CALIFORNIA INSTITUTE OF TECHNOLOGY
PRESIDENT'S REPORT 1979-80

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1979–1980

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June 1981

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REPORT OF THE PRESIDENT

Marvin L. Goldberger

Marvin L. Goldberger, President

The academic year 1979–80 begins the decade of the 80's. For whatever reason, perhaps related to our infatuation with a number system based on ten, periods of ten years called the 70's, or 80's, etc., are deemed more significant than any arbitrarily chosen decades. I shall avoid the temptation (for this year anyway) to either philosophize on or to predict the shape of things to come. As usual the timing of this report makes the period to be appropriately described somewhat uncertain. You will find consequently that although the Saturn encounter by the Voyager spacecraft took place in November of 1980, we shall take credit for it here. Detailed descriptions of research projects will be found in the divisional reports that follow. I do, however, want to highlight a few of them here:

Owens Valley Radio Observatory
The second of three 10.4-meter diameter telescopes that will eventually form the Owens Valley Radio Observatory (OVRO) millimeter-wave interferometer was put into operation this year. Some of the research done with the two operational antennas is described in this report under the Division of Physics, Mathematics and Astronomy. But the importance of the combined potential of these telescopes—a real breakthrough for millimeter-wave astronomy—is worth special mention. When completed the interferometer will be by far the most sensitive telescope system in the world for detection of short wavelength radio waves from extragalactic sources, and for star-forming regions within the galaxy.

The telescopes are almost totally products of the Institute. They were designed by Robert Leighton—a member of the physics faculty since 1949 and of the OVRO since 1976—and they were built and assembled in laboratories on campus under the supervision of staff machinist David Vail. (The third telescope is currently under construction and will be installed some time in 1982.) Professor of Physics Thomas Phillips and Professor of Radio Astronomy Alan T. Moffet are currently in charge of the development and construction of the three-telescope interferometer.

A fourth telescope—a submillimeter-wave telescope—also being constructed at the Institute is destined for a new observatory on top of Mt. Mauna Kea in Hawaii, of which Phillips will be director. This telescope will be most important for detection of molecular and atomic species whose fundamental emission wavelengths are too short to be detected by any existing radio telescopes. Astronomers can then obtain a better understanding of the chemical nature of the star-forming gas within the galaxy.

Voyager 1

The year 1980 was an exciting one in planetary exploration, as Voyager 1 successfully completed its flight from Jupiter and went on to a spectacular encounter with Saturn. Caltech Professor of Physics Edward C. Stone is NASA's project scientist for the Voyager 1 and 2 missions, with the responsibility for coordinating scientific studies.

The Voyager 1 mission has had an impact beyond the expectations of the professionals who planned it, because its discoveries about Jupiter and Saturn have captured the imaginations of people not only in the United States but throughout the world. It is through a mission such as that of Voyager that the work for which Caltech is noted—fostering scientific discovery—becomes most accessible to the average citizen.

Voyager 1 visited Saturn in November 1980, sending back many surprises in its close-up views, not only of Saturn's rings and its satellites, but of the planet itself. In all, Voyager 1 took nearly 17,000 photographs, and nine other science instruments contributed startling new data. Fascinating pictures of the ring system revealed a complexity that no one had imagined. Saturn's large classical A, B, and C rings showed an unanticipated diversity, consisting of hundreds of individual ringlets—some wide, some narrow, some dense and opaque, some wispy and translucent, some circular and others eccentric, some twisted or braided.

Saturn's atmospheric dynamics were probed by Voyager, and its weather system was compared with what was learned from Voyager about Jupiter's atmosphere. Intriguing views of Saturn's satellites—and information concerning their diversities—contain important clues concerning the formation of the solar system. Voyager 2 will fly by Saturn next August to verify findings and no doubt generate new surprises and scientific puzzles.

Integrated Optoelectronics

Ten years of research by Amnon Yariv and his group in applied physics and electrical engineering culminated in demonstrating the feasibility of integrated optoelectronics. This new technology combines laser and transistor elements on monolithically grown, layered single crystals that are capable of switching light signals on and off five billion times per second. Integrated optoelectronics provides the link to exploit the enormous data-rate capabilities of semiconductor circuits and optical fiber communication systems. After lagging behind the Japanese in picking up on this pioneering work being done at Caltech, American industry is finally developing research programs of its own in this new field, which heralds a revolution in communications.

Gene Machines

The expensive, time-consuming, and relatively insensitive nature of existing laboratory methods of analysis of macromolecules has been one of the major roadblocks to applying the new, powerful techniques of genetic engineering to medical and biological problems. Years and even decades of work were often required to isolate even tiny samples from immense amounts of tissue. And even after these huge efforts, the samples were often too small to allow proper structural determinations. Similarly, long and painstaking procedures were required to produce synthetic DNA and RNA molecules for use in analytical and cloning procedures.

Thus, the development by Caltech biologists of high-sensitivity, automated machines to structure protein sequences and to synthesize DNA is nothing short of revolutionary. Involved in these developments are Bowles Professor Leroy Hood, Professor William J. Dreyer, and Senior Research Fellows Michael Hunkapiller and Rodney Hewick. They and their colleagues have already used their protein sequenators to structure numerous biologically important proteins, including human interferon, and a long line has formed of researchers seeking to have samples of scarce proteins sequenced.

The "spinning cup" protein sequenator was the first in this line of remarkable, elegant machines. A greatly improved version of existing devices, the sequenator features a small spinning cup into which is injected a protein sample. The various reagents required to snip off, one by one, and wash away the amino acid units of the protein chain are introduced into the cup. This device has proved ten thousand times more sensitive than existing sequencing devices, and is capable of analyzing samples of less than a microgram.

The researchers are now developing a second-generation "gas-phase" protein sequenator more sensitive than the first. They are also building an automated DNA synthesizer using similar instrumentation to the protein sequenator, and in collaboration with scientists at JPL are developing a highly sensitive mass spectrometer for amino acid analysis.

Faculty-Student Conference

An important event associated with education at Caltech was held in February 1980. For two days, meeting at the von Kármán Auditorium at the Jet Propulsion Laboratory, faculty, students and alumni discussed in detail all aspects of student life including both academic and social issues. We all learned a great deal from these talks and there has been extensive follow-up on the issues raised.

Changes in the Administration

Two major changes in the Caltech Administration took place. Professor Ray Owen stepped down as Vice President for Student Affairs and Dean of Students after five years of service. He has been succeeded by Professor James J. Morgan, Professor of Environmental Engineering Science. Eugene R. Wilson resigned as Vice President for Institute Relations to return to ARCO as Director of the ARCO Foundation. Dwain N. Fullerton, formerly Associate Vice President for Medical Development of Stanford University Medical Center, has taken his place.

Changes in the Faculty

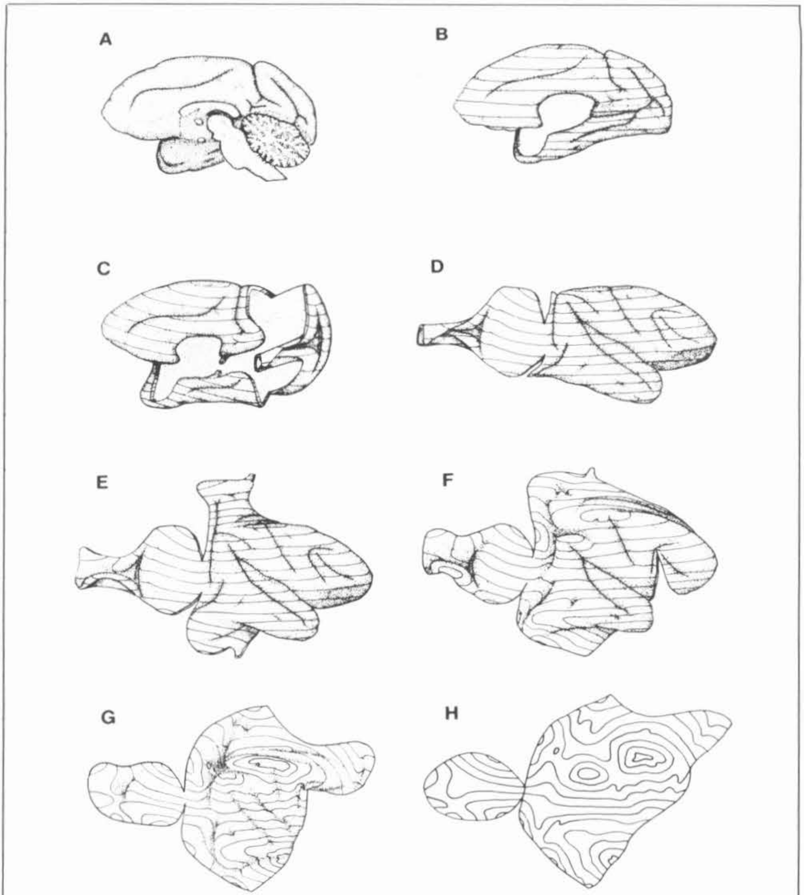
There were a number of resignations and retirements during the year. Professor Floyd Humphrey left to become Chairman of Electrical Engineering at Carnegie-Mellon University, and Professor James Mayer joined the Material Sciences Program at Cornell University. Professor Mayer was also Master of Student Houses; that position has been filled by Professor Sunney Chan.

Those who retired at the end of the academic year were: Francis H. Clauser, Clark Blanchard Millikan Professor of Engineering; Jesse L. Greenstein, Lee A. DuBridge Professor of Astrophysics; Robert V. Langmuir, professor of electrical engineering; Gilbert D. McCann, professor of applied science; John R. Pierce, professor of engineering; and Homer J. Stewart, professor of aeronautics.

Changes in the Board of Trustees

Two new members were added to the Board of Trustees: Mr. Donald R. Bower, Vice Chairman of the Board, Standard Oil Company of California; and Mr. Charles C. Gates, President and Chairman of the Board, The Gates Rubber Company.

DIVISION OF BIOLOGY



The cerebral cortex of the brain is divisible into many, functionally disparate subdivisions. Deep and complicated folds obscure almost half of the cortical surface, making the sizes and relative positions of these subdivisions difficult to determine. This diagram schematically depicts a process that allows the cerebral cortex of a monkey or other animals to be represented, without significant distortions of area or distance, on a flat map in which the folds have been opened.

Leroy E. Hood, Chairman

This has been an outstanding year for the Division of Biology in terms of research achievements and recruitment. Several professors have employed recombinant DNA techniques to make fundamental advances in our understanding of systems ranging from vertebrate antibody genes to Drosophila gene proteins. Among the highlights are the contributions by Professor Tom Maniatis and Bing Professor Mark Konishi. Maniatis is analyzing the organization and expression of the genes for human hemoglobin molecules. In addition to his fundamental contributions, these fascinating studies have yielded insights into the molecular basis of a series of human blood diseases termed the thalassemias. In quite another vein, Konishi has used barn owls to demonstrate that a particular nucleus in the brain stem is used to construct a three-dimensional auditory map of the external world. The question of how inputs from the two ears are interconnected to produce the map of auditory space constitutes a fascinating puzzle.

We welcome three new professors to our faculty—Howard C. Berg, John J. Hopfield, and Elliot M. Meyerowitz.

Berg received a Ph.D. in physics from Harvard in 1964 and subsequently shifted his research interests to the structure of cell membranes and bacterial motility. He came to us from the University of Colorado where he was professor of molecular, cellular and developmental biology.

Hopfield, formerly a professor of physics at Princeton, has brought to Caltech a general interest in the relationship between structure and function in biological molecules and assemblies. His particular interests include accuracy in the biosynthesis of macromolecules, electron transfer processes in bioenergetics, and nervous system function.

Meyerowitz, a Ph.D. from Yale in biology, comes to us from a postdoctoral fellowship in the department of biochemistry at Stanford Medical School. He is using recombinant DNA techniques to study gene expression in Drosophila, and he plans to pursue an analysis of eye-brain developmental interactions in this same organism.

The division wishes to pay special tribute to two of our own. Professor Norman Horowitz retired as chairman after a tenure of three years. We will miss his straightforward and common sense approach to running the division. Geraldine Cranmer, division chairman's secretary through the reigns of George Beadle, Ray Owen, Robert Sinsheimer, and Norman Horowitz, retired after 25 years of service. She takes with her our gratitude and appreciation for her incalculable contributions to division life, as well as for her tact and charm.

Research Notes

The Visual Cortex

Four research groups in the Division of Biology are involved in investigations of the visual cortex, the portion of the cerebral hemispheres concerned with processing information about sight. These studies are motivated in part by interest in the development and normal functioning of the visual pathways and in part by the fact that the visual system is currently the best model system for understanding the cerebral cortex in general.

There are two striking features in the organization of the visual cortex. First, the cortex is not homogeneous in its anatomical and physiological properties, but is divided into numerous areas, each characterized by a particular type of visual processing and a specific pattern of neural connections. Associate Professor John Allman was among the first investigators to demonstrate the extensive fragmentation of the visual cortex into smaller zones; he and his colleagues have by now found at least nine visual areas in the cerebral cortex of the owl monkey. While the physiological properties of nerve cells in the simplest of these regions are well described, work continues on areas specialized, for example, to detect moving stimuli.

The other important general feature of the visual cortex is that each of its subdivisions seems to contain a "map" of all or part of the visual field. In other words, the array of cells across the cortical surface corresponds to the array of positions in space at which visual stimuli affect the corresponding cells. While this arrangement is readily apparent in the simple brains of lower mammals, it is less clear in the highly convoluted cerebra of the higher monkeys whose vision most resembles that of man.

Associate Professor David Van Essen has found a simple means of "unfolding" the cortex of the macaque monkey in order to appreciate the relationships among various visual areas and the mapping of the visual field within each. This technique, which is schematically depicted in the illustration on page 10, allows the consistent representation of a highly folded cortex as a two-dimensional surface (see figure). The procedure is applicable to other cortical regions and to other species; it has already aided in the discovery of several new visual areas in the macaque and in the clarification of the pattern of connections among other regions.

The cerebral cortex of humans cannot be investigated with the range of experimental techniques available for animal studies. Professor Derek Fender and his colleagues have been able, however, to study cortical activity in the human visual system by extensive computer processing of electrical signals recorded from painless scalp electrodes. Visual stimuli evoke "brain waves" whose sites of origin may be inferred from a knowledge of the electrical properties of the head. Even simple stimulus patterns evoke relatively complex sequences of electrical signals that presumably correspond to the flow of excitation through multiple cortical areas. This technique for analysis of brain activity has the potential of extending our understanding of visual cortical areas from cats and monkeys to the human. Because of its non-invasive nature, it may also prove useful in the medical diagnosis of lesions in the posterior portion of the cerebrum.

Takuji Kasamatsu, senior research fellow in the laboratory of Associate Professor Jack Pettigrew, is continuing studies on the development of visual pathways. A complete repertoire of physiological functions is not present in the visual cortex of newborn animals. Instead, the cortex is "wired" crudely during development, then "fine tuned" as a consequence of early experience. While the cortex ordinarily reaches a stable, mature state within a few months after birth, Kasamatsu and Pettigrew have found that injections of the neurotransmitter norepinephrine into the visual cortex can prolong cerebral plasticity or even restore it to adult cats. This observation not only provides a valuable tool for further investigations of cortical organization, but offers hope that cortex returned to its plastic state with pharmacological agents could compensate for other cortex lost through trauma or cerebral vascular accident.

Architecture of the Animal Cell

A major tool used by the research group of Assistant Professor Elias Lazarides has been the fluorescent antibody technique. After inducing a rabbit to make an antibody against a purified protein, the antibody can be coupled to a fluorescent molecule, or the antibody can be detected by another antibody that reacts against rabbit antibodies and is fluorescently labeled. Fluorescence microscopy then provides an extremely sensitive technique for detecting this antibody, and the antibody can be used to find out where the original specific protein is located inside a cell.

David Gard, a graduate student in the Lazarides group, has been using this technique to study the formation of structures in developing muscle cells. His particular interest has been in two proteins, desmin and vimentin, which were originally identified as major protein components of "intermediate filaments" found in two distinct cell types. Both proteins also occur in typical skeletal muscle cells, and appear to be important for organizing the contractile proteins of the muscle into the highly ordered arrangement typical of skeletal muscle. The fluorescent antibody method indicates that desmin and vimentin have similar locations in both the developing and mature muscle cells. However, during development, the technique shows a sequential appearance of the two proteins. Vimentin is present at a very early state in development, while desmin does not appear until the final morphology of the cells begins to appear. A tentative hypothesis might be that newly synthesized desmin interacts with preexisting vimentin filaments to initiate the reorganization of the cytoskeleton into the form required in mature muscle cells, but other kinds of evidence will be required to support this hypothesis.

Antibodies have been used to probe the functioning of mature cells by Professor Charles Brokaw's group. This work is done with the tails, or flagella, which cause sea urchin sperm cells to swim by generating repeated bending waves that propagate along the flagella. Two proteins are known to be major constituents of flagella: Tubulin is the subunit protein of microtubules, which are the major structural element of flagella; and dynein is a multi-subunit protein structure that activates sliding between microtubules, and thus causes the flagella to bend.

Since these sperm flagella can be reactivated to move normally after removal of the cell membrane, they can be easily exposed to antibodies that have been made against dynein and tubulin by David Asai, a graduate student in the Brokaw group.

The effects of these two types of antibody are surprisingly different. At low concentrations, antibodies against tubulin reduce the amplitude of flagellar bending waves but do not show the inhibition of flagellar beat frequency that is found with antibodies against dynein. Other experiments show that under conditions where flagellar bending is completely suppressed, only the antibody against dynein inhibits the active sliding between microtubules. Makoto Okuno, a postdoctoral fellow in the Brokaw group, has been able to make direct measurements of the stiffness of flagella, by bending them with fine, calibrated glass microneedles. His measurements show that antibodies against dynein cause flagellar stiffness to increase, probably by stabilizing dynein cross-bridges between microtubules. Antibodies against tubulin cause only a very transient increase in stiffness, which decays within ten seconds. This may be sufficient to explain the inhibition of bending, but not sliding, by these antibodies. Dynamic measurements of the mechanical impedance of the flagella are now needed to gain further understanding.

Sequencing of Alphavirus Genomes

The alphaviruses are a group of about 20 closely related animal viruses, many of which are important human or veterinary pathogens. For example, several equine encephalitis viruses (Western, Eastern, Venezuelan) are endemic in the United States and each year cause hundreds of human cases, including a number of fatalities. The viruses are communicated by the bites of infected mosquitoes. They have the fascinating ability to replicate in both higher organisms such as birds and mammals and in lower organisms such as mosquitoes. The viruses are also of interest to the molecular biologist because they mature by budding through the host cell plasma membrane, acquiring a lipoprotein envelope in the process. Recent studies in the laboratory of Associate Professor James Strauss have used a combination of nucleotide sequencing of virus RNA and amino acid sequencing of the virus proteins to study the molecular biology of virus replication and the relatedness of the members of the group.

Nucleotide sequencing of the ends of several alphavirus RNAs has revealed interesting patterns of sequence homologies and divergences. For example, the sequences at the extreme ends of all the RNAs are similar. Probably these conserved sequences serve as binding sites for the virus enzyme that replicates the RNA after infection. Other sequences are found in some, but not all, alphaviruses; these are often found in different positions in the various RNAs. One particularly interesting set of conserved sequences is found in three virulent members of the group (i.e., viruses that cause severe human disease) but not in three avirulent members of the group. The significance of such findings is not clear at present but such studies may eventually help to define the evolutionary history of these viruses and the reasons why some viruses cause human disease while others, even though they infect humans, do not cause disease.

In a related sequencing study, the entire sequence (4000 nucleotides) of the messenger RNA for the structural proteins of one of the alphaviruses (called Sindbis virus) has been determined. Using the genetic code, the amino acid sequence of these proteins, which include a nucleocapsid protein and two integral membrane glycoproteins, can be deduced. This sequence reveals much about the functioning of these proteins. For example, the sites of attachment of the polysaccharide chains to the glycoproteins, and those regions of the proteins that traverse the lipid bilayer, are now known. In addition, much has been learned from the sequence about the processing and transport of the proteins. Thus these studies are important not only for what they tell us about the replication of these viruses but also for what they reveal about how membrane proteins are synthesized, processed, and transported.

Genetics, Motility, and Behavior

Genetics has not been a major source of information about the mechanisms of operation of muscles in higher organisms, because defective operation of muscle affects so many processes that mutations are usually lethal. With microorganisms the situation is different, because such organisms can usually remain viable even if their capacity for movement is seriously impaired.

Professor Howard Berg's group studies the motility of bacteria. Bacterial cells have rotary motors that drive a helical protein filament, which acts as a propeller to push the bacteria through the water. Berg and his collaborators have shown that the rotary motor is driven by a flux of protons—H^+ ions—through the bacterial cell membrane, in response either to a voltage difference or an H^+ ion concentration difference across the membrane. By manipulating these differences, they obtained the surprising result that the direction of rotation of the motor was the same for both inward and outward proton fluxes. At face value, this observation would make the operation of the motor very difficult to understand. However, there may be a trivial explanation. These cells also have a "gearshift," which allows them to reverse the direction of rotation of the motor in order to respond to chemical stimuli. They use this capability for chemotactic behavior to avoid repellant chemicals and aggregate in the presence of attractant chemicals. The experimental manipulations required to reverse the proton flux may reverse the motor rotation and also activate the "gearshift" reversing mechanism, which restores the original direction of rotation.

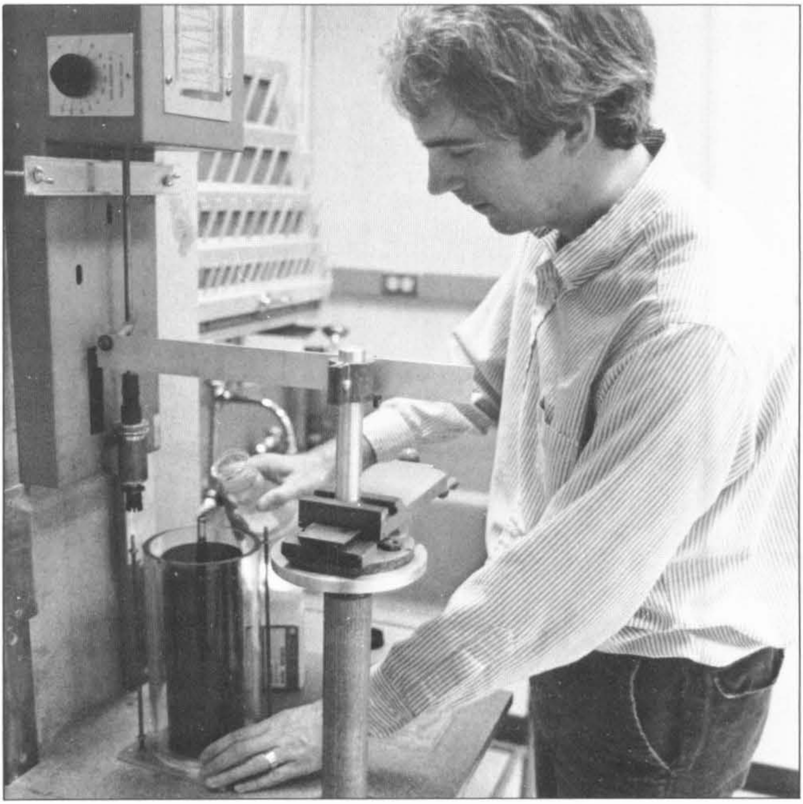
To test this hypothesis, Berg's collaborators are isolating non-chemotactic mutants, which are lacking the "gearshift" response. When fully characterized, these mutants can be used to reexamine the relationship between proton flux and motor rotation direction.

Another member of Berg's group, research biologist Dr. Robert Smyth, has been studying the phototactic, or lightseeking, response of a unicellular plant, Chlamydomonas. These cells have two flagella that extend from the forward end of the cell and propel the cell by a "breaststroke" pattern of bending. Strong light stimuli cause these cells to change the bending pattern of the flagella to a pattern of symmetrical undulation, which causes the cell to swim backwards.

These changes in beat pattern are difficult to study in actively swimming cells. In collaboration with Professor Brokaw and Professor David Luck of The Rockefeller University, Smyth has been using a mutant of Chlamydomonas that has only one flagellum. Instead of swimming forward in a normal manner, the single flagellum causes these cells to spin around next to a surface with their flagellum bending in a plane parallel to the surface. These conditions are ideal for photographic recording of the details of flagellar bending, and the use of this mutant will permit a much more detailed examination of the response of the flagellum to light stimuli.

Light responses are also an important part of the behavior of Phycomyces, a simple fungus that Professor Delbrück's group has been studying for over 25 years. Their work has revealed that the photoreceptor is probably a flavoprotein—a combination of a protein and the B vitamin, riboflavin. The next step is more difficult, because flavoproteins are involved in many roles in this organism—which flavoprotein is the photoreceptor? Members of Professor Delbrück's group hope to answer this by a search for non-photoreceptive mutants that are defective in the photoreceptor but normal in other flavoprotein functions.

DIVISION OF CHEMISTRY AND CHEMICAL ENGINEERING



Assistant Professor of Chemical Engineering Eric Herbolzheimer prepares a couette flow device used to measure the sedimentation velocity of particles in sheared suspensions.

Harry B. Gray, Chairman

During 1979–80, the Division of Chemistry and Chemical Engineering continued varied and exciting programs in many fields of research. Of particular interest were the outstanding contributions of new faculty members, and their research programs are featured in this report.

Randal K. Sparks, Noyes Research Instructor in Chemistry, received his A.B. from Harvard College and his Ph.D. from UC Berkeley; he studies crossed molecular beam reaction dynamics. Terrence J. Collins, assistant professor of chemistry, received his B.S., M.S., and Ph.D. degrees from the University of Auckland; he leads a group developing new classes of oxidizing agents. Kenneth C. Janda, assistant professor of chemistry, came to Caltech in 1978 as a Noyes Instructor in Chemical Physics after receiving a Ph.D. degree from Harvard University in 1977; he studies the structures of weakly bonded molecules.

