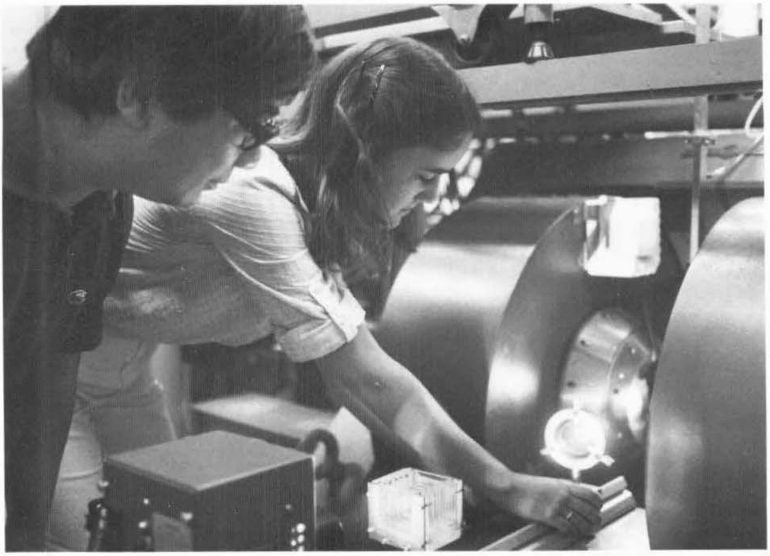
Members participated in a variety of activities, including field trips to the San Andreas Fault, Palomar Observatory, and areas of the south coast under study by faculty in the Environmental Quality Laboratory. Senator Charles Percy made a major policy statement at the annual black tie event held at the Athenaeum, and Associates participated in lectures and dinners in San Francisco, Santa Barbara, Orange County, and on the Caltech campus.

Development

In April 1981 Susan C. Pearce was appointed director of development. She has been on the development staff for five years, serving most recently as director of foundation relations.

Fiscal year 1981 set a new record of gifts received for a 12-month period — $19.7 million from private sources. About 75 percent of the total came from corporations, foundations, and associations. The remaining 25 percent was given by alumni, trustees, and friends of the Institute.

During the year Caltech received six gifts or pledges of $1 million or more. Two of those gifts established professorships



Support from foundation, corporation, and individual sponsors makes possible a successful and growing Summer Undergraduate Research Fellowship program. In 1981 Lynmarie Thompson, shown here with her faculty sponsor Professor Sunney Chan, was one of 46 students given the opportunity to formulate and complete their own research projects.

— one given by trustee Lew R. Wasserman and the other by the MacArthur Foundation. A third gift, from an anonymous donor, created an endowed undergraduate scholarship fund. The James R. Irvine Foundation awarded $1 million to complete the conversion of Gates Laboratory to Parsons-Gates Hall of Administration. Trustee John G Braun and his family pledged an additional $1.4 million to complete the construction of the Braun Laboratories, and the Weingart Foundation pledged $5 million for special innovative programs.

The 62 Industrial Associates companies provided $790,000 in unrestricted support. Special programs for members included campus and industry visits; company seminar days; library, publication, and technical information services; and a full conference program covering topics from turbulence to biomedical instrumentation. The corporations represent a diverse range of industries — aerospace, chemical, pharmaceutical, automotive, petroleum, food, and engineering.

In 1981, the Alumni Fund was led by National Chairman Andrew B. Campbell, BS46ME, assisted by 511 volunteers (including 13 regional chairmen and 124 area chairmen) who sought annual gifts from Caltech's 14,000 alumni. This year the Fund was credited with raising $1,079,653 from 4,724 donors to support the Institute's operations.

Public Relations

Thomas L. Branigan was named director of public relations for the Institute in June 1981. He came from TRW Inc. with 20 years of experience in technical publications, publicity, and community relations.

The Institute's news bureau keeps the public informed of research results and general news of Caltech by disseminating news releases, coordinating media interviews with the faculty, and staging press conferences for major news stories. The announcement of the award of the Nobel Prize in Physiology or Medicine to Roger W. Sperry attracted the greatest media attention during the past year.

The news bureau also has the unique responsibility of relaying reports of seismic events occurring in southern California to the news media, and handling queries from the press and the general public following such events.

Other elements of the Institute's public information program include tours (more than 2,000 visitors from all over the world took student-conducted tours this year), a speakers bureau, and distribution of films about Caltech.