Dennis Dougherty, assistant professor of chemistry, received a Ph.D. from Princeton in 1978 and joined the Institute faculty in 1979; his group hopes to develop long-lived biradicals that can be studied by spectroscopic techniques. Eric Herbolzheimer, who came to Caltech in 1980 as an assistant professor of chemical engineering, had been awarded M.S. and Ph.D. degrees by Stanford University; he investigates the flow phenomena of suspensions.

James E. Bailey, professor of chemical engineering, received his degrees from Rice University; he comes to Caltech from Houston. His research concerns chemical reactor theory and biochemical engineering.

Molecular Beams

Many important chemical processes such as combustion, smog formation, and ozone layer depletion occur in the gas phase. These gas phase systems are sufficiently dilute that the molecules in the gas spend a very small percentage of their time around other molecules. When the molecules do come in contact, they will interact, usually in twos and occasionally in threes, without consideration of the other molecules in the surrounding gas. The products of these encounters then travel off into the rest of the gas to undergo other collisions at some later time. The development of the chemistry of the gas as a whole is just the sum of the results of these individual collisions. If the outcome of these individual collisions were known, the chemistry of the gas under any desired condition of pressure, temperature, or flow could be predicted. Unfortunately, these individual collisions cannot be studied in the gas itself since the velocities and internal energies of the reactants are randomly distributed throughout the gas. Furthermore, the products usually undergo additional collisions before they can be studied.

Randy Sparks and his group are using the method of crossed molecular beams to study these individual molecular collisions under precisely defined conditions. Two separate beams, one each of the two reactants to be collided, are created by expanding gases of the reactants at high pressure through a small hole into a very low pressure vacuum. In such a supersonic expansion, all of the molecules end up traveling at the same speed. The internal energies of the reactants are also cooled to temperatures of only a few degrees above absolute zero, thus producing a very narrow distribution of internal energy states. The two beams are then collimated to a very narrow angular spread and crossed in a well-defined collision region. In this region, only about one percent of the molecules undergo a collision and only one half of one percent of those will have a second. A mass spectrometer detector is then placed "downstream" of this zone so that it sees only the molecules that have undergone collisions. The detector can determine the chemical composition, direction of travel, and energy of any molecule coming from the collision zone.

Results of these types of experiments, when performed at many different initial collision energies, provide a complete picture of all that these two molecules could do in a general real world gaseous system. Systems under study at present include reactions that are important in combustion processes and in the earth's atmosphere. These basic studies will lead to a much better understanding of these systems and should allow us to improve combustion efficiency, minimize pollutants, and protect the earth's fragile ozone layer.

Novel Oxidizing Agents
Because oxygen-containing compounds are among the most important chemicals, there is a pressing need for new ways of selectively introducing oxygen atoms into molecules. New methods might well expedite syntheses of complex organic molecules such as natural products or drugs, or to produce more economically simple oxygen-containing compounds like propylene oxide—a major feedstock for the chemical industry.

The incorporation of oxygen into molecules is often accomplished using oxidizing agents, a major class of chemical reagents, and Terrence J. Collins and his research group are endeavoring to develop novel metal-containing compounds that are expected to function as a new class of oxidizing agents. In these efforts they are focusing on an area of chemistry that bridges the major subdisciplines of inorganic and organic chemistry. The most frequently used oxidizing agents in organic chemistry are, in fact, a select few metal-containing oxygen compounds with a strong tendency to transfer their oxygen atoms to other compounds. The number of such oxidizing agents is rather small, however, primarily because only a few types of ligands are capable of stabilizing the metal in the very high oxidation states required. Virtually all these ligands are joined to the metal through one site. The Collins group is working to show that many more metal-containing oxidizing agents can be developed by using ligands that are joined to the metal through more than one position. Using this "chelation" approach it may prove possible to deliberately incorporate into oxidizing agents many of the highly desirable features that chemists seek in chemical reagents, including selectivity, that is, the tendency to react with other compounds in only one of a number of possible ways.

Weak Chemical Bonds
Most chemists study reactions that involve making and breaking strong bonds in molecules that are stable at room temperature. Much weaker bonds are also important in chemical reactions, even though they may exist for only a fraction of a second at room temperature and their position may fluctuate in a seemingly random manner. Weak bonds provide the initial attraction between a chemical reagent and a catalyst surface. Furthermore, when many weak bonds cooperate, they may determine the ability of solvents to promote one kind of reaction at the expense of another or define the way that large biological molecules coil up to obtain their special function in living

creatures. For all their importance the detailed properties of weak chemical bonds are virtually unknown. Ken Janda's research is addressing weakly interacting systems in an attempt to fill this gap.

Using a technique called supersonic expansion, Janda's research group is able to make very weakly bound molecules in the gas phase where their structures and reactions can be studied. Until they reach a wall of the apparatus, the molecules are effectively at a temperature near absolute zero, and thus they are stable. The molecules in the gas phase are studied by exciting them with a laser. In one experiment the laser deposits energy into a strongly bound part of the molecule. Eventually the energy flows from the region of a strong bond to the region of weak bonds. The molecule then falls apart. By timing this energy flow for different molecules, Janda's group hopes to determine the mechanism for energy flow within molecules. In a second experiment, weakly bound molecules composed of metal atoms are excited with a laser in such a way that their structure can be determined. An important question being addressed is how many metal atoms are necessary to establish the essential electronic properties of a metal solid. Collisions between cold gas molecules and cold metal surfaces are also studied to determine initial steps in certain reactions catalyzed heterogeneously.

Organic Biradicals

The current research efforts of Dennis Dougherty and his group focus on the design, synthesis, and characterization of small organic molecules that defy the standard rules of valence. In particular, they hope to study biradicals, chemical species which can be thought of as structures that contain one or more broken C-C bonds. Although biradicals are frequently postulated as intermediates in a variety of important chemical and photochemical reactions, they are extremely reactive species, and thus direct observation and characterization have been difficult. The presence of unpaired electrons in such species presents a challenge for current theoretical models of electronic structure. Dougherty's goal is to make long-lived biradicals that are amenable to direct spectroscopic characterization. Unusual physical and chemical properties can be anticipated for such species.

Using qualitative and quantitative theoretical models, systems are designed in which structural and electronic factors conspire to make the normal modes of biradical reactivity energetically and/or kinetically unfavorable. Thus the lifetimes of these biradicals should be greater than normal. New synthetic routes are also being developed to cyclic azo compounds that will serve as precursors to the biradicals. On exposure to ultraviolet light, azo compounds extrude molecular nitrogen (N_2) and leave behind an organic biradical. Such photochemical reactions can be done at temperatures as low as 4°K under matrix isolation conditions that minimize deleterious side reactions. A variety of spectroscopic techniques can then be used to study the electronic structure and stability of the biradicals. From the knowledge gained about the "bond-broken" species currently under investigation, the group anticipates new insights into the intrinsic reactivities of organic molecules.

Fluid Flow

In Eric Herbolzheimer's research program a combination of theoretical and experimental techniques is being used to investigate fluid flow problems that are important from both a fundamental and a practical viewpoint. Currently, his work is focused on examining flow phenomena of suspensions, particularly for systems in which the sedimentation of the particle inclusions relative to the suspending fluid plays an important role. Since such flows arise in a broad range of natural and industrial processes, the overall goal of this program is to develop a general framework for describing them theoretically. To this end, the flow is being examined on both the microscopic and the macroscopic level.

On the microscopic scale, information about the fluid motion around the individual particles is used in conjunction with averaging and statistical techniques to derive equations governing the motion of the suspension as a whole. Since that state of arrangement of the particle inclusions is a key factor in determining the flow characteristics of a suspension, a major part of Herbolzheimer's research is to investigate to what extent their positions can become partially ordered as a result of multi-particle hydrodynamic interactions within quiescent sedimenting suspensions and to determine how this ordering is altered when the suspension is sheared. For example, these considerations led to the prediction (which has been confirmed experimentally) that the average sedimentation velocity of the particles can be significantly increased by shearing the suspension. In order to understand this surprising result more fully, analytical methods are being employed in conjunction with numerical simulations to follow the time evaluation of the microscale structure from a given initial state. From the experimental standpoint, a specially designed shear device is being used to measure the average sedimentation velocity, and, in the future, Herbolzheimer hopes to use optical techniques to probe the microscale structure directly.

The second aspect of this program is to investigate how the interaction between the local state of motion of the suspension and its properties can affect macroscopic flows of technological importance. For example, it has been shown that the dependence of the sedimentation velocity on the local shear rate can lead to particle concentration gradients. Consequently, when a suspension is sheared non-uniformly, density variations can arise resulting in a novel form of natural convection that can dramatically alter the character of the flow. This phenomenon is being investigated in connection with several important flow processes including the stability of boundary layer flows of suspensions and the mixing of pure fluid jets with suspensions.

Chemical and Biochemical Reactors

The common theme underlying James Bailey's research in chemical and biochemical catalytic reactors is optimization of catalyst performance. Embraced within this theme are studies of steady-state and dynamic behavior of supported populations. Processes employing such catalytic entities are central to current and future reaction operations of the chemical, fermentation, and food processing industries.

Bailey's research on microbial population dynamics is aimed at determining basic biochemical kinetic and regulatory processes in individual cells based upon interrelated mathematical modeling and experimental studies. The cornerstone of the experimental program is a laser flow microfluorometry system that permits measurement of morphological and chemical characteristics of an individual cell in less than one millisecond. Accumulated data of this sort characterize the distribution of states in the cell population, which in turn is directly related to control of cell division and the kinetics of biosynthesis through the appropriate population balance equations. A spore-forming bacterium and two different yeast strains have been studied to date using this technique. This work seeks to optimize microbial reactor performance by viewing the reactor as a propagator of a microbial population. Then the biochemical reaction engineer's task is to design and operate that reactor in order to produce the best distribution of characteristics in the individual cells that make up the resident population.

Research in immobilized enzymes and immobilized cells focuses on the effects of immobilization chemistry and the physical and chemical characteristics of the support upon the intrinsic and overall characteristics of the immobilized catalysts. Previous research has revealed significant sensitivity of immobilized biocatalyst activity and deactivation properties to operating conditions during the immobilization reaction. Understanding these phenomena, which would lead to a rational design scheme for optimum catalyst formulation for given process requirements, is a major objective of the current immobilized biocatalyst research in Bailey's group.

Intentional unsteady state operation of catalytic reactors can provide experimental insights into the underlying physical and chemical steps and also can improve overall reactor stability, parametric sensitivity, and product yield. Transient studies of acetylene and ethylene hydrogenation on supported nickel catalysts are currently in progress in a gradientless, computer-coupled continuous flow reactor. A coordinated theoretical effort seeks to derive and to demonstrate a paradigm for deriving dynamic mathematical descriptions of catalysts. These dynamic models can then provide the needed basis for analysis of control, stability, and dynamic optimization of catalytic reactors, especially in cases where events on the catalyst surface significantly influence overall reactor dynamics.

Awards to the Division

Several members of the division were recognized for outstanding contributions to their fields. John Baldeschwieler was elected to membership in the American Philosophical Society. John Bercaw received the 1980 Award in Pure Chemistry from Alpha Chi Sigma, presented to a chemist under 35 years of age "for his pioneering research in synthetic organometallic chemistry."

William H. Corcoran was elected to the National Academy of Engineering, and was elected a Fellow of the American Association for the Advancement of Science. He was also chosen as the 1980 Engineer of the Year by the Institute for the Advancement of Engineering.

Norman Davidson was named California Scientist of the Year by the California Museum of Science and Industry. Dennis Dougherty was awarded a Dreyfus Grant for newly appointed young faculty in chemistry. Ahmed Zewail also received an award from the Camille and Henry Dreyfus Foundation—a Teacher Scholar Grant for his achievements in research and teaching.

Harry Gray was awarded the CUNY (City University of New York) Medal, as well as the Richard Chace Tolman Medal for 1979. Cornelius J. Pings was elected a Fellow of the American Institute of Chemical Engineers.

John Seinfeld received NASA's Public Service Medal for his work as chairman of a NASA committee to formulate a tropospheric research plan.

Two divisional faculty members were awarded named professorships in 1979–80. W. H. Corcoran became the Institute Professor of Chemical Engineering and John H. Seinfeld became the Louis E. Nohl Professor and Professor of Chemical Engineering. John J. Hopfield joined the faculty as the Roscoe G. Dickinson Professor of Chemistry and Biology; he received a joint appointment to the divisions of biology and chemistry and chemical engineering.

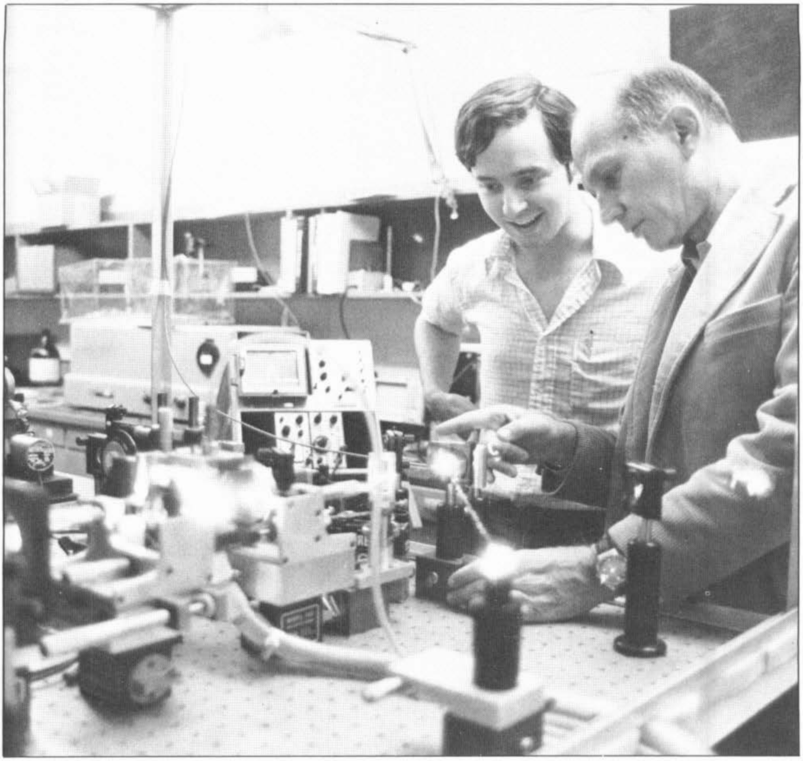
Sunney Chan, professor of chemical physics and biophysical chemistry and executive officer for chemistry, has traded his second title for another—Master of Student Houses. He will be responsible for the "quality of life" in the seven undergraduate houses.

Associate Professor of Chemistry Peter Dervan was given an award for teaching excellence by the Associated Students of the California Institute of Technology.

The Sigma Xi Award, given annually to a senior for an important piece of original research, was won in 1980 by twin brothers, Mark and Paul Seidler. They were given their award for research in organometallic chemistry in collaboration with Professor John Bercaw. The brothers also shared the American Institute of Chemistry Student Award.

The 1980 Herbert Newby McCoy Award for outstanding contributions to chemistry was won by an unprecedented number of graduate students, eleven predoctoral men and one woman: David Bomse, Gary W. Brudvig, Horace R. Drew III, Richard Hardy, Lawrence McGee, Anthony Rappé, Randy Robinson, Duane Smith, Clifford Spiro, Patricia Thiel, Richard Threlkel, and Peter T. Wolczanski.

DIVISION OF ENGINEERING AND APPLIED SCIENCE



Dr. Amnon Yariv and graduate student Tom Koch make adjustments on a dye laser and amplifier system capable of producing a continuous stream of gigawatt peak power optical pulses with durations of one picosecond (10^{-12}s). This system is used to study ultrafast processes and switching phenomena in semiconductors.

Roy W. Gould, Chairman

Honors and Awards

Gerald B. Whitham, professor of applied mathematics, received the 1980 Norbert Wiener Prize. One of the most prestigious awards in mathematics, it is given every five years by the Society for Industrial and Applied Mathematics and the American Mathematical Society. Whitham, who shared the prize with Tosio Kato at the University of California at Berkeley, was cited for his contributions to the understanding and methodology of fluid dynamical phenomena. The 1980 prize for outstanding achievements in fluid dynamics, awarded by the American Physical Society, went to Hans W. Liepmann, Charles Lee Powell Professor of Fluid Mechanics and Thermodynamics. Amnon Yariv, Thomas G. Myers Professor of Electrical Engineering and professor of applied physics, received the 1980 Award in Quantum Electronics from the Institute of Electrical and Electronic Engineers. The American Chemical Society's Award for Creative Advances in Environmental Science and Technology was given to James J. Morgan, professor of environmental engineering science and vice president for student affairs. A power converter, dubbed the "Cuk Converter," invented by Slobodan Cuk, assistant professor of electrical engineering, and Robert D. Middlebrook, professor of electrical engineering, was selected as one of the 100 most significant inventions of 1979 by *Industrial Research/Development* magazine. Professors William Bridges and Joel Franklin were cited by our undergraduate students for their excellence in teaching.

Gregory Gartrell, Jr., Weizmann Research Fellow in Environmental Engineering Science, was the winner of the 1979 Lorenz G. Straub Award for the best Ph.D. thesis in English in hydraulics, hydrology, or water resources. This is the fifth such award received for Caltech doctoral research in this field. The second recipient of the Henry Ford II Scholar Award, given annually to the student with the best academic record in the Division of Engineering and Applied Science, went to Erdal Erikan, now a senior in electrical engineering. Steven G. Eaton was awarded the David Joseph Macpherson Prize in Engineering as the 1980 graduating senior in engineering who best exemplified excellence in scholarship.

The Changing Scene

The division is pleased to welcome four new additions to our professorial faculty this year. Michael Hoffmann has joined us as associate professor of environmental engineering science. Hoffmann's research interests are in water chemistry; he joins us from the University of Minnesota where he was assistant professor of environmental engineering. Charles Seitz, previously a Caltech research associate, has been appointed associate professor of computer science and will continue his research on computer architecture. David Rutledge, who received his Ph.D. this year from the University of California at Berkeley and who has research interests in electronic devices, has been appointed assistant professor of electrical engineering. George Milne, whose interests lie in the theory of computation, has been appointed assistant professor of computer science. He received his Ph.D. at Edinburgh and served for one year as assistant professor of computer science at the University of Southern California. We are fortunate to have these young men and look forward to their contributions to our programs.

In recognition of their outstanding contributions to research and teaching, several of our younger faculty have been promoted: William L. Johnson to associate professor of materials science with tenure, Darryl L. Smith to associate professor of applied physics with tenure, Bengt Fornberg to associate professor of applied mathematics with tenure, and Associate Professor Christopher Brennen to tenure. We are also pleased to have three new endowed professorships in the division: the Gordon and Betty Moore chair in computer science, the Thomas G. Myers chair in electrical engineering, and the Simon Ramo chair in engineering. Carver Mead, Amnon Yariv, and Roy Gould have been named, respectively, to these positions.

This year, unfortunately, we have had an unusually large number of losses. Changes in the retirement program of the Institute have made it attractive for several of our distinguished senior faculty to retire earlier than might otherwise be the case. Of course we look forward to their continued counsel and guidance as professors emeriti. Francis Clauser, Clark Millikan Professor of Engineering, came to us from the University of California at Santa Cruz in 1970 to guide us as chairman of the division. He served us well in that capacity until 1975. John R. Pierce came to us in 1974 after a distinguished career at the Bell Telephone Laboratories. He has served as professor of engineering and, during the past two years, as chief technologist for the Jet Propulsion Laboratory. Robert V. Langmuir, professor of electrical engineering, and Gilbert D. McCann, professor of applied science, came to us from General Electric and Westinghouse, respectively, and served the division for 30 years and 34 years, respectively. Homer J. Stewart, professor of aeronautics, has been with us since receiving his Ph.D. in 1940. Each of these men received his doctoral degree from Caltech, and each has served his alma mater well.

Departures to other universities and to industry include: Professor Floyd B. Humphrey to Carnegie-Mellon University to become head of the department of electrical engineering; Ivan E. Sutherland, professor of computer science, to private consulting; James W. Mayer, professor of electrical engineering, to Cornell University; Thomas R. Hughes, associate professor of applied mechanics, to Stanford University; and Charles R. Minter, assistant professor of computer science, to industry. We wish them well in their new endeavors.

It is with deep regret that we report the passing of Jack McKee on October 22, 1979. Jack had been at the Institute since 1949 and was a professor of environmental engineering at the time of his death.

Below we give some highlights of our research program. A more complete account will be found in the division's annual report, which is available on request.

Conformal Mapping with Computers

The arrival of digital computers and a variety of powerful numerical methods in the past few decades has led to intense efforts in finding practical algorithms for various mathematical procedures. The well-known mapping theorem of Riemann was formulated by him in his thesis in 1851, but was not rigorously proven for about 50 years. Riemann's theorem states that any simply connected region can be mapped into a circle by an analytic function. Such mappings have become major tools in studying many physical phenomena, ranging from the distribution of electromagnetic fields to the flow past an airplane wing. During the past year, Bengt Fornberg, associate professor of applied mathematics, discovered a very efficient numerical method for carrying out this procedure. Several methods were known that map certain "near-circular" regions into circles, but mapping more general smooth regions required a great deal of computing time. If N is the number of points used to discretize the boundary of the region, then of the order of N^3 operations were required. Fornberg's method requires far fewer operations (order [N log N]), as did the simpler shapes. This result should dramatically increase the applicability of the conformal mapping by computers. Values of N from 10,000 to 100,000 can now be used, instead of about 100, which was all that was possible with earlier methods, thus increasing the accuracy of the representation. The new method has already been used to study time-dependent free surface waves in deep water, using the CDC CYBER 203 computer in Minnesota. Access to this machine has been made available to the applied mathematics group by the Control Data Corporation for research in numerical fluid mechanics.

U.S.-China Earthquake Engineering Activities

In 1976 a magnitude 7.8 earthquake destroyed the industrial city of Tangshan, causing more than a quarter of a million deaths. This disaster is one reason the Chinese engineering and science communities want to learn more about developments in earthquake engineering, and have sent several delegations to the U.S. and to Caltech. At the same time our division is interested in obtaining near field ground motion records from destructive earthquakes.

In 1978 the first earthquake engineering delegation from the United States visited China and was briefed on the engineering aspects of the Tangshan earthquake. Braun Professor George Housner was chairman of that delegation, and Professor Paul Jennings was secretary. A 200-page report, "Earthquake Engineering and Hazards Reductions in China," edited by Jennings and published by the U.S. National Academy of Sciences, describes the 1976 Tangshan and Sungpan-Pingwu earthquakes.

In 1979 a formal U.S.-China cooperative research program in earthquake engineering was approved by the two governments, and one of the first projects involves the installation of an array of strong-motion measuring instruments in China. Professor Wilfred D. Iwan is the principal investigator and coordinator of the project, which also involves the U.S. Geological Survey and the University of Southern California. A unique aspect of the array is that it will incorporate features of both a fixed and a mobile array. Deployed on a standby basis in a seismically active region of China, it will be capable of rapid deployment in the case of a credible earthquake prediction or to study strong aftershocks. Records will be made available to researchers through existing worldwide channels.

Seismic Ray Tracing

Signals from abrupt disturbances in the earth, such as earthquakes or explosions, propagate along curves known as seismic rays. A knowledge of the rays, which join a source to a known receiver, is of primary importance in locating hypocenters of earthquakes and in geophysical prospecting. They play an equally important role in the more general geophysical inverse problem of locating faults, material discontinuities, and density variations within the earth.

An extremely fast, accurate, and novel method for computing the trajectories of seismic rays joining two arbitrary points in a stratified medium has been developed by Professor Herbert B. Keller and his student, David Perozzi. Their method is based on a mathematical technique known as homotopy continuation. In general there are 2^N distinct rays joining the two points and meeting the N surfaces of discontinuity between them. When one of these rays is known, it is easy, using continuation methods, to compute the others. A trick is used to get the first ray. Any path joining the two points and meeting the N interfaces is chosen and then a "fake" medium is found for which this would be the exact seismic path. Using this ray as a start, the homotopy then changes the "fake" medium into the correct one and in doing so also provides the correct first path.

Using these results extremely complicated "seismograms" can be computed for various models. The ease with which all the details are now accurately determined for the model suggests that much of the detailed information previously disregarded in the observed seismograms can be used for more accurate predictions. The new technique has also been employed in designing a general geophysical inverse program, which determines source location, wave speeds, and discontinuity surfaces from seismic data.

Silicon Structures

The Silicon Structures Project, a joint endeavor between industry, Caltech, and the federal government, has grown significantly this year. New additions to the project include the Honeywell Corporation, Motorola, Fairchild, Sperry-Univac, and the National Science Foundation. Continuing sponsors include the Burroughs Corporation, Digital Equipment Corporation, Xerox Corporation, the Hewlett-Packard Company, Intel Corporation, and the International Business Machines Corporation. One of the key elements of SSP is the participation by visiting scientists from each of the industrial sponsors. The central problem addressed is the design of very large scale integrated systems, with particular emphasis on design tools.

Design of Computing Machines

The first group of students received their Ph.D. degrees in the computer science graduate option that was first offered four years ago. Though still small in number, the program is attracting outstanding students, and several of the theses written by members of this first group of students have developed into ongoing research projects sponsored by the Defense Advanced Research Projects Agency. Two of the notable pieces of research that will be continued were by Sally Browning on tree machines and by Bart Locanthi on the homogeneous machine. Both of these works deal with new forms of computer architecture for parallel computation and were supervised by Charles Sietz, associate professor of computer science.

A precise scheme for interprocessor communication was developed for the tree machine concept, which could involve thousands of small programmable processors. Programs and data can be loaded into the "tree" from the root, and communicated on up, and programs can be executed concurrently with the results communicated back down the tree to the root. Programs written to run on a hypothetical tree machine were useful in evaluating its potential performance.

Research on the homogeneous machine addresses the general problem of orchestrating many computing elements in the performance of general purpose computations. Programs must be expressed in a notation that allows concurrency to be discovered and exploited, and computations must be mapped onto a physical structure for execution by multiple processors—which must also have rapid access to storage while at the same time avoiding contention. These ideas were brought together in the design of a multi-level LISP system implemented on a tree of processors.

Interfaces between Semiconductors and Metals

The interface between a semiconductor like silicon and a metal has many important electrical characteristics that are useful in electronic devices. The most important property of the interface can be characterized by a single quantity, referred to as the Schottky barrier, the height of the electrical barrier that forms on the semiconductor side of the interface. In practice the simple classical model of Schottky barriers has been found to work well only for a few semiconducting materials, and a considerable effort has gone into understanding its failure in other cases. Recently Professor James O. McCaldin, working with graduate student Tom Kuech, has employed a particularly simple system to test various hypotheses for the nonclassical behavior. They have been employing "lattice- matched" heterostructures such as mercury-telluride, which is metallic, and cadmium-telluride, which is semiconducting. These combinations of materials have very nearly the same lattice spacings, and very few, if any, structural defects at the interface. This simplifies the situation considerably. Their studies of such heterostructures now suggest that the Schottky barrier height is related to the presence of certain types of defects in the bulk cadmium-telluride. Such studies may lead to the ability to control the barrier height in various electronic devices, such as solar cells and detectors, and therefore lead to improved performance.

Integrated Optical Technology

Professor Amnon Yariv and his colleagues have demonstrated in a series of electronic devices the feasibility of a new technology that brings together lasers and transistors. The new devices consist of single crystal monolithic structures of gallium-arsenide and "lattice-matched" gallium-aluminum-arsenide. By growing submicron-thick layers of these crystals, which have been doped with impurity atoms, on top of one another, the devices can be made to perform the functions of electronic transistors as well as those of miniature semiconductor lasers. The transistors are used to switch the lasers on and off at rates exceeding five billion times per second. This new technology is spurred on by the need for ultra-highspeed switching of light in optical fiber communication systems. In a separate set of experiments, Yariv's group has demonstrated experimentally the possibility of performing real-time holography, an idea that was conceived and analyzed by the group several years ago. The specific demonstration used the photorefractive effect (a change in the index of refraction of light by light itself) to simultaneously write and read holograms in bismuth silicate. A real-time convolver and correlator of optical images has been demonstrated.

Energy Loss in Fusion Plasmas

For more than twenty years scientists and engineers have been struggling to show that electrical energy production by nuclear fusion reactions would be possible. One of the key problems has been to determine why the rates of energy loss from the hot ionized gases, or plasmas, that would be used in a fusion reactor are so much larger than had been expected and to reduce them, if possible. Experiments of the past few years have shown that the rapid energy loss can be overcome by making the plasma vessels larger and by increasing the plasma density. They have also shown that the necessary burning temperatures can be achieved. On the basis of these favorable results, the fusion energy program is moving into serious effort to solve reactor engineering problems. Nevertheless the anomalous energy loss rates remain and make the objective more costly to attain. Professor Roy Gould and his students, Mark Hedemann and Bruce Levine, have been studying the plasma turbulence and its effect on energy transport. They have shown experimentally that the magnetic field containing the plasma is constantly fluctuating and have determined some of the properties of the fluctuations. Under some circumstances, fluctuations are found that are relatively simple and coherent over the entire plasma volume contained in a doughnut-shaped tokamak. Most of the time there are broad bandwidth fluctuations in the magnetic field, which are relatively uncorrelated at different positions and which are as much as a few percent of the confining (poloidal) field. The origin of the fluctuations is not well understood, but they appear adequate to cause the anomalous energy loss observed in tokamaks.

Flow of Granular Material

Every year very large quantities of bulk material in granular form are processed and transported throughout the world. Many different kinds of machines ranging from simple hoppers, chutes, and elevators to screw conveyers, pulverizers, and dryers are used for the transhipment, feeding, storing, and processing of a wide variety of granular materials such as coal, grain, ore, fertilizers, and plastic stock. A large investment is required to provide the equipment for the movement of this material, yet surprisingly little is known of the fundamental mechanisms of flow and heat transfer in flowing granular material. Such knowledge will be required not only for the improvement in design and efficiency of existing machines and equipment, but also for the design of new devices in expanding technologies.

Some years ago, Professor Rolf Sabersky became interested in this field while examining some of the problems involved in designing a heat exchanger to cool soap granules before packaging. Since then this research has expanded under his direction and that of Associate Professor Christopher Brennen. The present research, carried out jointly with Union Carbide, is being conducted in both laboratories. The problems in explaining the behavior of the flowing material are challenging and fascinating, and they parallel in many ways those which faced the fluid mechanists in the early 19th century before the work of Navier and Stokes. Attempts to establish constitutive relations are being made, and the difficulties encountered increase our respect for the accomplishments of those pioneers. The problem has also been approached by computing the motion and collisions of individual particles using methods similar to those in molecular gas dynamics. The experimental work involved relatively simple flows in hoppers and along open chutes. By comparing the experimental results with the analytical results, the researchers hope to obtain a better understanding of the flow mechanisms.

Coagulation of Fine Particulates

A significant development in the area of fluid-particle interactions is the particle coagulation work that formed the Ph.D. thesis of James Hunt, graduate student in environmental engineering science, working with Professor James J. Morgan. Hunt has shown both theoretically and experimentally that the coagulation of fine particulate matter suspended in a solution of high ionic strength such as seawater proceeds according to a well-defined pattern. Furthermore, within given particle size ranges, the parameters controlling the number of particles within that range can be reduced to, at most, two. Three basic size ranges in which different coagulation mechanisms exist have been found. For the smallest particles, Brownian motion is the controlling mechanism. This is followed by a size range in which fluid shear is the primary factor and this, in turn, by a range in which differential sedimentation is dominant. The results of this research are important both to the engineering design of very large-scale drinking and wastewater treatment plants and to predicting the fate of the fine particulate matter that carries most toxic materials into coastal waters.

Dynamics of Vapor Explosions

Accidental vapor explosions occur in industry, and the physical mechanisms involved must be understood in order that structures can be designed to protect against them. To this end, the explosive vaporization of a millimeter-diameter droplet of liquid butane is being studied by Professor Bradford Sturtevant and graduate student Joseph Shepherd. This limit can be achieved by immersing the volatile liquid in another hot liquid with which it does not mix. In this way liquids can be heated well above their boiling point before explosive boiling occurs. The process is important because departures from equilibrium, evaporative fluxes, and fluid accelerations are very much larger than occur in condensation and evaporation processes. This provides a unique opportunity to study the behavior of fluids under extreme conditions.

Single short-exposure photographs and fast-response pressure measurements were used to obtain a description of the explosive process, with emphasis placed on the early evaporative stage, which occurs in the first few microseconds. Despite the apparent simplicity of the vapor explosion of a superheated droplet, experiments have revealed a wide range of phenomena of varying complexity at different stages of the explosion.

DIVISION OF GEOLOGICAL AND PLANETARY SCIENCES

Members of Professor of Geology Barclay Kamb's research group drill to the bottom of Variegated Glacier in Alaska, measuring the pressure of water in the basal hydraulic system of the glacier and the movement of the glacier over its bed.

Barclay Kamb, Chairman

An active and growing research area of the Division of Geological and Planetary Sciences is the study of phenomena at high pressures, particularly as they bear on the nature of the earth's interior, the interiors of the planets, and the high-pressure shock effects generated by meteoroid bombardment on planetary surfaces. This is a research area currently shared as a common interest among a number of fields in geology, geophysics, and planetary science. Several faculty members have been actively involved in recent work in the area, and two faculty appointments in 1979–80 contribute new approaches to it: Bradford H. Hager, assistant professor of geophysics, working in tectonophysics; and David J. Stevenson, associate professor of planetary science, working in the theory of planetary interiors. The present report examines divisional research and teaching activities bearing on high-pressure and high-stress phenomena, and then closes with a brief summary of other noteworthy developments in the Division of Geological and Planetary Sciences in 1979–80.

Shock-Wave Geophysics

One of the best known and longest established programs in high-pressure research is the work of Professor Thomas J. Ahrens's shock-wave facility in the Lindhurst Laboratory of Experimental Geophysics. The central element of this facility is the "light-gas gun," or "big gun," in which shock pressures of up to 1.5 million atmospheres can be generated. The laboratory investigates the constitution of matter at pressures occurring in the deep mantle and core of the earth, down to depths of some 3000 kilometers beneath the surface. For example, it has been studying the possible role of potassium and sulfur in the earth's core by means of shock-wave experiments on the substance $KFeS_2$. At pressures near those at the core-mantle boundary this substance undergoes transformation to a dense phase whose properties allow estimation of the effect of potassium and sulfur on the density of nickel-iron in the core, and provide a basis for calculation of the partitioning of potassium between the nickel-iron of the core and the silicate mineral phases of the mantle. The results indicate that potassium should not be concentrated in the core, and that the somewhat low density of the core relative to pure nickel-iron, as inferred from shock-wave experiments, can be more satisfactorily explained by the presence of sulfur in reasonable proportions (about 12 percent).

An important new thrust in the work of the shock-wave laboratory is direct measurement of the high temperatures generated in shock waves. Since the high shock pressures and accompanying high temperatures last less than a millionth of a second in a shock-wave experiment, the measurement is difficult, yet it is important because without it, interpretations of the pressure-volume relationships observed in shock experiments depend entirely on theoretical calculation of the temperatures. Ahrens and his colleagues have solved the temperature-measurement problem by detecting the burst of electromagnetic radiation emitted from the sample when it is heated by the shock wave. In extensive studies of shocked quartz ($Si0_2$), which transforms to the high-density phase stishovite under high pressure, they found shock temperatures of 4500° to 5800° K at shock pressures of 0.7 to 1.1 million atmospheres. At about 1.2 million atmospheres they detected a drop in shock temperature to about 4800° K, which they interpret as being due to shock-induced melting of the $Si0_2$ at this pressure. By reasoning from these temperature measurements as a basis, Ahrens is able to place an upper limit of 3500° K on the temperature of the earth's lower mantle.

Planetary Impact Mechanics

Shock-wave experiments are useful not only for generating very high pressures per se, but also for simulating the impact processes that occur when planetary surfaces (including the earth's) are struck by meteoroids or comets. Shock-metamorphism studies have recently been carried out on serpentine, a hydrous silicate mineral that was probably the main carrier of primeval water in the stony planetesimals that accreted to form the earth and the terrestrial planets. The objective is to find out under what impact conditions the water in serpentine would be mobilized and lost. It is found that a shock pressure of 300,000 atmospheres is sufficient. Such shock pressures would be generated by impacts at a speed of about 2 km/sec, which is within the range of collision velocities estimated for infalling planetesimals in the accretion of the terrestrial planets. It thus appears that most of the primeval water brought to the earth in planetesimals was driven out of the host serpentine at the moment of accretion and thus was not incorporated into the rocky interior of the planet as it grew; if so, very little internal water could have been available for subsequent release to the surface by degassing processes operating over the course of geologic time, contrary to what has often been assumed in theories of the history of the atmosphere and hydrosphere.

Data on the shock-compression properties of planetary and cometary materials are being used by Ahrens and his colleagues to develop theoretical computer models of impact events on planetary surfaces, from which they can estimate the crater shape, ejecta velocity distribution, and shock metamorphism produced by impact of a specified type of meteoroidal or cometary object at specified velocity on a planetary surface with specified mechanical properties and gravity. The calculations are currently being applied to consider the great impact event that has recently been proposed as the cause of mass extinctions of many life forms on the earth, including dinosaurs, at the end of the Mesozoic era about 65 million years ago.

This dramatic proposition has been examined by Professor Eugene Shoemaker from the standpoint of assessing the probability that an impact event of the requisite magnitude could have occurred. Based on the historical statistics of crater-forming impacts recorded on the moon's surface, as documented in detail by the results of the Apollo missions, he finds that an asteroid or cometary object at least 15 kilometers in diameter can be expected to have collided with the earth about once every 70 million years, on average. Such an impact would have formed a crater at least 250 kilometers in diameter, and if it occurred in the ocean, as is probable, it would have ejected a vast amount of water vapor into the stratosphere, greatly increasing the atmosphere's greenhouse effect. Shoemaker and colleagues estimate that as a result the earth's surface temperature could have been increased by 10° C for a period of several years, and they believe that this temperature increase is most likely the cause of the mass extinctions.

High Pressure Theory

Theoretical study of matter at high pressure is an essential component of a coordinated attack on the nature of the earth's interior and other planetary interiors, because much of the experimental work at high pressures requires a substantial theoretical framework for its proper evaluation and interpretation, and because the deep interiors of the major planets, and even the earth's inner core, are beyond the pressures now attainable in laboratory experimentation. Professor David J. Stevenson, who specializes in high-pressure theory, has been active in examining theoretically the behavior of hydrogen and helium, the chief components of the major planets, at the extreme pressures of 5 to 40 million atmospheres in the deep interiors of these bodies. In particular, he has investigated whether hydrogen and helium will remain mutually soluble and well mixed under these conditions, or whether they may exsolve into two separate phases. Analysis of this question requires taking into consideration the theoretically predicted transformation of hydrogen from the molecular to the metallic fluid state above a pressure of about 3 million atmospheres. Using liquid perturbation theory with appropriate molecular pair potentials, Stevenson is able to calculate the thermodynamic properties of the pure and chemically mixed phases and thus determine the exsolution curve (limit of mutual solubility) as a function of temperature and pressure. He finds that for the probable chemical composition of Jupiter and Saturn (25 percent helium, 75 percent hydrogen by weight), and for the theoretically calculated adiabatic temperature vs. depth profiles in these planets, the exsolution limit is reached in Saturn below a depth of about 30,000 km whereas in Jupiter, because the internal temperatures are higher, the exsolution limit will not be reached. When exsolution of hydrogen and helium occurs, the helium accumulates preferentially in a deeper layer in the planet's interior, which releases gravitational energy. This can explain why the heat flow out of Saturn, measured by the Pioneer 11 mission, is significantly larger than what could be expected from simple cooling off of the planet without an extra internal energy source. The theoretically predicted depletion of helium in the outer region of Saturn appears to be confirmed by recent measurements of helium abundance by Voyager 1.

Stevenson is currently enlarging the scope of this work to consider the interactions and mutual solubilities at high pressure among the "ice"-forming phases (water, ammonia, and methane), and the solubilities of these components in the hydrogen and helium phases of the major planets.

Experimental Petrology: Origin of the Oceanic Crust

High-pressure phenomena in the comparatively modest but nevertheless substantial pressure range of up to about 50,000 atmospheres govern rock-forming and rock-destroying processes that, taking place in the earth's crust and outermost mantle, directly affect our existence on the earth's surface. This is the pressure range accessible to detailed study by the methods of experimental petrology, in which pressures corresponding to depths down to about 150 kilometers beneath the surface are generated by powerful presses and are applied to mineral samples in which controlled temperatures of up to about 1500° C can be established. In this approach the pressures attainable are more limited than in shock-wave experiments, but there are compensating advantages: the high pressures can be maintained indefinitely (allowing time for mineral reactions to occur), the sample temperature can be controlled independently of the pressure, and the samples can be readily and completely recovered for detailed study after each run. During 1979–80 Assistant Professor Edward Stolper set up a static-high-pressure laboratory of this type, and began a research program in experimental petrology. One of its principal objectives is elucidating the origin of the basalts formed at the mid-ocean ridges in the process by which new oceanic crust is created in sea-floor spreading. Stolper is carrying out experiments to find out the chemical composition of primary magma formed by partial melting of peridotite at depths of 30 to 50 kilometers in the upper mantle, where the basalt magmas are believed to originate. He has developed a new experimental technique in which basalt samples to be melted are placed inside capsules made of olivine and pyroxene, the principal mineral components of upper-mantle peridotites; when the sample melts it reacts with its container and achieves the composition of a melt obtained by partial melting of mantle rock under the pressure applied. In this way Stolper has determined that most mid-ocean-ridge basalts cannot be produced directly by partial melting in the upper mantle, and that instead they must develop by a more complex process in which the deep primary melts become trapped during their ascent in magma chambers at shallow crustal depths, where they undergo partial crystallization and resulting major chemical modification before being erupted at the ocean ridge crests. In certain rock masses believed to be chunks of oceanic crust thrust up onto land, such as the great Oman ophiolite discussed in last year's report, there are found layered gabbros that are interpreted as accumulations of crystals that settled out from crustal magma chambers beneath oceanic spreading centers, and hence represent independent confirmatory evidence for the magma-evolution process deduced by Stolper from the high-pressure experiments.

Why is it that the inferred deep primary magmas fail to reach the surface, whereas their chemically modified derivatives are erupted in abundance? Stolper has discovered that in chemical fractionation of the primary melt at shallow depths, the densities of the residual liquids at first decrease as olivine crystallizes out, but then reach a minimum and increase again once pyroxene and plagioclase join the crystallization sequence. Most erupted mid-ocean-ridge basalts have densities near the density minimum. This strongly suggests that the low-density oceanic crust acts as a density filter, allowing only the low-density magmas to rise up through it and be erupted. This simple but fundamental concept merits further study, particularly with the help of more abundant experimental data on the densities of basaltic and primary magmas under pressure.

Flow of Mantle Rocks under Pressure

The process of sea-floor spreading involves not only the flow of molten magma, generating new oceanic crust by eruption and plutonism, but also the flow of solid peridotite in the underlying mantle, which provides the "conveyor belts" that carry the newly formed crust away in opposite directions from the spreading centers. This process is controlled fundamentally by the flow properties of peridotite at the high pressures and temperatures in the mantle. A method for calculating these flow properties, and for relating them to seismic wave attenuation in the mantle, has been developed by Professor Don Anderson and Assistant Professor Bernard Minster. They have worked out a model of the stress-induced motion of crystal dislocations at the atomic level in major mantle minerals, and they find that dislocation motion can account not only for the slow, creeping flow of mantle rocks under deforming stresses applied over the long scale of geologic time, but also for the energy dissipation involved in the rapid, nearly elastic response of the rocks to stressing at the frequencies of seismic waves. The model parameters can be adjusted to match the observed seismic-wave attenuation in the mantle (high attenuation in the uppermost mantle and near the core-mantle boundary), and the model then yields a calculated curve of flow viscosity vs. depth that matches rather well with effective upper-mantle viscosities of 10^{19} to 10^{21} poise deduced from the rates of post-glacial uplift.

Mantle Flow and Plate Tectonics

Flow viscosity of mantle rock as a function of depth is an essential parameter in calculations of mantle convection being carried out by Assistant Professor Bradford Hager with the aim of elucidating the forces driving the lithospheric plates in plate tectonics. One approach he is using is to test convection models by calculating their detailed flow patterns around Benioff zones—places where plates are carried down into the mantle in the process called subduction—and comparing the predicted Benioff-zone configurations with those actually observed. Convection models in which flow is restricted to the upper 700 km of the mantle because of high viscosity in the lower mantle give calculated Benioff-zone configurations that are quite different from those observed, whereas models with mantlewide convection tend to agree reasonably with observation.

Hager has tested convection models in which plate motions and the accompanying mantle circulation are driven by lateral density contrasts within the plates and the mantle, and are resisted by the friction between plates at subduction zones and by viscous dissipation in the mantle. The models show that the density contrasts within the lithosphere are by themselves sufficient to drive the plates with their observed velocities if the drag at the base of the plates is a few bars and if yield stresses on bounding faults are of order 100 bars. There is no need to appeal to internal mantle density contrasts to drive the plates.

Glacier Flow and Surging

The flow of glaciers is a phenomenon analogous in many respects to solid flow at high temperature in the mantle and in crustal rocks during mountain building, and it is subject to similar controlling effects of pressure, temperature, and stress. Interest in glacier flow at Caltech goes back about 30 years to the work of Professor Emeritus Robert P. Sharp on glaciers in Alaska, Canada, and the Pacific Northwest, and it continues up to the present day in my own research program. In recent years our attention has concentrated on the least-understood and most inaccessible aspect of glacier flow: the basal sliding of glaciers over their beds, which is somewhat analogous to the tectonic motions of thrust sheets, nappes, and even lithospheric plates. A great increase in basal sliding, occurring for as yet unknown reasons, is believed to be the cause of one of the most dramatic of glacier-flow phenomena, glacier surging, in which certain glaciers, after many years of apparently normal flow, speed up greatly and flow at high speed for a year or so before returning to normal. With the objective of understanding the mechanics of surging, we have carried out three seasons of field work on Variegated Glacier in the St. Elias Range, Alaska. This glacier is known to surge every 20 years, approximately, and is expected to surge in about 1985.

In the process we have discovered the occurrence of "mini-surges"—short periods of dramatically accelerated motion, in which the glacier flow velocity increases suddenly from about 55 cm/day to as much as 250 to 300 cm/day and then decreases gradually over the course of a day. Five such flow events occurred in June–July of 1980. In each event, the acceleration in flow velocity propagates down the glacier as a wave with a velocity of about 500 m/hour. It is accompanied by a propagating pressure wave in the basal water system of the glacier, in which the pressure rises rapidly to a level greater than the ice overburden pressure at the glacier bed. These observations can be explained semiquantitatively by a physical model of the coupled pressure and movement wave: high water pressure reduces bed friction and accelerates basal sliding, which couples with the high pressure to induce basal cavitation; this increases the hydraulic conductivity of the basal zone, and the water pressure wave propagates downglacier in the longitudinal conductivity gradient so established. It seems likely that the mini-surges are premonitory to the forthcoming main surge and are related physically to it.

In an effort to obtain direct information on the basal-sliding mechanics of Variegated Glacier, we have made attempts to observe the sliding process actually taking place, by using a TV camera system to examine the glacier bed in boreholes drilled to the bottom. We find that the basal material is invariably rock debris, rather than solid bedrock, and that the basal sliding is accomplished mainly by shear in the debris zone underlying the ice, rather than by the classic mechanisms of ice plasticity and pressure melting at the base of the ice. This means that the sliding must be controlled mainly by rock friction. The great sensitivity of the sliding velocity to high water pressures is understandable in this context.

In 1979 graduate student Melinda Brugman undertook a study of Shoestring Glacier on Mt. St. Helens, Washington, with the aim of observing glacier flow behavior in a situation where buildup of basal water pressure is inhibited by high hydraulic permeability of the underlying bedrock materials. The explosion of Mt. St. Helens on 18 May 1980 blew away the upper twothirds of the glacier. The subsequent response of the remaining part is quite different from what would be expected on the basis of simple flow models and is providing an interesting test of glacier-flow theory.

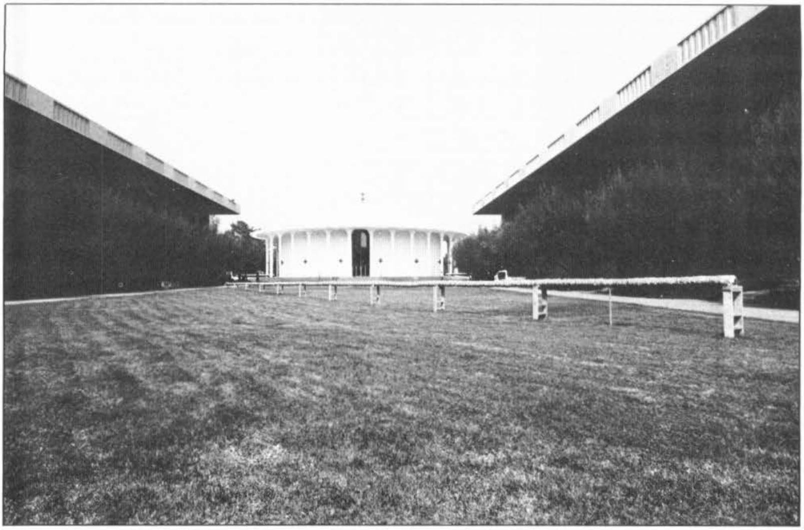
Ice at High Pressure

For years I have been studying the structures and properties of the dense ice polymorphs produced at pressures of 2000 atmospheres and up. Work on ice IV, a polymorph that is unusual because it occurs only metastably and because its structure has some very peculiar features, has been recently completed. Flow experiments on the high-pressure ice polymorphs, carried out by graduate student Keith Echelmeyer and me, indicate that most of the high-pressure ices flow much more rapidly than ordinary ice I under stress, whereas ice II flows much more slowly. These results are of much interest in relation to internal deformations within the icy Gallilean satellites Ganymede and Callisto, which are currently being studied by Professor Eugene Shoemaker and graduate student Quinn Passey.

Other News of the Division

Events of special note in 1979–80 were the election of Professors Heinz Lowenstam and Eugene Shoemaker to the National Academy of Sciences, the award of the Maurice Ewing Medal of the Society of Exploration Geophysicists to Professor Emeritus Hewitt Dix, and the award of the Goldschmidt Medal of the Geochemical Society to Senior Research Associate Clair Patterson. Professor Peter Goldreich was invited to give the prestigious Henry Norris Russell Lecture of the American Astronomical Society, and Professor Gerald Wasserburg inaugurated the Anton Hales Lectureship of the Australian National University. In April 1980 a Caltech alumni hike to the bottom of Grand Canyon was led by Professors Sharp and Shoemaker with the help of Susan Kieffer (Ph.D. 1971) of the U.S. Geological Survey. The Imperial Valley earthquake of 15 October 1979 was especially noteworthy to geologists as the first earthquake in which repeat movement occurred on a fault that had definitely moved previously in historic time, namely in the well known 1940 earthquake. The fault movement was studied in detail by Professor Kerry Sieh. The seismic records of strong ground shaking obtained in the earthquake were uniquely complete and valuable for earthquake risk analysis. The division's resource geology program made progress in the research areas of hydrothermal ore deposits and uranium mineralization, but efforts to appoint a program leader have not yet borne fruit.

DIVISION OF THE HUMANITIES AND SOCIAL SCIENCES



Last fall Baxter Art Gallery sponsored an exhibit, "Architectural Sculpture," which featured artist Jud Fine's *Horizontal Pillar* on the Court of Man.

Roger Noll, Chairman

During the past year the Division of the Humanities and Social Sciences made significant progress in research and teaching. A postdoctoral program in the humanities received an encouraging boost when the Andrew Mellon Foundation awarded a major grant to the Institute to expand from two to five the number of Mellon Instructors in Humanities. These additional positions will be invaluable to the division in enlarging the range of research and teaching activities in humanities and in providing an opportunity to contribute to the career development of outstanding scholars in these fields.