The Institute's publications program includes two external periodicals — *Engineering & Science* and *Caltech News.* A redesigned *Engineering & Science* began its 35th year of publication last fall, and through five issues per year continues its tradition of describing Caltech's research and researchers to members of the Alumni Association and friends of the Institute. *Caltech News,* published seven times per year, conveys general Institute information to all alumni plus selected friends.

Several publications are produced for use in student recruitment — *Caltech Catalog, Facts about Caltech, Financial Aid Information,* and a new (and successful) calendar/poster for potential women undergraduate students. The publications staff also assists academic divisions in developing brochures for recruiting graduate students. *Around the Campus* provides news of interest to the Institute's staff, and the *Caltech Weekly Calendar* and an inexpensive visitors' brochure continue to be popular publications.

Reduced government support of higher education affects Caltech, of course, causing an increased emphasis on developing and maintaining relations with the government, especially on the federal level. Caltech actively communicates its views on legislative matters of concern to our campus through Congressional testimony, personal visits, letters, phone calls, and participation in various academic consortia. In one well publicized example of the latter approach, Dr. Goldberger joined with the presidents of four other major research universities to question federal government restrictions on the publication of unclassified research results and on the participation of foreign scholars in research activities.

In the community relations area, the Institute enjoys positive relations with its immediate neighbors and with the city of Pasadena and surrounding communities. To commemorate the 90th anniversary of the November 2, 1891, founding of the Institute's original predecessor, Throop University, a luncheon for 60 community leaders was held on campus at which the president reviewed the history of the intertwined development of Pasadena and Caltech.

Business and Finance

David W. Morrisroe, Vice President for Business and Finance and Treasurer

Fiscal year 1981 was marked by a visible change in the appearance of the campus and by plans for other improvements in Caltech's buildings and grounds. It was also marked by a slowdown in federal support at the campus and JPL that, in turn, moderated the historically high growth in revenues and expenditures which Caltech experienced in the prior year. Finally, the instability of the 1981 financial markets resulted in higher income from investments but little gain in their underlying value.

Buildings and Grounds

Three major facilities were completed in fiscal 1981, and work on several others was in progress. All of these projects are made possible by restricted gifts from private individuals and foundations, and through grants from government agencies.

The Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory was completed. This facility, made possible by a bequest honoring Clifford and Ruth Mead, is one of the most modern chemistry teaching facilities in the world.

The Astronomical Data Processing Center was developed in the Robinson Laboratory to provide an on-campus facility for collecting, processing, and analyzing data from Caltech (and other) radio and optical observatories. The first elements of the computer systems have been installed and others are being developed for installation in 1982.

The NSF-Caltech Tandem Pelletron Accelerator Facility is a new underground laboratory adjacent to the Kellogg Laboratory. The accelerator, purchased through a grant from the National Science Foundation, is expected to be in full operation in the spring of 1982.

The completion of the Thomas J. Watson, Sr., Laboratories of Applied Physics (center) advances not only research at Caltech, but also a campus beautification project. New landscaping throughout the 82-acre campus enhances the varied architecture of 72 buildings.

Work continued to progress on the Watson Laboratories and the Braun Laboratories. The Watson Laboratories were occupied in February 1982 and the Braun Laboratories in May 1982. Landscaping of the Watson-Chester mall was completed. This project converted Chester Street in the area north of San Pasqual Street into an integral part of the campus. The ultimate objective is to make a cohesive landscaped area from the Watson-Chester mall on the east to the Braun Laboratories court on the west.

In the planning stage is the Parsons-Gates Hall of Administration, which will provide new office space for the members of the administration now residing in Millikan Memorial Library and for the student affairs activities located in Dabney Hall. The project involves the restoration of Gates Laboratory, which was damaged in the 1971 earthquake. Plans call for the occupancy of this facility in January 1983.

Also in planning is the refurbishment of Millikan mall. This project, part of the Campus Beautification Program, is aimed at improving the external appearance of the campus. The donor who funded the upgrading of the campus malls, pathways, and athletic grounds is also providing the support for this project, which is scheduled for completion in the fall of 1982.