Several important additions were made to the divisional faculty during 1979–80. Michael Graetz was appointed professor of law and social science; he will spend second and third terms at Caltech and the rest of the academic year at the University of Southern California Law Center. Richard McKelvey was appointed professor of political science. Eleanor Searle, professor of history, joined Caltech in the fall of 1979. Alan Schwartz was appointed visiting professor of law and social science, a position he will occupy in 1980–81. Steven Lippman was a visiting professor of business economics, and Almarin Phillips served as visiting professor of economics. Nobel Laureate Saul Bellow was a visiting professor of literature, James Jordan was a visiting associate professor of economics, and David DeLeon served as visiting assistant professor of history. Professors T. W. Anderson and G. S. Maddala, both econometricians, were Sherman Fairchild Distinguished Scholars. Leaving the division were two Mellon Instructors, Gordon Appleby in anthropology and Terrence McDonald in history, and Assistant Professor of Economics Forrest Nelson.

In a division of approximately eighty faculty, research activities are, of course, numerous and varied. The following is a necessarily incomplete description of a few of the research areas that were active in 1979–80.

The Theory Workshop

A group of economists and political scientists in the division has organized a highly successful weekly workshop to exchange ideas and comments about ongoing work with other leading theorists in southern California. The workshop has proven to be an effective vehicle for generating new insights on the basic theory of how economic and political systems work.

One area of extensive research activity is social choice theory—that is, mathematical models of the decisions that will result from different voting systems and other methods for "adding up" the preferences of rational, self-interested individuals. One axiom that is widely regarded as a desirable characteristic of a social choice system is the Independence of Irrelevant Alternatives, which states that the social preference between two alternatives should depend only on their direct comparison. Assistant Professor of Economics Kim Border recently proved that this axiom rules out the possibility that a nonauthoritarian social decision process can also obey collective rationality—that is, can produce transitive social outcomes.

Another active research area is the economic theory of research and development. Assistant Professor of Economics Jennifer Reinganum has examined the "diffusion of technology," which is the processes by which industrial rivals sequentially adopt innovations. Reinganum derives the best non-cooperative strategies for firms in selecting a date to make these changes and shows that these strategy choices lead to sequenced adoption rather than a simultaneous change by all firms. She also shows that innovation comes sooner if the rivals are noncooperative than if they operate as a cartel.

Another study in the economics of technological innovation focuses on the problems of monitoring research, work that is performed under contracts with the federal government in defense and energy R&D. One standard method used in government R&D programs is for a single firm to receive a series of contract awards on the same general R&D problem, with each award depending on the firm's progress to that point. Associate Professor of Economics Louis Wilde and graduate student Joel Balbien have examined two related issues: the optimal reporting and research strategies of the contracting firm, and the choice of reporting requirements that is best from the point of view of the contractor. One surprising finding is that the possibility of a longer sequence of contracts will entice a firm into doing research at a more rapid rate, but it will also lead the firm to report a lower fraction of its findings in a timely fashion.

Understanding Africa and Asia

Several faculty in the division are leading scholars of so-called Third World societies in Africa and Asia. Professor of Political Science Robert Bates's research is on political and economic development in Africa south of the Sahara. During the past year, Bates completed a major research project on agricultural policies in tropical Africa. His major finding, extensively documented in his forthcoming book, *States and Markets in Tropical Africa,* is that African states generally seek to control prices in markets important to farmers in a way that is adverse to agrarian interests. These policies, according to Bates, are a principal cause of shortages in food crops and balance of payments problems among these nations. Bates also shows how the structure of the political systems in many African nations causes such policies to be politically stable even though they work against the interests of most members of these societies.

Thayer Scudder, professor of anthropology, is also an expert on tropical Africa. His current research interests focus on government-sponsored and spontaneous settlement of new lands. Recently Scudder has expanded the scope of his research to include settlement projects in the Middle East and South Asia. By undertaking a comparative, long-term study of new land settlement areas, he seeks to identify the factors that influence the lives of the people involved at different stages of their socioeconomic development. Scudder has also recently completed a book on secondary education in Zambia, co-authored with Elizabeth Colson, who was a Fairchild Scholar in the division in 1975–76. The study traces the lives of the children in one region of Zambia who were the first to receive secondary public school education. It identifies the socioeconomic characteristics of the families whose children were among the few who attended secondary school, and the subsequent employment opportunities that education made possible for them.

Moving further south in Africa, Professor of Geography Edwin S. Munger edited a highly regarded compendium of essays that was published during the past year. Titled *The Afrikaners,* the book contains observations by leading South Africans from across the political spectrum on the possibilities for peaceful political change in their country. Among the authors represented in the study are novelist Alan Paton, heart specialist Christiaan Barnard, African banker Samuel Motsuenyane, and Minister of Education Gerrit Viljoen. In his contribution to the volume, Munger concludes that prospects for peaceful change are certainly not hopeless, and that the United States can play a major role in bringing about such change. But a prerequisite is that Americans abandon stereotypical views of South Africans—especially Afrikaners. The essays in the book demonstrate that Afrikaners are not a monolithic group of immovable objects dedicated to the prevention of progress.

Two members of the Caltech faculty are pursuing historical research about India. Assistant Professor of History Nicholas Dirks is studying the relationship of the political organization of south India to its landholding patterns during the eighteenth and nineteenth centuries. Professor of History Peter Fay, continuing his work on two Indian National Army figures, currently is analyzing why the British allowed the Red Fort trials of the defeated and captured INA leaders to turn into an INA political triumph.

Professor of History Robert Rosenstone's research includes an ongoing study of the influences of Japanese culture on America. One of his major findings was published this year in an issue of the *American Historical Review* that was devoted to the relationships between Meiji Japan and the West. Rosenstone's studies showed that during the nineteenth century Americans residing in Japan—usually as missionaries, teachers, or technical experts hired by the Japanese government—came to believe that the United States could learn important lessons from this Oriental culture. Paradoxically, neither in the last century nor today, when similar scholarly arguments are being made, have Americans been able to conceptualize clearly just what and how we can learn from the Japanese.

Law and Society

A major research focus in the division, developed in the last decade, is the study of legal institutions in both historical and contemporary societies. This program of research blossomed in 1979–80. Luce Professor of Law and Social Change Michael Levine returned to Caltech after a leave of absence as the General Director of International and Domestic Aviation at the Civil Aeronautics Board. Professor of Law and Social Science Michael Graetz, who had visited Caltech during the first of Levine's two years of leave, returned as a permanent member of the Caltech faculty. Professor of History Eleanor Searle, who studies medieval society, also was added to the Caltech faculty, and Alan Schwartz became a visiting professor of law and social science.

One research interest of this group is the development and analysis of the law with respect to property rights. Professor Searle's current work is on the transfer of property through time, including the use of marriage as a mechanism to acquire and retain property rights through inheritance, and the role of the court system in shaping and enforcing the land tenure system. Previous historians have assumed that since feudal times property rights have been strictly inherited, and that accidents of birth determined the identity of the most powerful lords. Through painstaking research on the ownership histories of important tracts of land and court cases involving disputes over property rights, Searle has demonstrated that the issue of land tenure—and the resulting distribution of political and economic power—is far more complex. Some transfers of ownership that have previously been identified as taking place within families who passed on property rights through inheritance have been shown to involve groups more akin to political parties than genealogical units. These groups manipulated marriages and inheritances to their own advantage through control of the system for enforcing property rights, sometimes conveniently redefining membership in the "family" if the stakes were high enough. Searle's work in this area now consists of gathering additional information to determine the frequency of legal and political, rather than strictly genealogical, practices for transferring control over property. The findings are especially important in two areas. First, they reveal a powerful mechanism behind the rapid centralization of feudalized "states" in the eleventh century. Second, they provide a better understanding of the reasons behind the development of English common law, a development that appears to have introduced modern concepts of property rights into Anglo-American jurisprudence.

Another area of research is analysis of tax law and regulations. Professor Graetz, a member of the American Bar Association Special Committee on Tax Simplification, has recently completed several studies analyzing pending proposals for tax reform. Among these is an analysis of the shareholder-credit method for eliminating the corporate income tax on profits that are distributed as dividends. Graetz has published an important study that works out the details of how this proposal could be implemented in a manner that preserves the various provisions in the tax code that create a special tax status for certain kinds of corporate expenditures, such as the investment tax credit.

A third major research area is the study of regulation. Professor Levine has completed a study in which he tests various theories of the behavior of regulatory agencies against the activities in airline regulation during the past five years. Finding that none of the existing conceptual models of the regulatory process explains adequately the movement by Congress and the CAB towards extensive deregulation, he proposes that the widely discredited "public interest" model be revived in modified form. In this model, political actors pursue a public interest composed of three distinct objectives: providing benefits to favored groups, achieving economic efficiency, and guaranteeing procedural fairness in regulatory decisionmaking. While industrial or geographic subgroups attempt to use governmental intervention for their own benefit, they justify these interventions in public interest terms. However, if it becomes widely perceived that a particular regulatory regime mainly produces private benefits at public expense, the regulatory regime becomes vulnerable to revision or repeal.

Meanwhile, Professor Schwartz and Associate Professor of Economics Louis Wilde made substantial progress in developing a conceptual basis for evaluating various forms of consumer protection regulation. Using the findings from various social science disciplines about how consumers actually make decisions about product purchases, Schwartz and Wilde developed a theory that predicts the effects on market efficiency of various forms of government interventions, such as mandatory disclosure rules regarding price and product quality. Present regulatory interventions do not rest on a sophisticated understanding of how shoppers and firms behave when information about price and product quality is imperfect. Schwartz and Wilde have demonstrated that this has led to some regulatory decisions that are mutually inconsistent and that make markets less efficient.

A final area of current research interest relating to law and society is the economic consequences of certain provisions of the law of contracts. Graduate student William Rogerson, who recently was appointed an assistant professor of economics at Stanford University, has completed an extensive study of the extent to which various legal remedies for breach of contract affect economic efficiency. When a contract is signed, one party often makes "reliance" expenditures—relying on the expectation that the contract will be fulfilled. These reliance expenditures can prove to be of substantially less value—even worthless—if breach of contract occurs. An important question for the development of an efficient system for enforcing contracts is the extent to which alternative rules for awarding damages from breach of contract affect the decisions of the parties to engage in reliance expenditures. Rogerson discovered that in certain circumstances the alternative measures for awarding damages can be strictly ordered in terms of their economic efficiency. A liquidation damage clause in a contract, specifying the damage award if a breach occurs, is the most efficient method; however, such clauses generally are not honored by the courts. The second most efficient approach is specific performance, in which the court requires that the contract be honored, thereby preventing breach. This, too, is generally in disfavor with the courts. Rogerson finds that the remedies for breach that generate the greatest economic inefficiency are the most common forms of damage awards: reliance damages, in which the victim of the breach is reimbursed for reliance expenditures, and expectation damages, in which the victim is awarded the profits he would have made had the contract been fulfilled.

Professor of History J. Morgan Kousser has addressed the historical roots of several civil rights cases before the U.S. Supreme Court. Recently the Court has placed great emphasis on the original intent of laws that end up having a discriminatory effect on women, members of racial and ethnic minorities, or other easily identifiable groups within the population. In the case of voting rights laws, the legislation establishing voting procedures in many states dates back to the nineteenth century. Kousser's work in recent years has focused on the political history of the relationships between whites and blacks in the American South between the Civil War and World War I, and his findings on the development of these laws have been interjected into several pending voting rights cases.

Interpreting Literature

Medieval and Renaissance studies have become a particular center of interest for the literature group. Assistant Professor of Literature George Pigman has continued to work on Renaissance concepts of imitation. He has been particularly concerned with Du Bellay's complex attitudes towards Rome and with Erasmus's use of Cicero. Visiting Assistant Professor of Literature David Burchmore's work on Chaucer relates medieval calendar iconography to the *Canterbury Tales.* He is also concerned with medieval and neoplatonic sources of Spenser's poetry. Associate Professor of Literature Jenijoy La Belle has made an important finding on the physiological context of the imagery in Shakespeare's *Macbeth* and has used it to develop a new reading of Lady Macbeth's characterization. Like most of the humanities faculty, these scholars have profited by the proximity and research opportunities of the Huntington Library.

Literary research encompasses foreign language studies as well as English literature. Lecturer in French Annette Smith has completed several papers on the works of French author Gobineau, analyzing his writing in the context of the knowledge of science and natural history that was current at the time of his writings. Smith believes that the state of science influences the genesis of literature, and is using the study of the highly controversial Gobineau as an illustration of her thesis.

Caltech's other lecturer in French, Sonia Ghattas, focuses her research on Arabic literature. She has recently completed a study of Egyptian and Algerian proverbs in which she explores the extent to which these proverbs reveal the cultural attitudes prevalent in these countries with respect to the concepts of chance, generosity, patience, and fatalism.

Valentina Zaydman, lecturer in Russian, is renowned at Caltech for her teaching; she is the only member of the Caltech faculty who has won an award for teaching excellence from the Caltech student body four times. But she is also an active research scholar, currently pursuing a study of recent emigrés from the Soviet Union on how their backgrounds, age, and other characteristics affect the process by which they learn English.

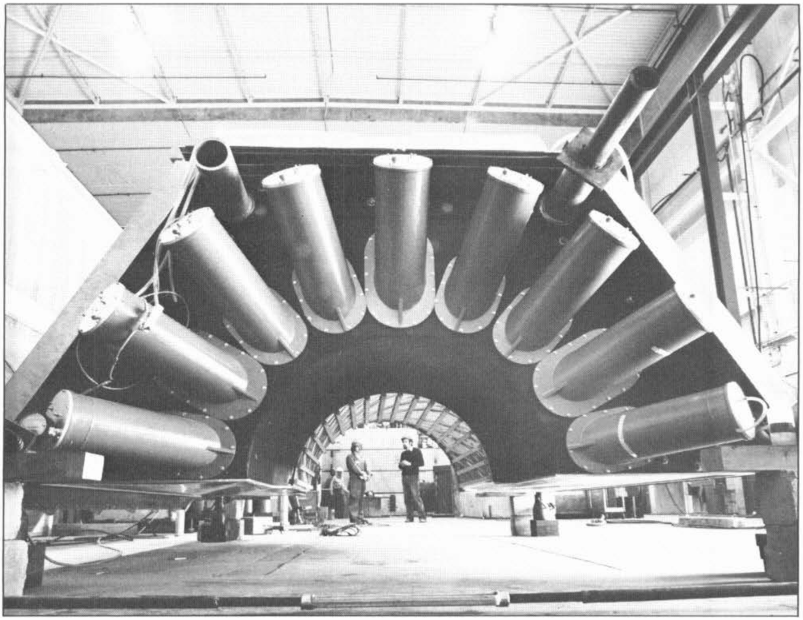
Developments in Legislative Politics

In the past few years Caltech has come to be widely recognized among political scientists as the home of the "Caltech School" of legislative scholarship. The characteristics of this school of thought are: theoretical analysis based upon the proposition that voters make voting decisions on the basis of evaluations of the job performance of candidates; a body of theory that concludes that politicians running for legislative office in districts represented by a single person (e.g., the U.S. House of Representatives or Britain's House of Commons) are becoming increasingly independent of political parties through the conversion of their jobs from policymakers to ombudsmen; and the use of sophisticated statistical techniques to test these and other theoretical propositions.

Assistant Professor of Political Science Bruce Cain has provided some recent dramatic examples of this work. In the most recent British election, Cain shows that the swing in the vote proportions of the political parties, had it followed historical averages, should have led to a swing of 64 seats from Labour to Conservatives; however, Labour actually lost 21 fewer seats than it should have. Cain goes on to show that this anomaly is explained by the efforts of the winning Labourite incumbents to make themselves known in the constituency independently from their indentification with the party. One consequence of this strategy could well be a decline in the discipline and strength of the party, which traditionally has had the responsibility for articulating positions on national policy issues.

This is not to say that policy issues are unimportant. The rationalist theory of political behavior accords importance to both constituency services and policy performance. One major policy issue is the state of the economy. Assistant Professor of Political Science Roderick Kiewiet recently completed an exhaustive study of the way in which economic conditions affect political outcomes in both congressional and presidential elections in the United States. Kiewiet confirms the standard result that people who care more about unemployment than inflation tend to vote Democratic, while people with the opposite view tend to vote Republican. But Kiewiet goes on to produce an entirely new result that is consistent with the rational choice theory of voting behavior: that general economic conditions have a much greater effect on voting behavior than do personal economic conditions. Thus, voters tend to assess the parties and the candidates on the basis of their perceptions of the general state of the economy, rather than holding politicians responsible for their personal economic condition.

DIVISION OF PHYSICS, MATHEMATICS AND ASTRONOMY



A large Cerenkov counter is being readied for installation at PEP, the newly finished 18 GeV electron-positron storage ring at the Stanford Linear Accelerator Center. This counter is part of DELCO (Direct Electron Counter), which is one of the first high energy particle detectors to be used at PEP. A Caltech group, under the direction of Professor Barry Barish, has developed this device. The particle identification provided by this counter will enable the group to identify the weak decays of new heavy particles produced at these high energies. The experiment will also use the Cerenkov Counters to study the constituents of "jets," which are believed to originate from e^+e^- annihilation into quark-antiquark pairs.

Rochus E. Vogt, Chairman

News of the Division

We welcome new colleagues, Professors Thomas G. Phillips (physics) and Richard M. Wilson (mathematics) and Assistant Professors Kwok-Yung Lo (radio astronomy), Stanley Whitcomb (physics), and W. Hugh Woodin (mathematics).

Physics is gaining additional strength and distinction from the appointments of Research Associates Andrew Buffington, Peter Haff, and Stephen Wolfram, and of Senior Research Fellows Siu Au Lee and Ryszard Stroynowski.

We congratulate Jens Ludwig, Robert Messner, and Frank Porter on their promotion to senior research fellow in physics.

We report with sorrow that Jon Mathews, professor of theoretical physics, and his wife Jean were lost at sea 24 December 1979 in the Indian Ocean while sailing around the world.

The new single-track freshman physics course was launched successfully under the leadership of Professor David Goodstein and an all-faculty staff of recitation instructors, including Nobel Laureate Max Delbrück.

The physics faculty continued its revision of the undergraduate program with a new syllabus for the sophomore physics courses. Henceforth, students will be able to choose from two offerings in the sophomore year: Ph 2, primarily designed for students for whom this may be a terminal physics course, and Ph 12, for those who plan on further training in physics.

In July 1980 the Hale Observatories, constituted in 1948, were dissolved by mutual agreement of Caltech and the Carnegie Institution of Washington (CIW). Henceforth, CIW will administer its facilities under the name Mount Wilson and Las Campanas Observatories. Caltech will operate its own facilities at Palomar Mountain and Big Bear Lake as part of the Physics, Mathematics and Astronomy Division. Both institutions will continue to share the scientific use of their facilities. Professor Gerry Neugebauer has been appointed acting director of Palomar Observatory and Professor Harold Zirin is the new director of Big Bear Solar Observatory.

Professor Alan T. Moffet retired after a five-year term as director of Owens Valley Radio Observatory (OVRO) in order to devote himself fully to the development and construction of a new, three-telescope millimeter-wave interferometer at OVRO. Professor Rochus Vogt has been acting director for OVRO since January 1980.

Research in the division continued at an exciting and rewarding pace over a broad spectrum of fundamental and applied areas. The following highlights represent only a small, and necessarily inadequate, snapshot of a much larger intellectual effort that embraces time scales much larger than yearly reporting intervals.

Gravitational Lenses and Quasars

Einstein's theory of relativity predicts that the gravitational field produced by a massive object will bend light rays passing near that object. Observations of stars near the Sun during a total eclipse have shown the starlight to be bent by the Sun exactly as Einstein predicted. The bending of light by mass has now been seen on a cosmic scale in the discovery of *gravitational lenses.*

In 1979 a pair of quasars (quasistellar radio sources) only 6" (seconds of arc) apart on the sky were discovered by astronomers in England and Arizona. What was extraordinary was that the spectra of both quasars were nearly identical, both having a redshift of 1.4. The quasars were so similar that it was suggested that two images of the *same* quasar were being seen. If a large mass (e.g., a galaxy) were to lie about halfway between the Earth and the quasar, then the light from the quasar traveling toward us would be deflected by the mass of the galaxy. Light rays passing on each side of the galaxy can be bent back toward Earth so that two images of the quasar would be seen (one on each side of the galaxy).

In November 1979, Assistant Professor Peter Young, Professors James Gunn, Beverley Oke, and James Westphal of Palomar Observatory, and Dr. Jerome Kristian from the Carnegie Institution of Washington used a new charge-coupled device (CCD) on the Palomar 200-inch Hale telescope to take very detailed pictures of the "double quasar." A cluster of galaxies at a redshift of $z = 0.36$ was discovered surrounding the image of the double quasar, and the brightest galaxy in this cluster was sitting nearly on top of the image of one of the two quasars. After some theoretical modeling of the Einstein deflection of light by both the big galaxy and the other galaxies in the cluster, it was found that the double quasar is indeed a gravitational lens effect; the "lens" is the brightest cluster galaxy yet discovered at Palomar.

Subsequently, Professor Gerry Neugebauer, Senior Research Fellow Tom Soifer, and Senior Scientist Keith Matthews of Palomar Observatory, together with Drs. E. E. Becklin and Gareth Wynn-Williams of the University of Hawaii, extended the spectral measurements out to wavelengths of two microns in the infrared. Showing that the energy distributions in the spectra of the quasars were the same out to that wavelength, they added crucial further evidence to the gravitational lens hypothesis. The group also observed the intervening galaxy directly by measuring the signal through various sized diaphragms. This was possible since the galaxy's light is redder than that of the quasars and thus dominates in the infrared.

Black Holes: The Quasar "Engine"?

Optical and radio observations show that quasars are powered by central, compact engines. Although the nature of the engines is not known for certain, observations and theory suggest strongly that they are *black holes,* collapsed stars with between one million and ten billion times the mass of the Sun spinning on their axes with surface velocities near the speed of light. Gas with entangled magnetic fields should orbit around such a hole in a gigantic accretion disk, somewhat like Saturn's rings but bigger and thicker. Caltech's theoretical astrophysicists have been exploring the ways in which such a hole and disk can power a quasar. One possibility, studied in detail by Research Fellow David Meier, involves frictional heating of the disk to such high temperatures that radiation blows a strong wind of gas off the top and bottom faces of the disk. As Research Fellow Michal Jaroszynski has shown (with collaborators in Poland), the disk may be very thick near the hole, with a whirlpool-shaped surface reaching down to the hole; and the wind may be channeled by the whirlpool into jets that emerge from the hole's north and south polar regions. Further channeling and focusing of the jets may occur by passage through layers of gas above and below the disk—a process first proposed and studied by Professor Roger Blandford and his British colleague Martin Rees several years ago. Such jets have been observed and examined in detail by Caltech's optical and radio astronomers.

An alternative to the heating-makes-wind-makes-jets process was proposed by Blandford and his British colleague Roman Znajek several years ago; it has been explored in mathematical detail recently by Professor Kip Thorne and graduate student Douglas MacDonald. In this alternative possibility, a magnetic field, in interaction with the hole's "gravitomagnetic force" (gravitational analog of ordinary magnetic force), acts as a 10^{19} (1 billion billion) volt battery, and the magnetic field lines stretching up from the hole's north and south poles toward the jet region act as power lines. The battery near the hole transmits power up the magnetic power lines in a precise relativistic analog of a DC power line crossing the countryside. All aspects of standard power line theory apply with only minor relativistic changes. This theory is so simple and familiar that one can't help feeling that, if supermassive holes really exist in quasars, then such power transmission must really occur. Less certain is the issue of whether the DC electrical power, propagating up the magnetic power lines, actually accelerates enough particles to high speeds to form the observed jets.

The reason why most quasars radiate powerfully all the way from the infrared wavelengths up to x-ray energies rather than in a restricted portion of the spectrum (in the way that, for example, a star radiates) has been a long-standing puzzle. Blandford and Research Fellow David Payne have analyzed one possible mechanism in which individual photons are created at low frequencies and have their frequencies raised by repeatedly scattering off electrons in a converging fluid flow. By the time the photons eventually leave the source region, a significant fraction of them can have very high frequencies, and under appropriate conditions, spectra somewhat like those observed can be reproduced.

Much further theoretical and observational work is required before we will have a definitive understanding of quasar engines; but we seem to be on the way toward such an understanding.

Nucleus of the Galaxy

The nucleus of our own Milky Way galaxy is an active region, containing a compact nonthermal radio source similar to the ones found in quasars and radio galaxies. Even though the radio source is fainter than the extragalactic ones, observations of details more than 100 times smaller are possible because it is so much closer to home.

For the past several years, Assistant Professor K. Y. Lo, along with Professor Marshall Cohen and Research Associate Anthony Readhead, has been studying the Galactic Center compact radio source using VLBI techniques. They have found that the radio source is as small as 100 AU, about the size of the solar system. The properties of the radio source are such that the underlying energy source is probably not associated with pulsars or binary stars, but possibly with a massive collapsed object.

Additional evidence for the nature of the compact radio source at the Galactic Center has to come from other observational means. So far, because the Galactic Center is highly obscured by intervening dust, it has been studied intensively only in the infrared and radio wavelengths. Recently, using the 200″ telescope, Assistant Professor Peter Young, in collaboration with Lo, obtained CCD pictures of the center showing clearly a very faint and reddened optical image at the position of the compact radio source. Spectroscopic observations have been planned for the next observing season by Lo and Young to determine the nature of the optical counterpart that may represent the actual center of our galaxy.

Stellar Nucleosynthesis Cooks Heavy Elements

For some years Professor Wallace Sargent has been working with Dr. C. Hazard and his colleagues at Cambridge, England, to identify radio sources—radio galaxies and quasars—from a survey made by astronomers at the University of Sydney, Australia. As part of this work, Sargent obtained pictures with the Palomar 48″ Schmidt telescope in which three separate exposures were made of each field through ultraviolet, green, and red filters with the telescope slightly displaced between each exposure. The resulting plates, on which each object is recorded three times, are very useful for the discovery of abnormally blue objects, such as quasars. In an entirely accidental discovery, Hazard noticed that one of the 100,000 or so stars on one of the plates had two satellite images, one on each side of the main image, and only on the exposure through the green filter. It turned out that this particular star was the central star of a known planetary nebula, Abell 30. Planetary nebulae are diffuse envelopes of glowing gas that are ejected by stars toward the end of their evolution. They are supposed to be the main mechanism by which gas enriched in helium, carbon, and heavier elements synthesized in the central star is returned to the interstellar medium. Hitherto, spectroscopic measurements of planetary nebulae have shown little direct evidence for this expected enrichment. When Hazard and Sargent obtained spectra of the two green objects near the central star in Abell 30, they found that they were gaseous knots composed of helium, carbon, neon, and oxygen with no trace of hydrogen which, however, is abundant in the main outer nebula. (The green color of the knots is due to very strong emission lines of oxygen.) Thus, for the first time, and entirely by accident, we have direct evidence that planetary nebulae do return material that is highly enriched in the heavier elements to the interstellar medium.

The Rings of Uranus

The accidental discovery during a stellar occultation by Uranus that nine narrow rings encircle that planet is one of the most unexpected findings in planetary science during the past decade. Subsequent to this discovery, Caltech's infrared astronomers, Keith Matthews and Gerry Neugebauer, and Carnegie's S. Eric Persson, convincingly demonstrated that infrared observations were the best way to observe future occultations, and they also succeeded in mapping the infrared brightness of the rings. The leading theoretical model for the formation and stability of the Uranian rings is due to Professor Peter Goldreich and Research Fellow Scott Tremaine. They propose that each ring consists of centimeter-sized particles, which are herded together by the torques exerted upon them by two small satellites, one of which orbits just inside and the other just outside the ring. The particles collect into a narrow ring at the precise location where the torques exerted by the inner and outer satellites balance. Since these satellites cannot be detected from earth-based observatories, support for their existence must rest on indirect arguments. Such evidence has recently been supplied by Goldreich and Tremain, who have shown that these hypothetical satellites could produce the small but non-zero orbital eccentricities that characterize the Uranian rings.

Galileo Observed Neptune!

One cloudy night at Palomar, Senior Scientist Charles Kowal was reading the amateur magazine *Sky and Telescope* and came across an article that listed the rare events in which one planet has passed directly in front of another as seen from the earth during the last 2000 years. Kowal noticed that Jupiter had occulted Neptune, which was discovered only in 1846, on two occasions—in 1613 and 1702. He conjectured that astronomers observing Jupiter may have accidentally seen Neptune on these occasions, and he decided to search through the literature. By 1702 many astronomers were active, but in 1613 by far the most active astronomer was Galileo, who had discovered the moons of Jupiter when he first used the astronomical telescope only three years earlier. With the help of Stillman Drake, Professor of the History of Science at the University of Toronto, Kowal examined the published facsimiles of Galileo's observing logs and found that Galileo indeed observed Neptune on the nights of December 28, 1612, and January 28, 1613. The latter observation yielded an accurate position for Neptune that differs by one minute of arc from the best ephemeris based on more modern measurements. Galileo even noticed that Neptune moved relative to a nearby fixed star but he did not make the bold step of realizing that he had discovered a new planet.

Microwave Receivers Open New Astronomical Windows
Professor Thomas G. Phillips, who came to us from Bell Laboratories, has established a new laboratory for research into techniques for the detection of millimeter- and sub-millimeter-wave radiation. The primary emphasis is on astronomical receivers for use at the Owens Valley Radio Observatory, at high mountain sites, on flying platforms such as NASA's Kuiper Airborne Observatory, and on future space-shuttle-launched observatories. Phillips's new OVRO receivers have already indicated, by their performance in the laboratory, that they will improve the millimeter-wave system efficiency by an amount equivalent to a factor of 50 in observing time.

Two types of detection schemes are under investigation and development by Phillips and Senior Scientist David Woody. The first involves a novel superconducting electrode tunnel junction structure that can act as a sensitive receiver of millimeter-wave radiation because of the quantum effect of photon-assisted tunneling. It is hoped that this will allow quantum noise limited detection, even at frequencies as high as 300 GHz (1 mm wavelength).

A second detection scheme is aimed at higher frequencies, extending into the sub-millimeter band. It uses a hot electron bolometric effect in single-crystals of the semiconductor InSb. So far this system has proved to be the only effective receiver for sub-millimeter line astronomy. Used up to frequencies of about 500 GHz, it has recently allowed Phillips to make the first astronomical detection of the ground-state fine-structure line of atomic carbon in the galaxy.

OVRO mm-Interferometer Shows Fringes
The Owens Valley Radio Observatory millimeter-wave project has progressed this year to the point where two 10.4 m telescopes became operational. These are the first two elements of an interferometer that will consist of three telescopes with baselines

of up to 400 meters. For wavelengths in the range 1.5–3 mm this system will give angular resolution of the order of one arcsecond (the angle subtended by a dime at a distance of about a mile) and will be useful for continuum and molecular studies. This summer marked an important step when the interferometer achieved a successful detection of fringe (interference) patterns at a wavelength of 2.6 mm. Using a telescope baseline of 50 m and the edge of the Sun as a source, it demonstrated the phase stability of the overall system. Up to this point there had been some question as to whether interferometers could operate through the atmosphere at such short wavelengths.

Magnetic Fields Aid Star Formation

It has long been suspected that magnetic fields play a significant role in the dynamics of dense interstellar clouds. They are both the prime candidate for angular momentum removal and a possible source of support against self-gravity. Thus magnetic fields may be an essential factor in the process of star formation. Unfortunately, there is as yet no technique for directly detecting the presence of magnetic fields in dense clouds. This situation may soon improve. Professor Peter Goldreich and Research Fellow Nikolaos Kylafis have predicted that many interstellar radio-frequency lines should possess measurable amounts of linear polarization whose alignment is determined by the projection of the magnetic field direction on the plane of the sky. The millimeter wavelength interferometer that Caltech is constructing at OVRO will be the best instrument in the world for measuring these polarized lines.

Smog among the Stars

The second season of single-dish observations with the 10-meter millimeter-wave telescope was focused on interstellar molecular lines. The Caltech team (Professor Thomas Phillips, Associate Professor Peter Wannier, and Assistant Professor K. Y. "Fred" Lo, Research Associate Gillian Knapp, Research Fellows Anneila Sargent and Alwyn Wootten) made the discovery of interstellar ozone—a well-known seasonal component of Los Angeles air. Other highlights included the detection of carbon monoxide (CO, $J = 2\text{-}1$) emission from circumstellar shells such as the clouds around Betelgeuse and from galaxies such as M82, measurements of CO distributions near ionization front regions around hot stars, and studies of CO distributions in the highly disturbed gas of the Orion Molecular Cloud center.

In nearly all of these investigations new results were obtained mainly because of the large signal collection area now available at millimeter wavelengths at OVRO and because of the new sensitive radio receivers now being developed at Caltech.

Superluminal Sources

A major astronomical achievement of Very Long Baseline Interferometry (VLBI) at radio wavelengths has been in the use of hybrid mapping to study the "superluminal" sources, i.e., radio sources that are apparently expanding at a speed greater than the speed of light. This has been a subject of controversy since the phenomenon was first reported in 1972. Until now the expansion speeds have been inferred from model fits to the observations; there was some controversy as to whether it was the same radio blob seen at two different times at two different positions. Now, for the first time, Research Fellows Timothy Pearson and Stephen Unwin have produced sequences of hybrid maps that clearly show superluminal motion in the quasar 3C 273. These maps show a bright blob moving away from the nucleus along a long, narrow jet at an apparent speed of ten times the speed of light. These "superlight" expansions are a result of special relativistic effects and prove directly that the one-sided jets observed in such sources are injected in a direction toward the earth.

A Transcontinental Radio Telescope

Another major effort of Caltech's VLBI group this year has been a joint feasibility study with JPL for a possible transcontinental radio telescope. The results of the study show that a ten-antenna array of telescopes spanning Hawaii, Alaska, and the continental United States from coast to coast, would be able to form images of radio galaxies and quasars that are an order of magnitude better than those formed with the present ad hoc network. This report comes at an opportune time because a National Academy of Sciences committee is now making recommendations to the federal government on the astronomical projects that should be initiated in the 1980s.

The Quest for Gravitational Waves

Caltech's new program to search for cosmic gravitational waves and make them into a tool for astronomy is getting off the ground under the leadership of Professor Ronald Drever. Our first gravity-wave detector will involve the monitoring of relative motions of three masses 40 meters apart suspended by wires in vacuum. Mirrors attached to these masses form two optical cavities illuminated by an argon laser. By observing interference between the light from the two cavities, gravity-wave-induced changes can be monitored in the cavity lengths with a precision of 10^{-15} centimeters (one ten-millionth of the diameter of a single atom). A new L-shaped building is under construction on campus to house this 80-meter laser-interferometer gravity-wave detector, and in the meantime the experimenters are struggling with a variety of technological obstacles to ultimate success of the project.

One serious obstacle has been the need for laser light with a wavelength that is constant to within at least one part in 10^{15} (1 million billion) over times of 0.01 second and less. Recently, Drever invented a new method of controlling lasers so they produce light of this stability. His method compares the phase of freshly produced laser light with the phase of light that has been stored for a few microseconds between two mirrors, and it corrects the laser output to keep the laser wavelength a fixed fraction of the mirrors' separation. The method works with the required precision and gives promise of important applications elsewhere in science and technology.

Scooping Up Cosmic Nuclei

Two new cosmic ray instruments were launched during the last year. The first of these, designed by Professors Edward Stone and Rochus Vogt in collaboration with scientists at Washington University, St. Louis, and the University of Minnesota, was an electronic detector with a collecting area of four square meters for measuring the very rare cosmic ray particles heavier than iron. These ultra-heavy cosmic rays are nuclei of elements such as platinum, lead, and uranium with speeds almost that of light. Launched on the third High Energy Astronomy Observatory (HEAO-3), the instrument has already provided data indicating that there are almost equal abundances of selenium and strontium in the cosmic ray source. Previously, it had been thought that the bulk of these heavy cosmic rays were synthesized by rapid neutron capture during supernova explosions, which would have resulted in ten times more selenium than was detected. It now appears that at least some of these cosmic ray nuclei were synthesized by slow neutron capture in pre-explosive stars, resulting in an increased abundance of strontium.

The second new instrument was designed by Research Associate Andrew Buffington in collaboration with scientists at the University of California at Berkeley. Launched by balloon from Manitoba, Canada, the instrument searched for antimatter in cosmic rays. About one antiproton is expected for every 10,000 protons, created by normal cosmic rays colliding with interstellar gas in exactly the same way as antiprotons were first produced in the laboratory by particle accelerators. The presence of an excess of antiprotons or of antihelium would require other sources of antimatter in the galaxy. Although the analysis of the flight data has just begun, a number of cosmic ray antiprotons have already been identified in the photographic record of their annihilation with normal matter in the instrument.

QCD, Parton Showers, Bound Quarks

Many of the original paradoxes and mysteries of the quark constituent model of nuclear matter have been resolved in recent years through the development of a detailed theory of the interquark force, known as quantum chromodynamics (QCD). It must be noted that this theory currently only makes quantitative predictions for unobservable partons (quarks and gluons), and one must use phenomenological parameterizations for the "condensation" of the partons into (observable) protons and other hadrons. A large research group, including Professors Geoffrey Fox and David Politzer, Research Associates Richard Field and Stephen Wolfram, Senior Research Fellows Keith Ellis and Douglas Ross, and graduate student Anthony Terrano, applied QCD to very high energy collisions of particles (e^+e^- and pp). They found that at the quark level the reactions could be accurately described in a manner analogous to the well-established theory of electromagnetic showers in matter, replacing in this case electron by quark, and photon by gluon.

This work is a good example of phenomenology: we do not have a rigorous prediction for the complete process, but rather a model that satisfies nearly all known relevant theoretical constraints and economically parameterizes the currently unknown aspects of the problem. One interesting result was the suggestion that partons travel a distance proportional to their momenta before interacting. In high-energy nuclear interactions, this long parton mean free path implies that the final state particles are produced outside the nucleus and so do not multiply scatter even in large nuclei. This conforms with recent experimental results, including those from a Fermilab experiment in which Caltech Professors Fox, Ricardo Gomez, and Jerome Pine had leading roles.

These new predictions will serve not only as more stringent tests of the theory but also as a standard against which new, unexpected phenomena could be identified in future experiments.

A detailed picture of how quarks bind together to form protons and other nuclear matter remains elusive, even within the QCD framework. A significant step in that direction was made by Professor Fredrik Zachariasen, collaborating with Professors Marshall Baker of the University of Washington and James Ball of the University of Utah. They derived the effective long-range force that exists between quarks, resulting from the inherently nonlinear iteration of the basic, short-range QCD processes.

Charmed Quark States

Continuing the experimental study of the interactions of the charmed quarks produced in e^+e^- annihilations with the Crystal Ball apparatus, Professor Charles Peck, Research Fellow Frank Porter, and a group of physicists from Stanford, Harvard, and Princeton have made new contributions to this important subject, which some people have called "the hydrogen atom of the strong interactions." Following their announcement last year of the discovery of a likely candidate (η_c) for the long sought charmed quark analog of the π meson, the group has found further evidence for this lowest lying *charmonium* state, including some of its hadronic decay modes. However, evidence is still lacking for a definitive identification of this particle, and the group is currently taking more data at SPEAR, one of the Stanford e^+e^- storage rings, to further our understanding of this system.

The group has also made a careful search for confirmatory evidence of the F meson, the lightest example of a bound state consisting of a charmed quark and a strange antiquark. According to experiments performed in Germany several years ago that reported the discovery of this meson, the Crystal Ball apparatus should be especially sensitive for its observations, but so far no evidence for it has been seen. The large body of data collected for this study is still being analyzed, but it is already clear that the F meson is more elusive than originally thought.

Unified Field Theories

The strong force of QCD and the much weaker electromagnetic and "weak" forces are distinguished from each other primarily by their strengths, but they are otherwise of such similar underlying structure that it is conjectured that they all have some common origin. In search of this unifying principle, Research Associates Pierre Ramond and John Schwarz and graduate students Jeffrey Harvey and David Reiss explored different possible ways of fitting together the known pieces of the puzzle, conjectured the existence of still missing pieces, and even invented some alternate rules under which the puzzle might be assembled. But a satisfactory solution that fits together *all* known features of the fundamental forces has not yet been found.

The Cosmic Connection

Various elements of the unified theories of particle interactions have been suggested as being responsible for the observed preponderance of matter over antimatter in the universe. Research Associate Stephen Wolfram and Research Fellow Edward Kolb demonstrated quantitatively that these mechanisms account sufficiently well for the observed asymmetry so that no other (more ad hoc) phenomenon need be invoked. This same research team also used cosmological inputs to deduce properties of particle physics: Starting from astrophysical observations and theory, they deduced constraints on the possible existence of as yet unobserved heavy elementary particles.

The Search for Free Quarks

The search for free quarks has intensified in the last year. The quarks in question are assumed to be survivors of the "big bang." Presumably there was a time very early in the history of the universe when the mean separation between quarks was much less than their typical separation today inside strongly interacting particles. As the universe expanded and cooled, quarks eventually clustered in groups of three, forming protons and neutrons. Conceivably, not all quarks found partners. These isolated quarks would then have interacted with ordinary matter to form "quark atoms," i.e., nuclei with fractional charge surrounded by electron clouds. Professor George Zweig and Research Fellow Klaus Lackner have outlined the chemistry of such quark atoms and suggested a number of different quark searches, some of which are currently being undertaken here at Caltech.

Neutrinos: A Mixed Bag?

The possibility that neutrinos, the neutral particles accompanying weak-interaction processes, are not "pure and simple" but rather "mixed and complicated" is causing much excitement in particle physics and astrophysics. Among other things, the famous "solar neutrino puzzle" could be explained on such a basis. If neutrinos are in fact mixed particles with finite masses, we would expect, for example, that the so-called electron-neutrinos would "oscillate" into muon-neutrinos. A test to find out whether these oscillations occur in nature is now being conducted using the neutrinos emitted from a fission reactor at the Laue-Langevin Institute in Grenoble.

Professor Felix Boehm's group with Caltech researchers Alan Hahn, Jean-Luc Vuilleumier, and graduate student Heemin Kwon, in collaboration with former Caltech Professor Rudolf L. Mössbauer and his team from Munich and colleagues from Grenoble, have designed a neutrino detector with which they observe the energy spectrum of the electron neutrinos. Their results—combined with Research Associate Petr Vogel's calculations—contain no evidence that these oscillations exist, disproving a widely publicized claim by a University of California Irvine group. The Caltech work sets important upper limits for the level at which the oscillation phenomena may occur.

Many-Body Systems Become Tractable

One of the basic tasks of theoretical nuclear physics is to solve the many-body problem; that is, to understand the diverse properties of atomic *nuclei* as a consequence of quantum mechanics and the fundamental interactions of their constituent *nucleons*. The general complexity of this problem makes its exact solution impossible for all but the smallest nuclear systems, so that approximations are necessarily invoked. Recently, Associate Professor Steven E. Koonin and collaborators have shown that one such approximation, Time Dependent Hartree-Fock (TDHF), can provide a unified description of the dynamics of large nuclear systems.

The TDHF method is based on a well-known property of weakly excited nuclei: Nucleons move relatively freely through the nucleus, influenced only by the average effects of all of the other nucleons. It provides an excellent description of the sizes, shapes, and other properties of nuclei throughout the periodic table. To extend the independent-nucleon framework to collisions of nuclei, Koonin, Research Fellow K. R. Sandhya Devi, and graduate student Brad Flanders numerically evolve wave-functions describing the colliding nuclei using the TDHF partial-differential equations. The results provide a vivid representation of the collision process and, for times after the collision, may be directly compared with experimental data.

Some calculations for light nuclei have focused on the fusion cross section (probability that the colliding nuclei remain coalesced for a very long time), yielding the surprising result that for moderately high bombarding energies, nuclei in glancing collision fuse, while head-on ones do not; instead the nuclei separate promptly, losing a large amount of kinetic energy in the process.

To refine the TDHF approximation, Chaim Weizmann Research Fellow Yoram Alhassid and Koonin have used "functional-integral methods" to develop a new formulation of the independent particle picture for collisions of many-body systems. In contrast to TDHF, it opens the possibility of calculating the more subtle features of experimental observables, such as cross sections for reactions to specific final channels. In collaboration with Devi, this new formulation is being applied to atomic collision problems and should ultimately result in improved calculations of charge-transfer cross sections important in the plasmas of controlled thermonuclear reactors.

The Melting of Two-Dimensional Solids

The melting of an ordinary solid is one of the most familiar phenomena in nature for which theoretical physics has no explanation.

Some years ago Professor David Goodstein and his colleagues showed that mono-atomic layers of adsorbed films of helium form two-dimensional solids. When warmed up, these solids melt into two-dimensional fluids. Professor Richard Feynman pointed out at the time that the melting of the two-dimensional solid could be caused by the formation of certain kinds of defects in the crystal lattice. The same idea was proposed at nearly the same time by two English physicists, Michael Kosterlitz and David Thouless. When told that others had had the same idea, Feynman said: "If they thought of it too, it's gotta be right."

Since then, application of a powerful theoretical technique called the Renormalization Group has turned the idea into a rigorous theory, the first real theory of how a solid melts. Recently, Goodstein and his students have been able to show that the theory does indeed account for the behavior of their two-dimensional solids.

Unfortunately, the theory does not apply to the melting of ordinary three-dimensional solids, which still remains a mystery.

Nuclear Physics Applied to Earthquake Prediction

The automated radon-thoron monitoring network for earthquake prediction research developed by Professor Thomas Tombrello, Senior Scientist John D. Melvin, and Visiting Associate Mark H. Shapiro is now in its fourth year of operation.

During the second half of 1979, substantial radon anomalies were recorded at two stations, Kresge and Dalton Canyon, which are located approximately 30 km apart on the frontal fault system of the Transverse Ranges of southern California. At both sites the anomalous levels of radon decreased shortly before October 15, 1979. During the week of October 15, 1979, a 6.6 magnitude earthquake occurred about 290 km to the southeast of the two stations, and later in that week earthquakes of magnitude 4.2 and 4.1 occurred at Malibu and Lytle Creek. The latter two events were within 60 km of the monitors. A radon-thoron monitor at Lytle Creek recorded no long-term anomaly, but did record a sharp spike-like decrease in the radon level on October 13, 1979. Coincident with these observations of anomalous radon levels, other investigators have reported anomalies or suspected anomalies in several other geodetic, geophysical, and geochemical signals from the same general region. The rapid temporal development of several of the anomalies, together with the large area over which they were observed, suggest that a large-scale, dynamic strain event took place that may have been responsible both for the widespread anomalies and for the seismicity that occurred after the onset of the anomalies.

The Earth's Dynamo
Professor Eugene Cowan has been working on an old unsolved problem in physics, the origin of the Earth's magnetic field. Although it appears that currents flowing in the metallic core of the earth are responsible, the manner in which these currents are generated is still unknown 400 years after Gilbert observed that the Earth behaved as a giant lodestone. A specific mechanism involving fluid motions in combination with variations in resistivity in the molten core of the Earth has been proposed and tested by Cowan with computer simulation and a working model. The parameters required are within the range of possibility. A second computer model is also under investigation in an attempt to account for the known peculiarity that the Earth's magnetic field has repeatedly reversed in direction every few hundred thousand years.

Neurons Communicate through Microcircuits
Professor Jerome Pine has been exploring new techniques for studying neurons grown in culture dishes. For some time it has been known that nerve cells can be transplanted to culture dishes and grown in a monolayer on the dish bottom. These transplanted cells are initially stripped of all their input and

output structures (dendrites and axons) but can regenerate them in culture and become connected, functional, neuronal networks. The study of the factors that influence how neurons become connected synaptically, and how these connections become modified, is of great interest to those trying to uncover the organizational scheme of the central nervous system. Many people believe that learning and memory are the result of synaptic modification. The culture may provide a particularly accessible medium for studying some of these very interesting questions, since developing neuronal networks are easily created. In the past the anatomical and electro-physiological techniques for studying such neurons have been borrowed from work with intact animals, and were so destructive as to make developmental studies awkward if not impractical. In Pine's work, the cultures grow as a thin layer, and thin film microcircuits deposited on the dish bottom are used to record electrical activity non-destructively. In addition, these circuits can be used to give selected patterns of stimuli to developing networks. During the past year, when the techniques have been developed, cells have been listened to and stimulated with an electrode pattern primarily designed to study the applied physics of the process, and the initial results are very encouraging.

Computers Learn Symbolic Manipulation

Caltech physicists are taking the lead in the development of the computer as an aid to science. We expect the computer to become a tool of scientists in more and more areas as the hardware gets cheaper. Currently the computer is extensively used for numerical calculations and the analysis and monitoring of experiments. We anticipate that symbolic uses will grow in areas such as graphics, database management systems, and computer-aided algebra. A group led by Professor Geoffrey Fox, Research Associate Stephen Wolfram, and graduate student Chris Cole has developed a new algebra system (SMP-Symbolic Manipulation Program), which for most applications should be more powerful than the other algebra programs currently available. Computer algebra has already been used extensively in both high-energy physics and relativity, and we expect the new program to open up new investigations that hitherto have been intractable.

Leibniz Revisited

Research in mathematics at the Institute is conducted in many of the fundamental branches of mathematics: algebra, analysis, applied mathematics, combinatorics, geometry, logic, number theory, and statistics. The present report will be devoted to some of the recent research in analysis. It is frequently said that analysis is the branch of mathematics that has its roots in the calculus, so that it is the part of mathematics most intimately related to the sciences. On the other hand, much of contemporary research in analysis is based upon fruitful interplays with other branches of mathematics such as algebra, geometry, topology, and logic.

The nineteenth-century mathematician Sophus Lie introduced a method for studying differential equations that opened a new chapter in mathematics, the theory of Lie groups and Lie algebras. These mathematical systems have been used to represent many physical and mathematical phenomena, such as continuous (actually, differentiable) flows and elementary particles. Assistant Professor Jack Conn is investigating a class of more complicated structures, the so-called Lie pseudogroups, whose properties are not yet well understood. These pseudogroups can be used to describe such phenomena as the so-called canonical transformations of the phase space of a dynamical system and what are known as conformal transformations of a complex variable.

Conn's investigations have focused on the interplay between the algebraic and geometrical aspects of the subject. He has found that the infinitesimal objects that generate certain Lie algebras have certain structural properties (algebraic invariants) that reflect the essential geometrical characteristics of the phenomena these systems describe. Using these insights and the related work of Herbert Goldschmidt at Columbia and Donald Spencer at Princeton, a long-standing problem in the theory of differential geometry has been resolved. This involves an important case of the so-called integrability problem, which is concerned with the definition of structures in differential geometry via systems of partial differential equations. These discoveries have revealed unsuspected new phenomena, such as close relationships with the geometry of surfaces defined by several complex variables.

Professor W. A. J. Luxemburg and his students have been actively engaged over the past decade in a branch of analysis that is closely intertwined with mathematical logic and that has application to diverse areas in analysis, algebra, probability, and even mathematical economics. These studies have come to be known as Non-Standard Analysis. What is involved is the introduction into mathematics of a class of new number systems that were proposed by the late Abraham Robinson and based on ideas from mathematical logic. The key feature of these number systems is that they include infinitesimally small and infinitely large numbers. Such numbers are excluded from the usual system by the axiom of Archimedes. This axiom states that if c and d are positive, adding c to itself enough times will yield a number larger than d. By contrast, the non-standard number systems include infinitesimals, ω, such that no matter how many times you add ω to itself, $\omega + \omega + \omega + \ldots + \omega$, the result is always less than 1. Also included are infinitely large numbers, Ω, bigger than every one of the numbers, 1, 2, 3, 4 . . . .