Investments

The carrying value of Caltech's investments at September 30, 1981, totaled $232.9 million — or $12 million more than the prior year. Investment income earned during the year totaled

$19.8 million, up $3.5 million from 1980. The income increase reflects largely the higher investment yields on fixed income investments in 1981. Caltech's investments, in millions of dollars, were comprised of the following:

	September 30			
	1980		1981	
	Amount	%	Amount	%
Marketable securities (mostly bonds and common stock)	$150.4	68%	$156.3	67%
Savings accounts, short-term commercial obligations and settlements in process	49.8	23	52.1	22
Real estate (less amortization and depreciation), mortgage notes and other securities	20.7	9	24.5	11
	$220.9	100%	$232.9	100%

Fund Groups

Caltech's financial accounts are grouped into self-balancing entities or funds. Their status is reported in Exhibits 1 and 2 and discussed below.

Current Funds

These are funds available for the operation of the Institute. This fund group is subdivided into unrestricted funds (available for any Institute purpose) and restricted funds (available for only those uses specified by a donor or outside agency). Of the total fiscal 1981 Current Funds expenditures of $87,655,000, $38,791,000 were unrestricted, and $48,864,000 were restricted.

The fiscal year ended September 30, 1981, saw increases in financial support for the programs at the campus and the Jet Propulsion Laboratory at more modest levels than in the previous fiscal year. Operating revenues and expenditures were in balance. The campus 1981 total was $87.7 million — an increase of 9.9% over the prior year. (In 1980, the percentage increase was 18.7% over the prior year.) The 1981 JPL total expenditures, funded almost exclusively by NASA, totaled $396.6 million — an increase of 5.6% over 1980. (The 1980 JPL expenditures were 17.7% higher than the prior year.) The more modest levels reflect the slowing of federally funded support for research.

Loan Funds

Funds in this group are provided to students as a portion of the financial aid package that assists them in furthering their education. As these loans are repaid, the principal and accumulated interest are lent again. These funds are provided primarily through gifts and federally sponsored programs, such as the National Direct Student Loan Program.

Loan funds for interest-bearing loans to students amounted to $4.8 million at September 30, 1981. Of this amount $4.3 million represented outstanding loans to Caltech students, with $2.9 million provided by the federal government under the National Direct Student Loan Program and $1.4 million from contributions by private donors. Loan principal payments in arrears for 120 days or more amounted to $142,600 or 3.9% of the total loans outstanding. This percentage continues to be well under the national average after more than two decades of student loan activity.

Endowment and Similar Funds

Funds received from donors for various purposes with the provision that the principal is to be maintained either in perpetuity or for a specific time period are placed in this group. Included also are funds designated by the Trustees to function as endowment with only the income to be used to support the purpose of the fund. The income earned through the investment of endowment funds is recorded in the current funds group and is available for expenditure according to the purposes specified. If a portion of the income is to be added to the principal of a fund, in accordance with the donors' instructions, it is recorded as a transfer from the current fund to the endowment fund.

The carrying value of the Institute's endowment increased from $174.9 million in fiscal 1980 to $183.5 million in fiscal 1981. This increase resulted primarily from gifts of $3.9 million and capital gains of $4.3 million.

Life Income and Annuity Funds

Life Income and Annuity Funds consist of funds held in trusts, the terms of which require the Institute to manage such funds separately and to make stipulated payments to designated beneficiaries. Upon the termination of the beneficiary agreements, the principal of these funds is transferred to other fund groups as designated by the donor.

Life Income and Annuity Fund balances amounted to $21.5 million at September 30, 1981, and represented some 127 trust and annuity agreements. These funds will become a major source of endowment funds upon termination of the agreements.

Plant Funds

This fund group is comprised of funds that have been received or designated by the Trustees for facilities. The group is divided into two categories: unexpended plant funds and investment in plant. Unexpended plant funds are available for expenditure. As these funds are used for construction, they are transferred to the funds invested in the plant. This transfer records the original cost of the Institute's physical facilities.

The Plant Fund balances increased $13.2 million to $167.1 million after provision for $2.9 million of equipment retirements. Gifts, grants, and transfers of $7.1 million and current fund acquisitions of $6.8 million constituted the major additions to the Plant Funds.