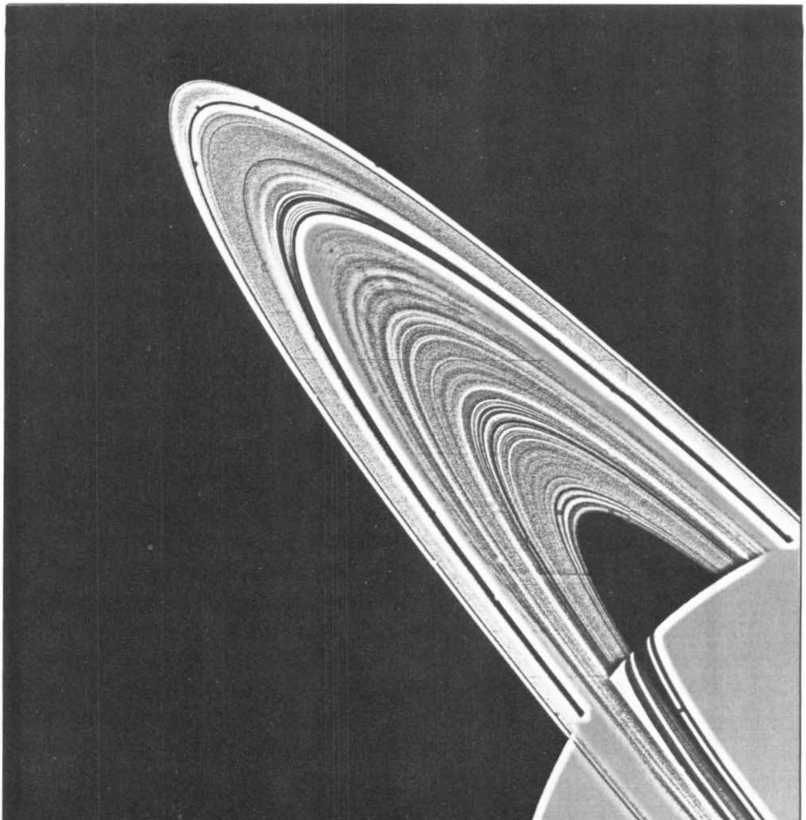
Anyone who studied calculus 50 or so years ago may recall that the textbook had the words "infinitesimal calculus" in the title and that the derivative of a function was defined as the ratio of two infinitesimals, as Leibniz did in his development of the calculus. Actually, it was in the latter part of the nineteenth century that the current ϵ,δ methods were introduced into the calculus and analysis based on an axiomatic foundation of the real number system. So we may now return to Leibniz in a rigorous manner via these non-standard number systems. As Luxemburg and his students have shown, the basic theorems of the calculus may be proved in a more straightforward and transparent way via non-standard analysis. Moreover, they have pioneered in using this technique to prove old results and obtain new results in such areas as analytic function theory, functional analysis, and probability. For his pioneering work in non-standard analysis Professor Luxemburg received a Senior U. S. Scientist Award of the Humboldt Foundation of West Germany this past year.

Gerald B. Whitham, professor of applied mathematics, was awarded a Norbert Wiener Prize, given every five years jointly by the American Mathematical Society and the Society for Industrial and Applied Mathematics. This award was given in recognition of his outstanding contributions to fluid mechanics.

Professor Michael Aschbacher received the Cole Prize in Algebra from the American Mathematical Society for his paper, "A characterization of Chevalley groups over finite fields of odd order." This work is of central importance in making possible the complete classification of finite simple groups, a landmark problem in twentieth-century mathematics.

In recognition of her extraordinary accomplishments in mathematics, Professor Emeritus Olga Taussky Todd was presented with a Golden Diploma by the University of Vienna on the fiftieth anniversary of her receiving the Ph.D. degree from that university.

THE JET PROPULSION LABORATORY



Saturn's multitudinous rings (perhaps 1001) provided a major discovery as Voyager 1 approached the planet last November. This computer-assembled mosaic was taken at a range of 8 million kilometers (5 million miles) six days before the spacecraft's closest approach to Saturn. Until this encounter, the planet was thought to have six rings rather than the multitude shown in the photo. Voyager 1 also discovered two more moons, one of which is seen (upper left) just inside the very narrow F-ring, which is less than 150 kilometers (93 miles) wide.

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

The awesome discoveries of the diversities of Saturn and its satellites by Voyager 1 made 1979–80 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 textbook operation while Voyager 1 was rewriting the basic text on the Saturnian system. The scientific bonanza will require years to assimilate. Meanwhile Voyager 2 will fly by Saturn next August to verify findings and to open up new controversies.

As NASA's lead center for planetary exploration, JPL continued preparations for Galileo (the follow-on mission to Jupiter) and two international projects, the Infrared Astronomical Satellite and the International Solar Polar Mission.

Energy and energy conversion technology are other major endeavors. Solar thermal power conversion studies for the Department of Energy (DOE) are going forward at the JPL test site at Edwards, California. The Laboratory also is lead center for the DOE's Solar Photovoltaic Program, aimed at a viable civilian solar cell technology in this decade. Important research and development are also continuing in coal-pump and gas-extraction techniques for the DOE.

With dedication and resolve, JPL looks forward to a future of steady contributions to the nation's space exploration and energy development programs.

Voyager

The Voyager 1 spacecraft successfully completed its flight from Jupiter to a spectacular encounter with Saturn on November 12. A healthy Voyager 2 continued its flight with closest Saturn approach due August 25, 1981.

Voyager 1 took nearly 17,500 photographs, and nine other science instruments contributed startling new data during the nearly flawless encounter. Among the more important preliminary findings:

The speeds of equatorial winds on Saturn are up to five times higher than those of Jupiter, perhaps 500 meters per second (over 1100 mph).

Auroral emissions were measured at the poles and near illuminated limbs. Radio signals typical of lightning discharges were sensed although no lightning flashes were observed. The discharges may originate in the rings rather than in Saturn's atmosphere.

The planet may have a thousand rings. The large classical B and C rings consist of hundreds of individual ringlets. Even the Cassini Division was filled with many individual rings of very fine material. One gap in the C ring was found to contain an eccentric ring. The F ring was resolved into three strands, two of which were intertwined.

Spoke-like features, found in the B-ring, appeared to consist of very fine ring material. Although the origin of sporadically occurring spokes is not currently understood, static electrical charging of the fine material may play a role.

Saturn's rotation period—the length of its day—was fixed at 10 hours 39 minutes 26 seconds.

Superb photographs of several of Saturn's satellites will permit surface morphology studies. Mimas, Tethys, Dione, and Rhea are heavily cratered, but Enceladus appears smooth.

The mystery moon Titan was shrouded in a thick haze layer and clouds, and its surface was not photographed. Various measurements indicate that the atmospheric pressure at Titan's surface is 60 percent greater than Earth's and consists predominantly of nitrogen. Titan's diameter was shown to be about 5140 kilometers, establishing Jupiter's Ganymede as the largest satellite in the solar system.

Voyager 2 science observations will be modified to take advantage of the Voyager 1 findings in order to maximize the return from the two encounters. It may require years of analysis to realize the full return of this mission.

Voyager 1's trajectory past Saturn deflected the spacecraft upward out of the ecliptic plane and, eventually, the solar system, toward the constellation Ophiuchus. All going well, Voyager 2's path past Saturn will permit a Uranus encounter in January 1986.

Galileo

This dual-launch follow-on mission to Voyager, scheduled for early 1984, will further investigate Jupiter and its Galilean satellites. Using the Space Shuttle, an orbiter and an atmosphere entry probe will be launched about a month apart. The orbiter will rendezvous with Jupiter in mid-1986 and make up to 11 close encounters with the four largest moons. The probe will be released into the Jovian atmosphere in mid-1987 and return information about its composition and stratification.

As project manager, JPL is developing the orbiter. Ames Research Center is responsible for probe and probe carrier, and the Federal Republic of Germany will supply the retropropulsion module for the orbiter.

Infrared Astronomical Satellite (IRAS)

An international endeavor of the United States, the Netherlands, and the United Kingdom, IRAS will provide a one-year infrared telescopic survey from an Earth-orbiting satellite. The all-sky broad band survey is expected to achieve a sensitivity a thousand-fold greater than any existing infrared astronomical system.

The project, co-managed by JPL and the Netherlands Aerospace Agency, will launch a cryogenically cooled U.S. telescope aboard a Dutch spacecraft in August 1982 into a near-polar 900-kilometer orbit. The U.K. will furnish the tracking station and operations center. The spacecraft is nearing completion and the telescope, which is the responsibility of Ames Research Center, is undergoing performance and environmental testing. Eighteen scientific experimenters include two from the campus and one from JPL. Science data analysis and infrared source cataloging are JPL responsibilities.

International Solar Polar Mission (ISPM)
This dual spacecraft mission will permit observations of hitherto uncharted regions on and surrounding the Sun. Under the joint sponsorship of NASA and the European Space Agency (ESA), launch is now set for March 1985, having been rescheduled from 1983.

The two spacecraft will be launched on high-speed trajectories outward to Jupiter, whose gravity will deflect each vehicle into orbits nearly perpendicular to the ecliptic—the plane of the solar system. One spacecraft will pass first over the Sun's north pole, the other near the south pole. Each will then pass over the opposite pole.

The NASA spacecraft is being developed by TRW under contract to JPL; the European craft, by Dornier Systems for ESA. Twenty-one investigation teams numbering 150 European and American scientists (5 from JPL, 3 from campus) will study the Sun's surface and corona, magnetic fields, solar wind, heliosphere, cosmic dust, and interstellar gas.

Viking
The Viking Project, begun in 1968, was officially terminated September 30, 1980, its mission successful beyond expectation. Of the four spacecraft that began observations at Mars in the summer of 1976, Orbiter 2 operated until July 1978, Lander 2 until April 1980, and Orbiter 1 until August 1980. Thus data on the planet were obtained through more than two Martian years.

Lander 1 is still acquiring data in an automatic mode programmed to continue until 1994 barring component failure. With 52,000 photographs from the orbiters, 4500 from the landers, and vast quantities of other data, the Viking mission has provided an as-yet incalculable advance in our understanding of Mars—plus a mine of information that scientists will be working for years to come.

Other Flight Activities
The Solar Mesosphere Explorer, to be launched September 1981 into a polar, Sun-synchronous orbit 535 kilometers above Earth, will provide a comprehensive study of the atmospheric ozone and the processes that form and destroy it. As project manager, JPL will supply the spacecraft module while the University of Colorado Laboratory for Atmospheric and Space Physics is developing five instruments and will run the mission operations from its facilities in Boulder.

Several JPL science instruments continued to provide valuable data aboard satellites. The Nimbus scanning multichannel microwave radiometer launched in October 1978 and the high-resolution spectrometer on HEAO C-1 launched September 1979 contribute important data for meterology and gamma-ray studies, respectively. Total solar irradiance was studied by another JPL radiometer on the Solar Maximum Mission.

Three projects are being developed as possible missions for the 1980s—the Venus Orbiting Imaging Radar (VOIR), a Halley's Comet Mission, and an Extreme Ultraviolet Explorer satellite.

Telecommunications and Data Acquisition
The Deep Space Network (DSN) was intensely involved in the success of the Voyager mission. The Voyager 1 encounter of Saturn required intricate advance preparations, with particular challenges for radio science operators who had to react and interact in real time with the reflections of the spacecraft signal from Saturn's rings received at DSN tracking stations.

The DSN also provided excellent data during 50 radio science solar conjunction opportunities and continued supporting the Pioneer Venus Orbiter and Pioneer 10 spacecraft, both NASA Ames Research Center projects. The record tracking distance to Pioneer 10, on its way out of the solar system, passed the 3-billion kilometer mark. Communication with the Viking lander still active on Mars is continuing.

The network was upgraded for the Voyager Saturn encounter. The sensitivity of the 64-meter stations at Goldstone, Madrid, and Canberra was increased by lower-noise X-band traveling wave maser amplifiers. Telemetry arraying—combining receiver outputs of 34-meter and 64-meter stations—stepped up the data rate.

Such arraying will be increased under NASA's five-year plan to consolidate the DSN and Goddard Space Flight Center's ground net. The consolidated net, to be operated by JPL, will also track highly elliptical Earth orbiters.

Future deep space projects will require frequency stabilities about ten times better than the one part in a quadrillion now achievable. In pursuit of this objective, development of compatible ultra-stable time and frequency distribution systems began, and a 3-kilometer fiber optic test link was installed. A new phase stabilizer was developed to permit such accurate frequency and timing to be distributed to the several stations in a tracking complex.

Planetary radar data accomplishments included three-station interferometry of Venus and radar altitude contouring of Venus and Mars. Scientific findings were reported on the strange Earth-based radar returns from the Jovian moon Ganymede. Voyager radio science observations corroborated results of Voyager instruments, helped to fix the density of Jupiter's ring, and determined electron distribution in the Jovian atmosphere.

The geodynamics program conducted geodetic measurements in southern California with the 9- and 4-meter antennas of the ARIES (Astronomical Radio Interferometric Earth Surveying) Project. Baseline changes measured between JPL and both Goldstone and Owens Valley indicate micro-strain events that are compatible with measurements made by the United States Geological Survey using other instruments.

Space Science and Applications

The distribution of water in the Martian atmosphere, and the distribution of water ice in the subsurface and polar caps of Mars, provides the key to the weather and climate of the planet. A model has been developed that successfully reproduces the absorbed water vapor distribution on Mars and the polar ice distribution in the north and south as a function of season. A measurement technique also was developed that allows the monitoring of water ice concentrations on Mars from Earth or spacecraft. The ability to monitor the change in the distribution of ice with the seasons will allow testing of newly developed models of the Martian weather and climate.

Voyager observations of hot spots on Io led to re-examination of early Earth-based infrared observations of this Jovian moon. Using these data, it was determined that the average heat flow through Io's surface is about that of an active geothermal area on Earth and implies that Io has a partially molten interior.

Uranus and Neptune are the next targets for reconnaissance of the outer solar system. Using ground-based telescopes, the first spectrum has been obtained of the transient haze on Neptune, which constitutes the only weather ever observed on either Uranus or Neptune. Also, the first indisputable evidence for the existence of a substantial stratospheric temperature inversion has been obtained, not only on Neptune where both methane and ethane are seen in emission at 8 and 12 micrometers, respectively, but on Uranus where no emission features have previously been detected.

Progress in the remote sensing of geological information was demonstrated by a NASA/Geosat test case study. Several test sites were selected to compare the data from the Landsat, the thematic mapper simulator, and other remote sensing instruments, with data obtained from field sampling.

Petroleum test sites selected were Patrick Draw, Wyoming, Lost River, West Virginia, and Coyanosa, Texas. Linear features not noted before were revealed. Large-scale subcircular anomalies, though covered by subtle topography, thick soil, and alluvial deposits, were located.

The Patrick Draw test resulted in the most detailed geologic map currently available. Stratigraphic units are subdividable to an extent not possible before. Structural features not previously recognized are clearly delineated.

In a project for the Bureau of Land Management, JPL integrated and analyzed a variety of conventional and remotely sensed data to estimate the range-carrying capacity of the 25-million-acre California Desert Conservation Area. The results provided forage capacity statistics that were used to assign range quotas for the conservation area's environmental impact statement and proposed operational plan.

Technology Development

A Mobile Automated Field Instrumentation System (MAFIS) is being designed and developed by JPL for the U. S. Army to test the effectiveness of new weapons systems and associated strategies in simulated battlefield conditions. With 1985 set for operational readiness, MAFIS will consist of position-locating and communications networks that operate over a 50-kilometer-square area.

Within that area more than 1000 units carried by soldiers, tanks, helicopters, or other vehicles can be monitored in real time by using the networks in combination with the universal field element carried by each unit involved in the maneuvers. Engagement information, position location, and casualty assessment can be transmitted to a command and control center monitoring the battle test.

The Laboratory achieved several improvements in data processing imaging and electronics for information systems. One advance was in fault-tolerant computers, which might recognize and solve problems to keep missions from catastrophic failure. This was accomplished by developing the memory interface and core blocks of a fault-tolerant microcomputer.

Also in the area of space flight technology, an ultra-sensitive screening and test facility for solid-state charge-coupled devices (CCDs) was activated and work was begun in the development of higher-resolution visual imaging CCDs. Charge-coupled devices will supplant vidicon-tube technology as the spacecraft imaging system on Galileo.

An instrument of potential value in a high-speed comet mission—an ion mass/velocity spectrometer—was experimentally tested after two years in development. It is expected to provide improved performance in mass resolution and angular response as a space-borne instrument.

Long-duration thrust capability was demonstrated in a high-energy fluorine-hydrazine rocket engine being developed for future planetary missions. Using a refractory rhenium metal firing chamber, the engine accrued nearly 700 seconds of test firing time, demonstrating that its feasibility may soon be established. This propulsion system should deliver 25 percent more specific impulse than the Viking Orbiter engines.

Initial shallow-water testing was successful on an undersea vehicle employing side-looking digitized sonar for preparing images of the ocean bottom. Significant improvements in automation and quality of images will result from this approach, which was spun off from the space exploration program.

Energy and Technology Applications (E&TA)

The Laboratory continued its efforts in the application of space-derived technologies to energy, transportation, biomedicine, and related fields. The E&TA Program worked with the Department of Energy to broaden the scope of JPL's responsibilities in the major projects, particularly in solar energy.

As the DOE Lead Center for Technology Development and Applications on photovoltaics, JPL increased its activities in program planning, implementation, and assessment, as well as coordinating the related work of other national laboratories. The nation's largest photovoltaic experimental application, a 100-kW system at the Natural Bridges National Monument (Utah) visitor's center, was brought on line in June 1980, with excellent performance to date. Also, the nation's first photovoltaic house was completed in Phoenix, Arizona. In industrial photovoltaics, low-cost production of high-purity silicon entered the pilot-plant stage and the growth of 10-cm-wide multiple ribbons of crystalline silicon was demonstrated.

The Laboratory's solar thermal energy project selected a systems integration contractor to perform detail design for a small-community engineering experiment, sponsored by DOE. Candidate communities were solicited and six finalists were selected. Major test equipment was installed at the parabolic dish test site at Edwards Test Station, where two large test-bed concentrators are being used to evaluate solar-ray focusing technology and subsystems. Contractors were selected to design a low-cost concentrator and heat receivers using air and steam.

A joint project was undertaken with Southern California Edison Company, the California State Energy Commission, DOE, and Ormat Turbines of Israel to demonstrate salt-gradient solar pond technology for electrical generation in a 5-megawatt pilot plant at Salton Sea, California, in the 1982-7 period. The process relies on using the thermal energy of warm high-salinity water that concentrates at the pond bottom.

An electric and hybrid vehicle systems project for DOE continued with the awarding of a contract to General Electric Corporation and Volkswagen of America for the design and development of a near-term hybrid vehicle. Evaluation tests also were conducted on nickel-iron, nickel-zinc, and lead-acid battery systems for electric automobiles.

An important task for the Department of Transportation produced a traffic monitoring sensor that shows multilane traffic speeds, density, and volume by computer image data processing, using a single television camera.

A utility systems project is developing methodology for integrating new energy technologies into existing utility networks. Toward this end, a computerized simulator was devised to examine electric utility operational problems on an interactive basis. It has been demonstrated to many utility managers and was used at an electric utility to simulate field tests of power load management, including storage.

Other tasks performed for the DOE: Coal research to increase organic sulfur removal and expedite a continuous flow reactor; assessment of relative merits of gasification systems; planning control systems for fossil-energy plants; fuel-cell processing research; and acoustic measuring of commercial burner efficiencies.

In biomedical technology, a muscle biopsy analyzer was licensed for manufacture, affording a diagnostic aid in neuromuscular disease. The system, using JPL digital image-processing techniques, identifies diseased and healthy muscle fibers from a biopsy specimen. Another image-processing application may provide low-cost diagnosis of cervical cancer, under National Cancer Institute sponsorship.

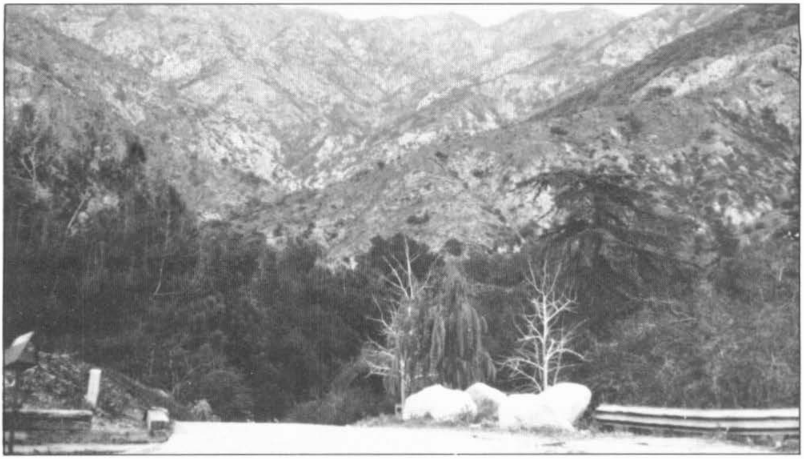
An experimental study, testing the feasibility of polymer immunomicrospheres for cancer treatment, demonstrated that cancerous cells possess receptors that differ from nonmalignant cells. If antibodies to these receptors can be isolated, then immunomicrospheres could be used to deliver anti-cancer drugs selectively to malignant cells, reducing adverse side effects of chemotherapy.

Discretionary Research Funds

The memorandum of understanding between NASA and Caltech provides for two discretionary research funds—a JPL Director's Discretionary Fund (DDF) supplied by NASA, and the Caltech President's Fund (PF). Their key objectives 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 DDF initiated 21 tasks, the PF, 20. Besides Caltech, schools involved were the Universities of Arizona, Chicago, and Utah, three campuses of the University of California, plus Stanford and Cornell.

ENVIRONMENTAL QUALITY LABORATORY



Rubio Canyon watershed, Altadena, (upper photo), which burned over in 1979, produced record floods in February 1980 with huge loads of sediment and debris. Rubio Debris Basin (lower photo) trapped most of the material and saved Altadena from widespread damage.

Norman H. Brooks, Director

The challenge of managing our resources and the environment becomes greater every year. Energy problems and inflation create a strong push toward relaxation of environmental controls. But dramatic news events are sharpening some environmental health concerns (e.g., hazardous waste dumps contaminating ground water, and the accident at the Three Mile Island nuclear plant). When adverse human health effects are believed to be a problem, there probably will be little or no slippage in environmental objectives. On the other hand, environmental aesthetics (e.g., visibility in the atmosphere) and the health of ecosystems (as in the coastal waters) may decline somewhat in the years ahead if the American people give them less priority.

Regardless of where the balance is struck by the political process, the problems are difficult to resolve, and patience with government regulation is wearing thin. EQL's policy studies involving a broad spectrum of disciplines in natural and social sciences, engineering, and law produce analyses and policy alternatives that help decision-makers in government and industry. Not only is it necessary to establish goals, but also control measures to achieve them must be cost-effective.

During the past year, EQL sharply increased its commitment to graduate student support through research assistantships and fellowships. Thirteen graduate students, mostly Ph.D. candidates, are being supported by EQL in the academic year starting in September 1980. The new Institute-wide Haagen-Smit/Tyler Graduate Fellowship for environmental study and research (awarded to four students for 1980–81) is also helping to attract outstanding new applicants.

Several appointments of additional teaching faculty in areas of strong EQL interests over the next few years would strengthen EQL considerably in the long run by increasing the size of the core group of investigators. Associate Professor Michael J. Hoffmann, an experimental environmental chemist, joined the environmental engineering science faculty in August 1980; he is an important resource person for work on hazardous substances in the environment (now being supported by a three-year grant to EQL from the Andrew W. Mellon Foundation in 1979). In the past year, EQL has hired three new postdoctoral research fellows (two engineers, one economist), and another (a chemist) starts in January 1981. The number of our full-time research staff will then be nine, in addition to the fourteen professors who are engaged part-time in EQL work, two part-time consultants, and EQL's full-time support staff of eight people.

With two welcome additions of office space, EQL is better housed than a year ago. Most of the air pollution group now occupies a suite of new offices at the north end of the second floor of Dabney Hall (where the old lecture hall was), and energy policy and water resources staff are using the historic Bateman house, formerly the home of public relations and publications and located on San Pasqual Street. Since this was the site of the new Braun building (now under construction), the house was cut into three pieces, moved to a double lot on Lura Street, reassembled, and refurbished inside and out. EQL headquarters (with staff working on hazardous substances, water quality, sediment management, and air pollution) remains on the third floor of Dabney Hall.

For 1979–80, EQL's support has been distributed as follows: gifts for general support (from corporations, foundations, and individuals), 26 percent; gifts for specific research programs, 18 percent; Caltech funds, 4 percent; and government sponsored research, 52 percent (federal government, 25 percent; state government, 25 percent; local government, 2 percent).

Some highlights of last year's research projects and conferences are presented below.

Air Quality

Air Quality Trends in the South Coast Air Basin

In September 1979, an eight-day air pollution episode occurred in the Los Angeles area that was described by many observers as the worst such incident in more than a decade. At that time, the question was raised, "Does the return of such a serious spell of bad air quality indicate that emission control strategies for photochemically related air pollutants are failing to work?"

Under the chairmanship of Assistant Professor Glen Cass, an EQL conference, sponsored by the California Air Resources Board, was held at Caltech in February 1980 to assess measured trends in air quality in the Los Angeles area. It was shown that air quality improved markedly from the mid-1960s through 1975. However, despite the introduction of additional emission controls since 1975, oxidant air quality has worsened since the mid-1970s because of periods of unusually adverse meteorology, such as the one in September 1979. Even when meteorological variations are factored out, the trend in oxidant air quality shows no improvement over the past five years. Additional discussions at the conference focused on uncertainties in emissions estimates that could account for observed air quality trends, and on the role of oxides of nitrogen emissions within the photochemical smog complex. Over 200 people from government, industry, academia, and the general public participated.

Modeling of Photochemical Air Pollution

For effective evaluation of air pollution control strategies, EQL has developed a validated and reliable computer model that can relate pollutant emissions to atmospheric air quality. During the past year, further improvements in the computer model have been made by Professor John Seinfeld, graduate student Greg McRae, and Senior Research Engineer James Tilden. Effects of uncertainties in model parameters, solution procedures, and input data are being assessed using novel sensitivity analysis techniques.

Marketable Permits to Emit Air Pollutants

The most commonly used method to regulate air pollution is for regulators to set control standards for each source of emissions. Several alternatives to this approach, such as marketable permits, are now being actively considered in hopes of reducing abatement costs and government red tape. While the theoretical case for applying market mechanisms to control pollution is persuasive, there are several stumbling blocks that arise in their application. An EQL research project, headed by Professors Roger Noll and Cass, and sponsored by the California Air Resources Board, focuses on the design of a workable scheme of marketable permits to emit air pollutants. The general idea is to organize a market where rights to emit one or several pollutants can be bought and sold (in much the same way stocks are traded on a stock exchange).