California Institute of Technology
Balance Sheet

(in thousands)	September 30, 1980
	Total All Funds
Assets	
Cash (demand deposits)	$ 805
Accounts receivable:	
United States government (note B)	52,672
Other	1,945
Student accounts and notes receivable	5,234
Investments (notes A and C)	220,964
Interfund interest bearing advances	
Prepaid expenses and other assets	2,002
Campus properties (note A):	
Equipment	64,493
Buildings	75,536
Land	8,977
	$432,628
Liabilities and Fund Balances	
Accounts payable and accrued expenses (note B)	$ 55,192
Deferred student revenue	2,190
Funds held in custody for others	6,394
Annuities payable (note A)	2,161
Fund balances	366,691
	$432,628
Fund Balances [comprise] (Exhibit 2):	
United States government grants refundable	$ 2,669
Institute funds—	
Unrestricted	1,750
Discretionary endowment	
Unrestricted	33,719
Restricted	22,751
Endowment principal	118,441
Other restricted funds	43,810
Invested in plant	143,551
	$366,691

See accompanying notes to financial statements.

September 30, 1981

Total All Funds	Current Funds	Loan Funds	Endowment & Similar Funds	Life Income & Annuity Funds	Plant Funds
$ 746	$ 383	$ 13	$ 3	$ 347	$ —
45,987	45,987	—	—	—	—
1,813	1,813	—	—	—	—
6,257	1,970	4,287	—	—	—
232,931	21,296	549	184,461	23,034	3,591
—	3,807	—	—	—	(3,807)
2,226	2,226	—	—	—	—
70,679	—	—	—	—	70,679
88,357	—	—	—	—	88,357
9,937	—	—	—	—	9,937
$458,933	$77,482	$4,849	$184,464	$23,381	$168,757

Total All Funds	Current Funds	Loan Funds	Endowment & Similar Funds	Life Income & Annuity Funds	Plant Funds
$ 51,588	$49,635	$ —	$ —	$ 306	$ 1,647
2,921	2,921	—	—	—	—
7,046	6,082	—	964	—	—
1,600	—	—	—	1,600	—
395,778	18,844	4,849	183,500	21,475	167,110
$458,933	$77,482	$4,849	$184,464	$23,381	$168,757

Total All Funds	Current Funds	Loan Funds	Endowment & Similar Funds	Life Income & Annuity Funds	Plant Funds
$ 2,862	$ —	$2,862	$ —	$ —	$ —
2,288	942	—	—	—	1,346
34,438	—	—	34,438	—	—
25,256	—	—	25,256	—	—
123,806	—	—	123,806	—	—
43,610	17,902	1,987	—	21,475	2,246
163,518	—	—	—	—	163,518
$395,778	$18,844	$4,849	$183,500	$21,475	$167,110

California Institute of Technology
Statement of Changes in Fund Balances

(in thousands)	Year Ended September 30, 1980
	Total All Funds
Fund balance at beginning of year (Exhibit 1)	**$335,002**
Revenues and other additions (notes A, D and F)	
Student tuition and fees	7,562
Investment income	16,259
Net gain (loss) on disposal of investments —	
Unrestricted	4,196
Restricted	12,095
Gifts and nongovernment grants	16,958
United States government grants and contracts —	
Reimbursement of direct costs	32,187
Recovery of indirect costs and management allowance	17,183
Auxiliary enterprises revenues	3,087
United States government advances	264
Plant acquisitions, etc. (including $6,753 included in campus operating expenditures and $16,062 included in plant acquisitions, payments on interfund advances and renewals)	15,513
Adjustment of actuarial liability for annuities payable (note A)	(139)
Other	950
Total revenues and other additions	126,115
Expenditures and other deductions:	
Campus operating expenditures (Exhibit 3)	(79,748)
Plant acquisitions, payments on interfund advances and renewals	(10,789)
Retirement and disposal of campus properties	(2,134)
Interest on advances for plant purposes	(221)
Payment to life beneficiaries	(1,372)
Other	(162)
Total expenditures and other deductions	(94,426)
Transfers among funds:	
Gifts allocated	—
Discretionary endowment transfers to (from) current funds	—
Allocations for plant purposes	—
Terminated trust and annuity agreements	—
Other	—
Total transfers	—
Increase (decrease) for the year	31,689
Fund balance at end of year (Exhibit 1)	**$366,691**

See accompanying notes to financial statements.