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.

In order to demonstrate the viability of marketable permits without actually implementing the alternative, the project had to select a particular pollution problem, identify the key implementation barriers, and then design a market system that would work properly. The problem of controlling sulfur oxides emissions was selected, because the scientific aspects are well understood and the requisite data on abatement costs could be constructed. Furthermore, the economists could benefit from Professor Cass's extensive background of engineering research on sulfate air quality management.

The work to date has provided useful information on the expected price that permits to emit sulfur oxides would command in a competitive market, as a function of the level of air quality sought. Areas for future research in the remaining year of the contract include identifying penalty schemes for dealing with violations, demonstrating how the transition from the current standards-based approach to the market approach can be achieved, and designing market institutions that will not be susceptible to manipulation by sources owning a large share of the permits.

Atmospheric Carbon Particles

Carbon-containing particles are emitted from most combustion processes. The soot fraction of these pollutant emissions contains an appreciable amount of black carbonaceous material, often referred to as elemental or graphitic carbon. Elemental carbon particles are thought to be the most abundant light-absorbing aerosol species in the atmosphere, but their importance to visibility deterioration has been understood only qualitatively because there are few historical data on elemental carbon concentrations in the atmosphere. This problem has become increasingly important in California with the growing number of diesel engines.

During January and February 1980, Professor Cass and graduate student Martha Conklin conducted a field study of atmospheric aerosols at downtown Los Angeles and at Pasadena. They determined that elemental carbon at present concentrations is having a significant effect on visibility degradation in Los Angeles.

Floods and Sediment Management

While concluding our study on overall sedimentary balances in the southern California coastal strip, we have again had a live demonstration of the violence of floods in this area, with huge movements of sand, gravel, and boulders, especially on burned-over watersheds. To document the natural flood events of the winters of 1978 and 1980 and the damages caused by these disasters, EQL convened a two-day symposium in September 1980, which was attended by 300 people from agencies responsible for flood management, from universities and from the private sector. The proceedings, which will be published as a joint National Research Council/Environmental Quality Laboratory report in 1981, include papers covering storm meteorology, streamflow, sediment movements, engineering successes and failures, hazard mitigation, and flood-fighting operations.

Ocean Discharges

The national policy for controlling discharges of wastewater and digested sewage sludge from municipalities to the ocean has come under renewed scrutiny in recent years. Two EQL projects in the last few years have added to the analysis of the problems and the options. In a project for the National Oceanic and Atmospheric Administration, EQL staffers (Research Associates Robert C. Y. Koh and R. Talbot Page, and Professors Brooks and James E. Krier (UCLA)) wrote four chapters (out of thirteen) of a definitive technical book on ocean discharge of sewage effluent and digested sludge. The final chapter by Brooks assesses the technical problems and policy alternatives. The book will be edited and published by MIT Press in 1981.

The other study, by George Jackson (now at Scripps Institution of Oceanography), Koh, Brooks, and James Morgan, analyzed a new method of sewage sludge discharge into the ocean—injection into the deep ocean basins off southern California. While national policy is to phase out ocean dumping by 1981, Brooks believes that that policy decision lacked a scientific basis. The EQL study (including physical and chemical modeling) showed that discharge through a special outfall pipe at the optimum depth (about mid-depth, or 400 m) into the basins would probably cause very small environmental impacts at the surface, the bottom, or in the water column. In the context of other alternatives for southern California (such as incineration or land filling), the ocean option was judged most attractive by the local agencies (on the basis of lowest cost, low energy use, no additional emissions, as well as low environmental impact in the ocean), but it was not adopted because of the prohibition by federal and state laws. However, further research and demonstration projects in the ocean may be undertaken by one of the local agencies, if permitted by the Environmental Protection Agency (EPA).

Other Areas

EQL's work in other areas will be reported in more detail in subsequent reports. Topics of research in energy policy include:

- regulatory problems in the energy industry,
- natural resources pricing and markets,
- energy-environment trade-offs, such as adaptation to the CO_2 problem,
- bidding strategies for mineral leases (including petroleum),
- peak-load pricing, and
- licensing of nuclear power plants.

In water resources, topics of research include:

- water requirements for energy extraction and for synthetic fuels industries in relation to water availability in the upper Colorado River Basins,
- use of water markets to improve efficiency of allocation and distribution, and
- optimal management of multiple water sources (such as surface and groundwater).

The new three-year grant from the Andrew W. Mellon Foundation is supporting EQL's enlarged research on hazardous substances, including individual regional problems such as:

- effectiveness of source control (or pretreatment) for municipal sewers,
- transport and fate of trace contaminants in the ocean,
- hazardous substances in the atmosphere that are not yet regulated,
- exposure to trace contaminants entering ground-water basins (such as from landfills).

Page and Professor John Ferejohn will be continuing the analysis of trade-offs between uncertain long-term risks and short-term benefits of society's use of hazardous substances.

THE CALTECH LIBRARIES

Librarians use computer terminals to access over 6,000,000 records to be used for cataloging and interlibrary loan processing.

Johanna E. Tallman, Director

Library Survey

In April 1980 the Faculty Library Committee sent a questionnaire to each faculty member to probe his or her perception of the CIT libraries—their resources and services. The response was remarkably high, totaling 176, of which 40.9 percent were full professors.

The quality of collections was rated as inadequate in 30 percent of the responses, and 94 percent said that added expenditures were urgent/desirable. The quality of reference service, interlibrary loan, circulation, and interdepartmental copying is seen as high by over 90 percent of the respondents. Speed of acquisition and cataloging of new books was rated by 74 percent as excellent or adequate. Copies of the questionnaire and analysis are available on request to the director.

Cost of Books and Periodicals

It has been the policy of libraries at Caltech to build to the strengths of current research and teaching programs, based on faculty input, within budgetary limits. This means there are gaps in holdings if interests shift, if new or visiting professors come, or if new courses are introduced. The lack of adequate budgets to keep up with needs further erodes the adequacy of collections. For example, the number of books ordered has dropped from a high of 12,731 in 1968–69 to a low of 3015 in 1979–80.

The cost of journals and serials has escalated well beyond the cost-of-living index and has consumed more of the budget dollars. Some scientific journal subscriptions have jumped nearly 400 percent in recent years. These costs have put a tight squeeze on book purchases. For example, in 1972–73 the libraries spent 30.2 percent of the acquisitions budget on books. In 1979–80 it was only 16.8 percent. On the other hand, the share of the budget spent on periodicals in 1972–73 was 49.8 percent, which increased to 64.7 percent in 1979–80. In terms of percent increase, the book budget went up only 1.3 percent in this time period, whereas the periodicals went up 137 percent. Continuations (annuals and similar serials) went up 145 percent.

The processing of books (purchases and gifts) has declined 36.7 percent in the period 1973–74 to 1979–80. The number of periodical and serial titles received has been kept fairly even, with 5485 received as of September 30, 1974, and 5422 as of September 30, 1980. This is a result of constant vigilance to cancel duplicates and less-used material and to add only those new titles deemed essential. Occasionally canceled titles have had to be reinstated due to continued demand and to the copyright law restrictions in interlibrary photocopying of journals beyond specified amounts without paying steep royalty fees.

Networking

The Caltech libraries are involved in a number of consortia and networks, resulting in both expanded resources and savings in costs. OCLC is an international network of 2300 libraries. The data base, now over six million bibliographic entries, can be used for pre-order verification, on-line cataloging, location of libraries holding copies, and the transmission of messages to selected libraries for interlibrary loans. Nearly all of our book cataloging is done using this on-line system, which produces and alphabetizes catalog cards for 21 Caltech libraries.

The Center for Research Libraries, located in Chicago, serves member libraries by providing access to rarely held material such as foreign dissertations and unusual journals or documents. Membership also gives access to the resources and services of the British Library Lending Division.

CALINET is the consortium between Caltech, UCLA, and USC. The most used feature is the intercampus vehicle for transporting riders, mail, and lab specimens between these campuses. With gasoline prices soaring, the ridership from CIT increased 35 percent to 624. The van also speeds the delivery of interlibrary loans.

On-Line Data Base Searching

The library staff has increased the searching of on-line bibliographic data bases, through Lockheed DIALOG, SDC Search Service, and Medline. A total of 572 searches were made, an increase of 160, or 38.8 percent. Of these, 234 were for faculty and 174 for students. All divisions availed themselves of these useful services.

Institute Archives

The Institute archives has completed the Theodore von Kármán microform project for the Smithsonian Air and Space Museum. A series of three microfiche publications has been prepared for the U.S. Geological Survey, dealing with seismology and records covering periods from 1904 to 1968. The Caltech Photographic Research Archive has been indexed by subject. Guides have been prepared for the correspondence of astronomer Marshall H. Cohen, biochemist Jerome Vinograd, neurophysiologist Cornelis A. G. Wiersma, and the Jet Propulsion Laboratory, for the period 1941–1968. Scientists interviewed for the Oral History Program this year include geologist Robert Sharp, mathematician Olga Taussky-Todd, and biologist James Bonner.

Among acquisitions for the archives were materials relating to the Palomar Observatory, Clark B. Millikan papers, Charles E. Taylor Collection of Aviation Memorabilia, the Hugo Benioff slide collection—including the 1906 San Francisco earthquake—and photographs relating to the Gnome Club, 1914–1930s.

Friends of Caltech Libraries

During the second year of this support organization, three events were held. Jess Marlow, NBC anchorman, spoke at a luncheon about his experiences on a two-month trip to China. A dinner featured writer Saul Bellow, and a wine and cheese party was held at a presale evening for Friends before the annual book sale. As of September 30, 1980, there were 163 members.

A Chip Off the Old Block

A bolt of lightning struck the top northeast corner of the Millikan building during a severe thunderstorm on March 18. The lightning danced past windows, the thunderclap seemed as if all Caltech labs were exploding, and pieces of granite were scattered over adjacent areas. A large piece (about 150 pounds) of the granite fell into the pool, and is now serving as a piece of sculpture in the office of the director.

Holdings and Circulation

Books	206,045
Bound Periodicals	139,831
Periodical & continuation titles	5,422
Microform	
Reels	9,344
Fiche	213,493
Cards	7,755
Circulation, Millikan Library	41,859

INDUSTRIAL RELATIONS CENTER

Fred H. Felberg, Assistant Director of the Jet Propulsion Laboratory, confers with Victor V. Veysey and Reed M. Powell, Director and Associate Director of the Industrial Relations Center, at the 40th Anniversary program.

Victor V. Veysey, Director

For more than 40 years the Industrial Relations Center at Caltech has pursued four designated objectives:

1. Instruction of Caltech students in the field of business economics and management,
2. Meetings and conferences for the development of line managers and industrial relations specialists,
3. Research and studies directed to the development of effective managerial policies and techniques, and
4. Collection in the Management Library of the best materials for reference by users from on and off campus.

The Center at Caltech was established in 1939 as the fifth in a series of institutions (now numbering 85 universities and colleges) to emerge as a center for study, research, and teaching of industrial relations. During World War II, the Center took on new responsibilities for conducting seminars for management development, specializing in the management problems of private businesses operated for profit.

Because of the nature of Caltech, the Center has focused on the management problems of technical people and on industries employing high technology. There has been a particular concern for the management of human resources in ways that optimize productivity and enhance the quality of working life.

Concerns of Higher Management

During its early years the Center concentrated on the management problems of lower level line supervisors because this appeared to be an area of weakness in establishing and maintaining effective industrial relations. Industry has responded by establishing programs to strengthen the ability of first line supervision to meet the growing demands placed on it.

During the past three years the Center offered an increasing number of programs for middle management and some for the highest levels of corporate governance. Among these were seminars for project and program managers, for divisional controllers, and, through The Executive Forum, programs for chief executive officers and general managers. In addition, the Center organized and presented a three-day program for corporate directors, concentrating on the new legal, regulatory, organizational, and societal challenges aimed at corporations.

A significant addition to this effort will be the Center's sponsorship of the very popular Drucker/Powell seminar for advanced executives, "The Effective Executive in the 1980s." The interest in the program has been so great, and the drawing power of Dr. Peter Drucker and Dr. Reed Powell so strong, that the seminar, to be offered in October 1980, is overfilled and will be repeated in December 1980.

Management of Technical Professionals

The management of technical professionals presents a problem of great interest to Caltech and to the Center because a high proportion of Caltech graduates are in jobs at important management or executive levels. An intensive technical background supplemented by high task orientation provides a strong basis for success in management, provided sensitivities and skills in the area of human relationships are also developed. The Center continues to offer opportunities to Caltech students to develop managerial competence.

For engineers who are encountering the difficult problems of management in their work, the Center has developed its engineering/management program in cooperation with a dozen employers of large numbers of engineers. Completion of the program requires 120 hours of instruction in designated areas, and Caltech has permitted the Center to award a certificate for satisfactory achievement.

Improvement of Productivity

Periodic seminars have been held during the last five years in which successful productivity improvement projects in various industrial settings have been described and studied. Interest and participation in these seminars have increased sharply in 1980, paralleling the growing national realization that shortfalls in labor output must be overcome if we are to cope with problems of inflation, foreign competition, and the stagnation of our standard of living.

In the volume published late in 1979 to commemorate the 40th anniversary of the Center, "The New World of Managing Human Resources," extensive attention was devoted to the economic, managerial, and motivational aspects of problems of declining productivity. While some of the problem centers on national policies with respect to money and taxation, there is reason to believe that much can be done through management attention to the problem, through better directed incentives, and through understanding the needs of employees. The importance of this prospect prompted the Ann Peppers Foundation to sponsor a widespread university and library distribution of the commemorative volume.

The Industrial Relations Center is planning the expansion of its efforts in productivity by integrating a library resource with the existing group in Productivity Improvement, and to add research and study components as well as specific seminars and publications to disseminate the findings. This new function, under the loose association of a Productivity Center within the Industrial Relations Center, would be responsive to the concerns of industry and to a national need for new directions.

In this regard, attention is now focused on the remarkable success that Japanese industry is achieving in improvement of productivity. This is an area in which the Center has planned research, studies, seminars, and publications. Tentative conclusions include the possibility of adopting some of the Japanese management techniques in the United States, and the impossibility of adopting others because of great cultural dissimilarities.

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 1945, and they are being used with growing frequency both by the Center and by others. Careful analysis of employee opinions and attitudes may prove to be a powerful tool to strengthen management in its efforts to achieve higher productivity.

The Management Library

A resource of ever-increasing value to students from Caltech and from the world of business is the Management Library, which has attracted serious scholars from many nations. The collection was expanded and rearranged during the past year with funds made available from contributions to the Robert D. Gray Memorial Library Fund. It was also possible to weed out less-used and obsolete materials.

Special efforts have been made by Librarian Mary MacKintosh to acquaint those attending management seminars with the Library, and to arrange displays of newly acquired books for exhibit at seminars.

Orange County Programs

Starting in June 1980 some seminars presented by the Center have been offered in Orange County for the convenience of that rapidly growing industrial community. Reception has generally been cordial, and plans call for a gradual expansion of effort in this direction.

Reed M. Powell, who joined the Center as associate director in 1980, is taking a leading role in the establishment of the Orange County Management Center, attuned especially to the needs of the rapidly expanding business community in that area.

Sponsors and Donors

The Center is sustained through continuing annual fees or gifts, and through the participative cooperation from a number of sponsor companies and donors. The sponsors of the Center as of September 30, 1980, were:

Atlantic Richfield Company
Automobile Club of Southern California
Avery International
Avon Products, Inc.
Barco of California
BDP Company, Division of Carrier Corporation
Beckman Instruments, Inc.
Bell & Howell, Inc., Electronics & Instruments Group
Bourns Inc.
Burroughs Corporation, Computer Systems Group
Carnation Company
City of Hope National Medical Center
Coca-Cola Bottling Company of Los Angeles
Dart Industries Inc.
Data-Design Laboratories
The Digitran Company
Walt Disney Productions
Glendale Federal Savings and Loan Association
Gould, Inc., NavCom Systems Division
The W. W. Henry Company
Home Federal Savings and Loan Association of San Diego
Industrial Indemnity Company
International Business Machines Corporation, Western Area
The Irvine Company
Jacobs Engineering Group Inc.
Earle M. Jorgensen Co.
Knudsen Corporation
Lear Siegler, Inc., Astronics Division
Mobil Oil Corporation, Western Resale Region
Mobilehomes, USA, Inc.
James M. Montgomery, Consulting Engineers, Inc.
Norris Industries
Northrop Corporation
The Ralph M. Parsons Company
Purex Corporation
San Fernando Electric Manufacturing Company
Security Pacific National Bank

The Signal Companies
Singer, Librascope Division
Southern California Edison Company
Southern California Gas Company
Southern Pacific Transportation Company
Southwestern Portland Cement Company
Sparkletts Drinking Water Corporation
Standard Oil Company of California
Summa Corporation
T&B/Ansley Corporation
Texaco Inc.
TRW Systems & Energy
Twentieth Century-Fox Film Corporation
Union Bank
Union Oil Company of California
United Parcel Service
Unitek Corporation, Division of Bristol-Myers
VSI Corporation
Wells Fargo Bank, National Association
Xerox Corporation, Electro-Optical Systems

Caltech Industrial Relations Donors

Building Owners and Managers Association of Los Angeles
Robertshaw Controls Company, Grayson Controls Division
Ticor

THE FACULTY

For fifty years the members of the faculty have gathered at the Athenaeum for lunch and an exchange of information and ideas.

Changes in the Faculty, 1979-80*

ADMINISTRATIVE OFFICERS

L. G. Bonner, Administrator for Student Affairs and Registrar
C. J. Brokaw, Associate Chairman of the Division of Biology
S. I. Chan, Master of Student Houses
L. E. Hood, Chairman of the Division of Biology
A. J. Hudspeth, Executive Officer for Biology
W. D. Iwan, Executive Officer for Applied Mechanics and Civil Engineering
H. B. Keller, Executive Officer for Applied Mathematics
E. J. List, Executive Officer for Environmental Engineering Science
J. J. Morgan, Vice President for Student Affairs
J. D. Roberts, Vice President and Provost, Dean of the Faculty
J. H. Strauss, Executive Officer for Biology
D. B. Wales, Dean of Students

PROMOTIONS

To Professor Emeritus

F. H. Clauser, Clark Blanchard Millikan Professor of Engineering, Emeritus
J. L. Greenstein, Lee A. DuBridge Professor of Astrophysics, Emeritus
R. V. Langmuir, Professor of Electrical Engineering, Emeritus
G. D. McCann, Professor of Applied Science, Emeritus
J. R. Pierce, Professor of Engineering, Emeritus
H. J. Stewart, Professor of Aeronautics, Emeritus

To Named Professorship

W. H. Corcoran, Institute Professor of Chemical Engineering
R. W. Gould, Simon Ramo Professor of Engineering; Chairman of the Division of Engineering and Applied Science
M. Konishi, Bing Professor of Behavioral Biology
J. H. Seinfeld, Louis E. Nohl Professor and Professor of Chemical Engineering; Executive Officer for Chemical Engineering
A. Yariv, Thomas G. Myers Professor of Electrical Engineering and Professor of Applied Physics

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*This report covers the period from July 1, 1979, through September 30, 1980. All new appointments effective October 1, 1980, or after will be included in the 1980-81 President's Report.

To Professor
G. C. Fox (Theoretical Physics)
D. V. Helmberger (Geophysics)
T. P. Maniatis (Biology)

To Visiting Professor
M. Rem (Computer Science)
M. K. Simon (Electrical Engineering)

To Associate Professor
B. Fornberg (Applied Mathematics)
W. L. Johnson (Materials Science)
D. L. Smith (Applied Physics)

To Research Associate
B. R. H. Evans (Biology)
G. R. Knapp (Radio Astronomy)

To Assistant Professor
K. -Y. Lo (Radio Astronomy)

To Visiting Assistant Professor
D. W. Burchmore (Literature)

To Senior Research Fellow
D. M. Anderson (Biology)
J. P. Ary (Biomedical Engineering)
M. C. Citron (Biomedical Engineering)
L. Hesselink (Fluid Mechanics)
H. V. Huang (Biology)
J. Ludwig (Physics)
R. L. Messner (Physics)
M. Okuno (Biology)
F. C. Porter (Physics)
S. B. Yancey (Biology)

NEW APPOINTMENTS
Sherman Fairchild Distinguished Scholars
Theodore W. Anderson, Professor of Economics and Statistics, Stanford University
Rutherford Aris, Professor of Chemical Engineering, University of Minnesota
Carl J. Ballhausen, Professor and Head of Physical Chemistry, University of Copenhagen
Alexandra Bellow, Professor of Mathematics, Northwestern University
Julian D. Cole, Professor of Engineering and Mathematics, University of California, Los Angeles
Lennox L. Cowie, Research Staff Member, Princeton University Observatory
Richard A. Easterlin, Professor of Economics, University of Pennsylvania
Mostafa A. El-Sayed, Professor of Chemistry, University of California, Los Angeles

Horst Hoffmann, Full Professor and Head of Physics Department, University of Regensburg
Fritz John, Professor of Mathematics, Courant Institute of Mathematical Sciences, New York University
Irving Kaplansky, George Herbert Mead Distinguished Service Professor, The University of Chicago
Robert P. Kraft, Professor and Astronomer, Lick Observatory, University of California, Santa Cruz; Chairman, Board of Studies in Astronomy and Astrophysics
Gerald H. Kramer, Professor of Political Science and Economics, Yale University; Staff Member, Cowles Foundation for Research in Economics
William R. Levick, Professorial Fellow in Physiology, The Australian National University
Allan J. Lichtman, Assistant Professor of History, The American University
Donald M. MacKay, Professor and Head of Research, Department of Communication and Neuroscience, University of Keele
G. S. Maddala, Graduate Research Professor of Economics, University of Florida
Bo G. Malmström, Professor of Biochemistry, Head of Department of Biochemistry, University of Göteborg
Venkataraman Radhakrishnan, Director, Raman Research Institute
Peter A. G. Scheuer, Assistant Director of Research in Physics, Cavendish Laboratory, University of Cambridge
Barry Simon, Professor of Mathematics and Physics, Princeton University
Lyman G. Spitzer, Professor of Astronomy, Princeton University
Valentine L. Telegdi, Enrico Fermi Distinguished Service Professor, The University of Chicago; Institute of Nuclear Physics, Swiss Federal Institute
John G. Thompson, Rouse Ball Professor of Mathematics, University of Cambridge
F. -Xavier Wilhelm, Head of Research, National Center for Scientific Research, Strasbourg

Named Professors
J. J. Hopfield, Roscoe G. Dickinson Professor of Chemistry and Biology

Professors
J. E. Bailey (Chemical Engineering)
H. C. Berg (Biology)
M. J. Graetz (Law and Social Science)
R. D. McKelvey (Political Science)
T. G. Phillips (Physics)
M. Ridge (History)
E. M. Searle (History)
A. Weinstein (Mathematics)
R. M. Wilson (Mathematics)

Visiting Professors
E. N. Adams (Computer Science) Staff Member, IBM Research (Yorktown Heights)
S. Bellow (Humanities) Raymond W. and Martha Hilper Gruner Distinguished Service Professor, The University of Chicago
M. M. Denn (Chemical Engineering) Allan P. Colburn Professor, University of Delaware

B. Fuchssteiner (Mathematics) Professor of Mathematics, Gesamthochschule Paderborn
D. Leviatan (Mathematics) Professor, Tel-Aviv University
S. A. Lippman (Business Economics) Professor, Graduate School of Management, University of California, Los Angeles
L. Margulis (Paleobiology) Professor of Biology, Boston University
J. Michl (Chemistry) Professor, The University of Utah
C. E. Molnar (Computer Science) Professor of Physiology and Biophysics, Washington University; Director, Computer Systems Laboratory; Professor of Computer Engineering
A. B. Thompson (Petrology) Research Associate, Harvard University; Professor ETH
G. Tiktopoulos (Physics) Professor, National Technical University (Athens)
J. K. Watson (Electrical Engineering) Professor of Electrical Engineering, University of Florida

Big Bear Solar Observatory
H. Zirin (Director)

Owens Valley Radio Observatory
G. A. Seielstad (Assistant Director)

Palomar Observatory
G. Neugebauer (Acting Director)

Associate Professors
D. G. Hitlin (Physics)
M. R. Hoffmann (Environmental Engineering Science)
C. L. Seitz (Computer Science)
D. J. Stevenson (Planetary Science)

Research Associates
A. Buffington (Physics)
T. Cole (Chemistry and Chemical Engineering)
P. K. Haff (Physics)
S. L. Johnsson (Computer Science)
P. C. Liewer (Applied Physics)
S. Wolfram (Theoretical Physics)

Assistant Professors
K. Border (Economics)
T. J. Collins (Chemistry)
N. B. Dirks (History)
D. A. Dougherty (Chemistry)
D. W. Galenson (Social Science and History)
B. H. Hager (Geophysics)
E. Herbolzheimer (Chemical Engineering)
D. R. Kiewiet (Political Science)
E. M. Meyerowitz (Biology)
G. J. Milne (Computer Science)
D. Psaltis (Electrical Engineering)
J. F. Reinganum (Economics)
D. B. Rutledge (Electrical Engineering)

E. J. Siskind (Physics)
E. M. Stolper (Geology)
S. E. Whitcomb (Physics)
W. H. Woodin (Mathematics)
P. J. Young (Astronomy)

Senior Research Fellows
R. K. Ellis (Theoretical Physics)
S. A. Lee (Physics)
P. F. Little (Biology)
M. D. Manson (Biology)
S. H. Pravdo (Physics)
N. J. Proudfoot (Biology)
M. V. M. Reddy (Biology)
R. Stroynowski (Physics)
S. Zweben (Theoretical Physics)

Visiting Assistant Professors
T. C. Douglas (Biology) Assistant Professor of Medical Genetics, The University of Texas
E. J. Green (Economics) Assistant Professor, Princeton University
A. Zaman (Economics) Assistant Professor, University of Pennsylvania

Instructors
B. S. Freedman (Literature)
M. J. Hoffman (Mathematics)
A. J. E. M. Janssen (Mathematics)
G. Majda (Applied Mathematics)
R. P. Morton (Mathematics)
R. Roth (Mathematics)
W. A. Squires (Mathematics)
D. Sundelson (Literature)
R. K. Sparks (Chemistry)
P. Taborek (Physics)
E. Tadmore (Applied Mathematics)

TERMINATIONS
Karen J. Blair, Instructor in U. S. History
Anastassios C. Bountis, Bateman Research Instructor in Applied Mathematics
Marc Citron, Senior Research Fellow in Biomedical Engineering
John M. Davidson, Senior Research Fellow in Physics
Richard Ellis, Senior Research Fellow in Physics
Herman F. Engelhardt, Senior Research Fellow in Geology/Geophysics
Sandra J. Ewald, Senior Research Fellow in Biology
Terrence J. Goldman, Senior Research Fellow in Physics
Sidney Graham, Bateman Research Instructor in Mathematics
Jerrold R. Griggs, Bateman Research Instructor in Mathematics
James E. Gunn, Professor of Astronomy
Mool C. Gupta, Senior Research Fellow in Aeronautics
R. Guralnick, Bateman Research Instructor in Mathematics
Eri Heller, Senior Research Fellow in Biology
Thomas J. Hughes, Associate Professor of Structural Mechanics
Floyd Humphrey, Professor of Electrical Engineering and Applied Physics

Holly Jackson, Assistant Professor of English
Vernal Kenner, Senior Research Fellow in Aeronautics
Clayton R. Koppes, Senior Research Fellow in History
Amy S. Lee, Senior Research Fellow in Biology
James C. Long, Instructor in Mathematics
Terrence J. McDonald, Mellon Postdoctoral Instructor in History
Telis K. Menas, Senior Research Fellow in Mathematics
Gary Miller, Assistant Professor of Political Science
Charles R. Minter, Assistant Professor of Computer Science
Manasche M. Nass, Senior Research Fellow in Biology
Forrest D. Nelson, Assistant Professor of Humanities
Joyce Penn, Assistant Professor of English
Martin Rubin, Assistant Professor of English
Douglas Ross, Senior Research Fellow in Physics
Eric Siskind, Assistant Professor of Physics
Mitchell S. Spector, Bateman Research Instructor in Mathematics
Ivan E. Sutherland, Fletcher Jones Professor of Computer Science
Neculai Teleman, Instructor in Mathematics
Alan Weinstein, Professor of Mathematics
Michael Werner, Assistant Professor of Physics
J. Whitcomb, Senior Research Fellow in Geology
Jung-Rung Wu, Senior Research Fellow in Biology

DEATHS
Jon Mathews, Professor of Theoretical Physics, Lost at Sea
Alfred Stern, Professor of Philosophy, Emeritus, January 31, 1980

Honors and Awards to Members of the Faculty

C. D. Anderson received the "Swede of the Year" award from the Swedish Council of America. This award pays tribute to the world's most distinguished Swedes and Swedish-Americans.