Year Ended September 30, 1981

Total All Funds	Current Funds Unrestricted	Current Funds Restricted	Loan Funds	Endowment & Similar Funds	Life Income & Annuity Funds	Plant Funds
$366,691	$ 284	$ 12,327	$4,409	$174,911	$20,880	$153,880
8,553	8,553	—	—	—	—	—
19,750	5,946	11,514	99	—	1,398	793
859	—	—	—	859	—	—
3,330	—	—	—	3,486	(248)	92
22,271	3,378	10,193	107	3,909	267	4,417
34,579	—	32,928	—	—	—	1,651
20,153	18,550	—	—	—	—	1,603
3,594	3,594	—	—	—	—	—
205	—	—	205	—	—	—
22,815	—	—	—	—	—	22,815
750	—	—	—	—	750	—
1,277	433	24	58	—	150	612
138,136	40,454	54,659	469	8,254	2,317	31,983
(87,655)	(38,791)	(48,864)	—	—	—	—
(16,634)	—	—	—	—	—	(16,634)
(2,933)	—	—	—	—	—	(2,933)
(224)	—	—	—	—	—	(224)
(1,398)	—	—	—	—	(1,398)	—
(205)	—	(130)	(50)	(25)	—	—
(109,049)	(38,791)	(48,994)	(50)	(25)	(1,398)	(19,791)
—	(293)	(58)	—	351	—	—
—	(188)	(2,016)	—	2,204	—	—
—	(119)	(378)	—	(541)	—	1,038
—	—	—	—	324	(324)	—
—	(405)	2,362	21	(1,978)	—	—
—	(1,005)	(90)	21	360	(324)	1,038
29,087	658	5,575	440	8,589	595	13,230
$395,778	$ 942	$17,902	$4,849	$183,500	$21,475	$167,110

California Institute of Technology
Statement of Operating Expenditures

Exhibit 3

(in thousands)	Year Ended September 30	
	1980	1981
Educational and general:		
Instruction, including departmental research	$ 25,177	$ 28,478
Organized research	31,743	33,781
Scholarships and fellowships	3,232	3,540
Institutional and student support	9,608	11,399
Plant operation, maintenance and utilities	6,571	6,587
Total education and general	76,331	83,785
Auxiliary enterprises	3,417	3,870
Total campus expenditures	$ 79,748	$ 87,655
Direct costs of sponsored research at Jet Propulsion Laboratory (fully reimbursed by the United States government)	$375,378	$396,557

See accompanying notes to financial statements.

California Institute of Technology
Notes to Financial Statements
September 30, 1981

Note A — *Summary of Significant Accounting Policies:*

Basis of accounting and reporting — The financial statements of the Institute, a not-for-profit educational organization, have been prepared in accordance with the principles of accrual basis fund accounting for colleges and universities. Under these principles Institute resources are accounted for by the use of separate funds so that visibility and control are maintained for the benefit of the Institute and its sponsors. Funds that have similar objectives and characteristics have been combined into fund groups. Within each fund group, fund balances restricted by outside sponsors for specific purposes are so indicated and are distinguished from unrestricted funds that are available for use in achieving any Institute objectives.

The financial statements of the Institute reflect the volume of activity at the Jet Propulsion Laboratory, which is managed by the Institute, but owned and supported by the United States government through the National Aeronautics and Space Administration.

Investments — Institute investments are stated at their approximate market value at date of gift, or at cost if purchased by the Institute, less applicable amortization and depreciation of real estate, unless there has been an impairment of value not considered temporary. All investments of endowment and similar funds are carried in an investment pool unless special considerations or donor stipulations require that they be held separately. Pool share values are computed periodically based upon the total market value of the investment pool and the total number of pool shares invested.

Income on investments of endowment and similar funds is recorded as current fund revenues for the purposes specified by the donor. Such income is supplemented, where necessary, by transfers of additional amounts so as to result in a total return from the investment pool equivalent to 5% of the average market of the pool over a three-year period. This total return concept is authorized by the California Uniform Management of Institutional Funds Act, which allows the prudent use of realized appreciation on investments, thus permitting greater flexibility in investment strategy.

Campus properties and plant funds — Campus properties are recorded at cost of construction or acquisition, or at appraisal value at date of gift, and no depreciation or amortization is recorded. The Institute provides for the renewal and replacement of its campus properties from funds designated for this purpose. Expenditures for maintenance and repairs are generally charged to current funds as plant operation and maintenance expenditures.

Annuities — Annuities payable to certain donors of the Institute are recorded at the present value of the liability calculated under an actuarial method which takes into account the life expectancies of the recipients.

Tax-exempt status — The Institute is a tax-exempt educational organization under federal and state income, gift, estate, and inheritance tax laws.

Note B — *United States Government Contracts:*

The Institute has many contracts with the United States government that provide for reimbursement of costs incurred for sponsored research at the Jet Propulsion Laboratory and at the campus. These contracts give rise to a substantial portion of the accounts payable and accrued expenses in the current funds at September 30, 1981 and 1980, and in turn to accounts receivable from the United States government.

Note C — *Investments:*

Institute investments, at carrying values (see Note A), comprise the following:

	September 30	
	1980	1981
Marketable securities (Approximate market value of $166,355,000 in 1980 and $148,367,000 in 1981)	$150,420,000	$156,261,000
Savings accounts and short-term commercial obligations	50,219,000	50,629,000
Settlements in process — Receivables for securities sold	4,720,000	2,751,000
Payables for securities purchased	(5,141,000)	(1,226,000)
Real estate, less amortization and accumulated depreciation of $3,431,000 and $3,560,000	16,114,000	18,242,000
Mortgages, notes and other securities	4,632,000	6,274,000
	$220,964,000	$232,931,000

Investments shown above include the investment pool as follows:

	September 30	
	1980	1981
Investment pool assets at year end — At carrying value	$151,654,000	$157,845,000
At approximate market value	$165,055,000	$152,505,000
Pool share value at market	$ 11.19	$ 10.06
Annualized income earned per pool share	$ .70	$ .85

Note D — *Funds Held in Trust:*

The Institute is the income beneficiary of certain funds, recorded at a nominal value, which are held in trust by others and which had current market values, estimated by the Institute, of approximately $8,000,000 and $9,000,000 at September 30, 1981 and 1980, respectively. The income derived from these funds amounted to $635,000 and $536,000 for the years ended September 30, 1981 and 1980, respectively. This income has been included as investment income in the Statement of Changes in Fund Balances.

In addition, the Institute is the trustee for several revocable trusts in which it has a remainder interest and for which it makes income payments for life to the grantors of the trusts. These trusts, totaling $3,464,000 and $3,300,000 at September 30, 1981 and 1980, respectively, have been excluded from the financial statements due to their revocable nature.

Note E — *Retirement Plans:*

The Institute has several retirement plans, covering substantially all its employees, that are funded by periodic transfers to the respective insurance companies. The provisions for these pension costs for the years ended September 30, 1981 and 1980, totaled $12,181,000 and $12,319,000, respectively, of which $9,483,000 and $9,398,000 are included in the direct costs of sponsored research at the Jet Propulsion Laboratory. The Institute's policy is to fund pension costs accrued. At the most recent annual valuation, the funded amount and balance sheet accruals for retirement plans were sufficient to cover the actuarially computed value of vested benefits. A comparison of accumulated plan benefits and plan assets for the Institute's defined benefit plans at the most recent annual valuation date (September 30, 1980) is presented below:

	September 30, 1980	
	Campus	JPL
Actuarial present value of accumulated plan benefits:		
Vested	$13,285,000	$59,142,000
Non-Vested	795,000	3,039,000
	$14,080,000	$62,181,000
Plan assets	$14,953,000	$65,041,000

In determining the actuarial present value of accumulated plan benefits as of September 30, 1980, the rates of return used were 5¾ percent for fixed dollar annuities and 3¾ percent for variable annuities. This represents a weighted average rate of 5 percent.

Note F — *Pledges:*

The Institute does not record pledges in its financial statements. At September 30, 1981, the Institute had pledges on hand (principally for restricted purposes) totaling approximately $23,100,000, of which $6,700,000 is expected to be collected in 1982. It is not practicable to estimate the net realizable value of such pledges.

Price Waterhouse

Century City
West Los Angeles, California
January 13, 1982

To the Board of Trustees of
California Institute of Technology

In our opinion, the accompanying balance sheet and the related statements of changes in fund balances and operating expenditures (Exhibits 1 through 3) present fairly the financial position of California Institute of Technology at September 30, 1981, and the changes in fund balances and the operating expenditures for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year. Our examination of these statements was made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

We have previously examined and reported upon the September 30, 1980, financial statements which are included in summary form for comparative purposes.

Price Waterhouse

Board of Trustees as of September 30, 1981