M. Aschbacher was awarded the 1979 Frank Nelson Cole Prize for Algebra for his fundamental contribution to the important classification problem for finite simple groups.

J. D. Baldeschwieler was elected to membership in the American Philosophical Society. He is one of 20 persons to be honored by the society this year for distinguished work in their fields and for promoting useful knowledge.

J. F. Benton was elected Vice-President (President-elect) of the Pacific Medieval Society, and President of the International Courtly Literature Society, a group of American and European scholars who study literature prior to the 18th century.

J. E. Bercaw received the 1980 Award in Pure Chemistry from Alpha Chi Sigma. This award is presented annually to a chemist under thirty-five years of age, ". . . for his pioneering research in synthetic organometallic chemistry. . . ."

M. H. Cohen and H. B. Keller have been awarded fellowships from the John Simon Guggenheim Memorial Foundation. Grants were made to 276 scholars, scientists, and artists chosen from among 3,066 applicants in the Foundation's 56th annual competition. The fellowships were awarded on the basis of demonstrated accomplishment in the past and strong promise for the future.

W. H. Corcoran was elected to the National Academy of Engineering. He was also elected a Fellow of the American Association for the Advancement of Science, "for his leadership role in chemical engineering education, his innovative applications of chemical engineering to chemical processes and systems, and his research in energy and momentum transport, applied chemical kinetics, and biomedical engineering." He was also chosen as the 1980 Engineer of the Year by the Institute for the Advancement of Engineering.

S. M. Cuk and R. D. Middlebrook have been awarded a national prize for the invention of the "Cuk Switching DC to DC Converter." This power converter was selected as one of the 100 most significant inventions of 1979 by *Industrial Research/Development* magazine.

N. Davidson was named California Scientist of the Year by the California Museum of Science and Industry.

D. A. Dougherty has been awarded a Dreyfus Grant for newly appointed young faculty in chemistry.

P. E. Duwez was one of the recipients of the 1980 American Physical Society International Prize for New Materials sponsored by the International Business Machines Corporation. The prize was awarded "for the discovery that metallic glasses can be obtained by melt quenching which gives promise of producing a vast source of metals with properties of unusual scientific interest and technical promise."

C. Eshelman has been awarded a creative writing fellowship by the National Endowment for the Arts. He was selected from some 3,500 applicants for his excellence in poetry.

W. A. Fowler has been awarded the 1979 Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific.

M. L. Goldberger received an honorary Doctorate of Humane Letters from the Hebrew Union College. He was also elected to membership in the American Philosophical Society.

H. B. Gray was awarded the Richard C. Tolman Medal for 1979 in recognition of his notable contributions to the experimental and theoretical determination of electronic structure of metal complexes, to the fields of bioinorganic chemistry and inorganic photochemistry, and to chemical education. He also was awarded the City University of New York Medal.

P. C. Jennings received the Honor Alumni Award from Colorado State University at their commencement. This award was for achievement while at CSU and in a chosen profession, and for service to CSU, community, state, and nation.

D. J. Kevles was awarded the National Historical Society's 1978 Book Prize for his recently published volume, *The Physicists: The History of a Scientific Community in Modern America.*

H. W. Liepmann was awarded the 1980 Fluid Dynamics Prize by the American Physical Society. The prize was established to recognize "outstanding achievement in fluid dynamics research."

H. A. Lowenstam was elected a Fellow of the American Academy of Arts and Sciences.

W. A. J. Luxemburg received the Humboldt Senior Scientist Award from the Humboldt Foundation in West Germany. Humboldt Fellowships are awarded to U. S. senior scientists for excellence in research.

J. J. Morgan was named the 1980 winner of the American Chemical Society Award for Creative Advances in Environmental Science and Technology. He was honored for his accomplishments in research, professional service, and teaching.

C. J. Pings was elected a Fellow of the American Institute of Chemical Engineers.

J. H. Seinfeld was awarded NASA's Public Service Medal. This medal is given annually to a U. S. citizen who is not an employee of the federal government, for exceptional contributions to engineering design and development or for the managerial coordination of programs that are NASA related. Seinfeld received the medal for his work over a two-year period as chairman of a NASA committee to formulate a tropospheric research plan.

E. M. Shoemaker received the 1980 Distinguished Service Award of the U. S. Department of Interior.

R. W. Sperry was named winner of a 1979 Albert Lasker Award. Sperry shares the coveted honor, which ranks just beneath the Nobel Prize in prestige within the scientific community, with three other researchers. Sperry was also one of the three scientists worldwide to share the 1979 Wolf Prize in Medicine. Both of these awards honored his pioneering work in "split-brain" research.

G. B. Whitham was awarded the 1980 Norbert Wiener Prize for Applied Mathematics. This award is given every five years jointly by the Society of Industrial and Applied Mathematics and The American Mathematical Society.

A. H. Zewail was awarded a Camille and Henry Dreyfus Foundation Teacher-Scholar Grant for his achievements in research and teaching. The grant is made to outstanding young faculty members throughout the country to help them develop full potential early in their careers.

Statistics

MEMBERS OF THE FACULTY

	74–75[1]	75–76[1]	76–77[1]	77–78[1]	78–79[1]	79–80[2]
Administration	5	6	3	3	3	5
Emeriti	36	42	39	39	37	40
Professors	185	187	197	190	195	195
Fairchild Scholars	28	28	24	31	22	25
Staff Members of Observatories	11	12	11	10	10	•
Senior Research Associates	3	2	2	2	2	2
Visiting Professors, Associate and Assistant Professors	10	13	18	30	37	39
Associate Professors	39	33	28	26	31	35
Research Associates, Associates	19	21	20	21	20	23
Visiting Associates	66	80	110	106	88	96
Assistant Professors	26	32	33	34	34	34
Senior Research Fellows	40	42	44	45	50	50
Instructors	8	7	10	10	16	15
Research Fellows[3]	197	182	209	208	202	204
Lecturers	8	8	10	6	11	11
Physical Education Staff	5	5	5	5	4	5
	686	700	763	766	762	779
Tenured Faculty	210	213	216	204	209	211

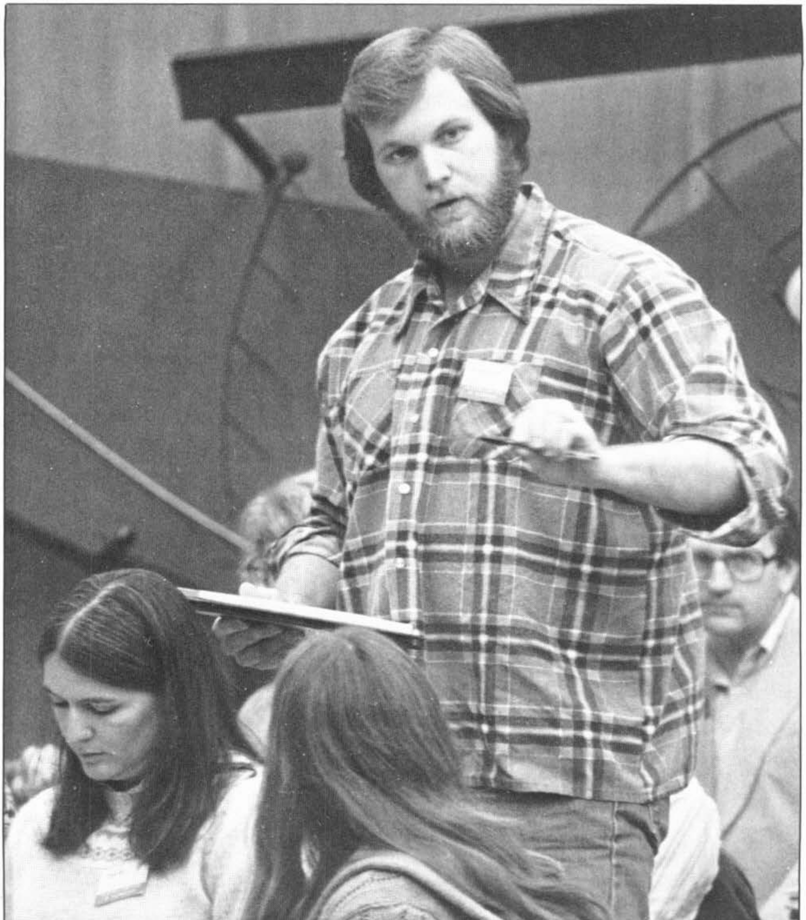
[1]July 1–June 30

[2]July 1, 1979–September 30, 1980

[3]315 Research Fellows were in residence at some time during 1974–75; 302 in 1975–76; 338 in 1976–77; 315 in 1977–78; 326 in 1978–79; 356 in 1979–80.

NOTE: Total number of Fairchild Scholars and visiting professorial members is shown for each year.

STUDENT AFFAIRS



Student body president Ray Beausoleil makes his point at the Faculty-Student Conference, held in February 1980 at JPL. One hundred Caltech students and faculty members sat down together for two days to discuss the total undergraduate program at the Institute.

James J. Morgan, Vice President for Student Affairs

Ray Owen, vice president for student affairs and dean of students since 1975, completed his term of office in September 1980; he returns to his duties as professor of biology. His concern for Caltech students, in general and in particular, providing a full measure of dedicated service, has been greatly appreciated by the Institute.

James J. Morgan, professor of environmental engineering science, has been appointed vice president for student affairs, and David Wales, professor of mathematics and former associate dean of students, has been appointed dean of students.

Admissions

The overall level of test scores—including Achievement Test scores—of Caltech applicants held substantially even.

Median College Board Scores of Applicants for Admission

Entering Year	*Application Volume*	*Aptitude Verbal*	*Aptitude Math*	*Math II*	*Physics*	*Chem*	*Bio*	*English*
1980	1378	600	720	750	700	680	660	610
1979	1392	610	720	740	680	690	670	600
1978	1482	610	720	750	700	690	680	610
1977	1391	620	720	750	700	690	670	620
1976	1177	620	730	770	700	690	680	650
1975	952	610	720	750	710	710	660	620
1974	901	630	730	760	720	710	700	630
1973	920	640	730	760	730	720	720	640
1972	899	640	730	760	720	730	700	630
1971	1124	640	730	750	730	710	700	630

It would appear that the quality of the class entering in September of 1980 as measured by ability and academic achievement is as good as that of the previous several years. Of the 1378 who applied in 1980, 391 were offered admission, and 207 freshmen were enrolled.

Upperclass Admissions

Upperclass admissions come from three sources, a special transfer program, a 3-2 (dual degree) program, and from regular competition.

The special transfer program affiliates Caltech with 12 local public community colleges. In 1980, three students were admitted under this program.

The 3-2 (dual degree) program grants degrees in conjunction with nine liberal arts colleges: Bowdoin, Bryn Mawr, Grinnell, Occidental, Ohio Wesleyan University, Pomona, Reed, Wesleyan University, and Whitman. Students attend these schools for three years and then transfer into the junior year of the engineering option at Caltech. After two years at the Institute, the student receives two bachelor's degrees—one from the liberal arts college and one from Caltech. Sixteen students, a record number, were admitted under this program in 1980.

In the regular upperclass admissions competition, 79 students completed applications (compared with 100 last year and 110 the year before). Sixteen students were offered admission, and 14 accepted.

Upperclass admissions from Caltech's three transfer programs thus totaled 33, compared with 26 in 1979 and 31 in 1978. A pleasant aspect of the transfer program this year is that among the 33 students, 4 are women.

Secondary School Relations and Special Student Programs

The office of the director of secondary school relations and special student programs is actively engaged in increasing the number of minority students and women in the areas of mathematics, science, and engineering. High schools are visited and letters and materials are sent to potential students, science teachers, and school counselors.

At Caltech, the office of the director conducted the Saturday school for secondary students—classes taught by undergraduates and graduate students in the various fields of mathematics and science. The average attendance in 1979–80 was 275 students. Other activities in secondary school relations include the seven Wednesday lecture series given by Caltech faculty members, and a seven-week summer session for high school students in physics/calculus, physics, chemistry, and biology.

The special student program was conducted for selected students from disadvantaged backgrounds in order to upgrade their subject matter competency before matriculation. These students are selected each year by the admissions committee to enter Caltech independent of race, color, creed, or national origin.

The Undergraduate Deans

The Deans continued their interest in and concern for the personal and academic well-being of the undergraduate students, many of whom visited the Deans' Office for discussions about academic motivation and ways to improve their academic performance. Numerous personal discussions were held about situations encountered by individual undergraduates. Several students sought advice about leaves of absence and transferring elsewhere, and many students who had been on leaves of absence returned ready to start work afresh.

The Deans are always considering suggestions for ways to improve the undergraduate life at the Institute; several programs centered in the Deans' Office attempt to do this. Faculty are encouraged to interact with students and be responsive to their needs, and a group of sympathetic faculty members serve as freshman advisers. Financial support is furnished for projects of interest to students. A loan fund is administered for emergency use. Several fellowships and scholarships are arranged through the Deans' Office.

During the spring and summer, preparations were made 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 1980, of the 170 students who received bachelor's degrees, 100 or about 59 percent graduated with honor—an average of B+ or better. Master's degrees were awarded to 168 students, Engineer's degrees to 3, and Ph.D.'s to 125.

In the context of commencement, graduation statistics for the past ten years or so might be of interest. Most bachelor candidates enter Caltech at the freshman level. Of these, 71 percent complete their work and receive a B.S. in the option (major) of their choice. Of students entering as sophomores or juniors, 92 percent graduate. At the graduate level, 91 percent of the students registering remain at Caltech until they receive their M.S. or Ph.D. (or, occasionally, both).

Registration for fall 1980 was simplified in that the core network of basic courses on a fixed schedule has been augmented by a course schedule for the freshman year. Times have been blocked out for chemistry, humanities, mathematics, and physics, and for most of the usual freshman electives. This scheduling is expected to make things easier all round—for the registrar, for the faculty, and for the students.

Registration statistics for first term 1979–80 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.

REGISTRATION ANALYSES
1979–80

Options	*Fr*	*So*	*Jr*	*Sr*	*Total Undergrads*	*Total Grads*	*Totals*
Aeronautics						46	46
Applied Math		4	4	8	16	28	44
Applied Mechanics						15	15
Applied Physics		22	13	25	60	59	119
Civil Engineering						31	31
Computer Science						30	30
Electrical Engineering		21	8	7	36	56	92
Engineering and Applied Science		53	61	70	184		184
Engineering Science						10	10
Environmental Engineering Science						20	20
Materials Science							
Mechanical Engineering						45	45
Total Engineering and Applied Science		100	86	110	296	340	636
Astronomy		8	6	4	18	20	38
Biology		9	10	8	27	76	103
Chemical Engineering		18	22	16	56	59	115
Chemistry		16	13	13	42	165	207
Geology		4	7	7	18	74	92
Math		17	11	10	38	17	55
Physics		35	41	23	99	119	218
Total Science		107	110	81	298	530	828
Economics		1		2	3		3
History							
Literature							
Social Science			1		1	22	23
Total Humanities and Social Science		1	1	2	4	22	26
Not Classified	219						219
TOTALS:	219	208	197	193	817	892	1709

Undergraduate Women Distribution

		AMa	*APh*	*Ay*	*Bi*	*ChE*	*Ch*	*EE*	*Eng*	*Ge*	*Ma*	*Ph*	*Total*
Fr	35												35
So			2		5	3	3	2	5		4	7	31
Jr		1		1	3	2	2		4	1	1	1	16
Sr					2	4	4	1	6	1	1		19
Total	35	1	2	1	10	9	9	3	15	2	6	8	101

Graduate Women Distribution

AMa	APh	Bi	ChE	Ch	CE	CS	EE	ES	Env	Ge	ME	Ph	SS	Total
2	1	20	4	26	2	4	4	1	5	17	2	8	2	98

Financial Aid

The office of financial aid awards available funds to students who have demonstrated financial need and to students who are eligible for loans, prizes, and outside awards and scholarships. The applicants for need-based financial aid (62 percent of the undergraduate student body in 1979–80) are required to report and document information on family income and assets so that the director and her staff can determine eligibility for federal, state, and Caltech grant, work, and loan funds.

In 1979–80 some sort of financial aid was received by a total of 615 students, representing 75 percent of the undergraduates. It was processed by the office of financial aid in categories as follows:

UNDERGRADUATE FINANCIAL AID
1979–80

Gift Aid	
Caltech scholarships & grants	$ 696,752
Federal grants	307,633
Cal Grants	379,087
Outside scholarships	286,992
	$1,670,494
Loans	
National Direct Student Loans	$344,308
Caltech loans	71,118
Federal Insured Student Loan/Guaranteed Student Loans	270,842
	$686,268
Employment	
College work-study	$134,566
Other campus employment	40,000
	$174,566
TOTAL	$2,531,328

The packaging policy for 1979–80 established the student's budget and subtracted: (1) expected contribution from parents, a percentage of the student's assets, and the student's summer job savings; (2) outside awards, such as Cal Grants or National Merit; and (3) self-help, such as low-interest loans and/or work. The remainder determines the amount of grant aid from Caltech. The number of students requiring aid has grown as the cost of a Caltech education has escalated in the wake of inflation.

The director of financial aid, Ursula H. Hyman, and the assistant director, Sandra Boyd, have relinquished their positions to Linda K. Berkshire and Ruth J. Wilson, respectively. The fine work of Hyman and Boyd in these challenging positions was much appreciated by, among others, the vice president for student affairs.

Master of Student Houses

A faculty member appointed Master of Student Houses oversees the undergraduate student houses, the resident associates who live in them in order to aid and comfort the students, and the living arrangements—and to some extent the social life—of the 850 undergraduate students.

Currently, the master's office on campus administers a room improvement fund that paid for carpeting, shelves, paneling, and sky beds for 122 students this year; it also furnished several off-campus houses for additional spaces for freshmen and transfer students. The tutors' program continued into its third year with upperclassmen in each of the seven houses offering help to students having difficulties with their studies.

Caltech faculty families were invited to the student houses for four special dinners during the year for social rather than academic fellowship. Other student house activities and events sponsored by the office included wine and candlelight dinners, ski trips, camping trips, theater parties, and twenty-two dozen doughnuts in the campus office every Friday morning that classes were in session.

James W. Mayer, professor of electrical engineering, was the Master of Student Houses in 1979–80. As is customary, he and his family lived in Steele House, a handsome and hospitable dwelling on Holliston Avenue. Professor and Mrs. Mayer entertained groups of students at the master's house several times a week all during the school year. The new occupants of Steele House, Sunney I. Chan, professor of chemical physics and biophysical chemistry, and Mrs. Chan, are continuing this friendly custom.

Health Center

Student Counseling Services

The student counseling services staff continued individual psychological work with students in counseling, psychotherapy, and crisis intervention, spending a total of 1630 hours on a one-to-one basis. An additional 8 hours were recorded in the drop-in center, and 32 hours were devoted to a newly established program in career counseling. The total number of direct service hours was 1678, only 7 hours less than in 1978–79. The current year may thus indicate that a norm has been reached in students' use of counseling services.

The new pilot program in career counseling was instituted in the spring, and 13 students took advantage of the program. They came in with various questions about their future careers, e.g., "I have to choose an option; what should it be?" "What shall I do after graduation—attend graduate school or take a job?" "I want to change fields; what else is out there?" The basic program involved at least two hours of vocational interest and personality testing and individual discussion. The psychologist in charge provided general information on specific careers—what environmental engineering is all about, not who is hiring environmental engineers—and techniques for exploring vocational information. Students left the program with specific options to explore or a sense of resolution for making changes.

Students used the various counseling services in the following numbers:

Freshmen	12
Sophomores	15
Juniors	19
Seniors	21
Undergraduates	67
Graduates	57
Spouses	8
Faculty/Staff	11
Ex-student	1
Total	144
Career counseling (all classes represented)	13
Total	157

The percentage of the undergraduate student body using these services was 8 percent (compared to 11.4 percent in 1978–79) and the percentage of the graduate student body was 6 percent (compared to 7.3 percent in 1978–79). Fewer students used a greater proportion of the psychologists' time.

Undergraduate and graduate women continued to seek psychological help proportionately in greater numbers than men—a total of 34 women (graduate and undergraduate) sought counseling compared to a total of 101 men.

Medical Services

The Young Health Center has continued to provide high quality health care to the undergraduate and graduate students and to their wives and husbands who are enrolled in the health program.

The goal of the health care team is not only to properly treat illness and injury, but to have students knowledgeable about how to care for their minds and bodies, and how to stay well. To this end health care information is provided in the hope that it will have a long-range positive effect on the well-being of Caltech students.

Statistics show that using a nurse practitioner (a licensed registered nurse with advanced training) this past year for independently managing a larger share of common problems (with constant physician consultation available) freed the physicians for more complicated diagnostic work-ups. Rhonda Campbell, one of the nurse practitioners, was appointed coordinator of nursing services.

Office visits September 1979 through June 1980 totaled 5604; 2375 to physicians, 3229 to nurses. Infirmary admissions for the same period totaled 41, and 117 students were "sleepers" in search of an undisturbed night's repose.

All of the medical staff participates in community programs in both advisory and consultation capacities in the Red Cross, Free Clinic, rape and mental health hot lines, and instruction in educational programs. They also attend seminars and workshops in all health areas and, in particular, those related to college health.

Musical Activities

Caltech supports a wide range of musical activities. A credit course for history, analysis, and performance is offered in music for piano ensemble, and a number of courses are offered in music history and theory. Another course explores the connections of music with the sciences.

The men's and women's glee clubs and their constituent smaller groups involve 57 men and 30 women. Classical and flamenco guitar classes are offered for interested students. Instrumentalists can join the jazz band, the wind ensemble, chamber music groups, and an orchestra formed in conjunction with nearby Occidental College. An annual musical involves students, staff, and faculty; *Fiddler on the Roof* was the February 1980 production.

These varied musical activities are supported by student affairs and by the humanities division. They are a necessary and well-patronized part of the undergraduate life at Caltech.

Athletics, Physical Education, and Recreation

The following chart presents the opportunities available to undergraduates, graduate students, and faculty and staff in the areas of instruction, competitive sports, and recreation.

	Instruction			*Competitive*			*Recreational*
Activity	Beg.	Int.	Adv.	Intra-mural	Club	Inter-collegiate	
1. Aquatic Games	X	X	X				X
2. Badminton	X	X					X
3. Baseball						X	
4. Basketball				X		X	X
5. Cricket					X(M)		
6. Cross Country						X(M/W)	X
7. Diving	X	X		X		X	X
8. Fencing	X	X				X(M/W)	
9. Figure Skating	X						
10. Football				X		X	X
11. Golf	X	X				X	
12. Gymnastics	X	X					X
13. Hockey					X(M)		
14. Karate	X	X	X				X
15. Modern Dance	X	X					X
16. Pre-SCUBA	X	X					X
17. Running							X
18. Sailing	X				X(M/W)		
19. SCUBA	X	X	X		X(M/W)		X
20. Soccer					X(M/W)	X	X
21. Softball				X			X
22. Swimming	X	X	X	X	X(M/W)	X(M/W)	X
23. Tennis	X	X	X	X		X	X
24. Track & Field				X		X(M/W)	X
25. Volleyball	X	X	X	X	X(W)		X
26. Water Polo						X	X
27. Weight Training	X	X					X
28. Wrestling						X	X

All areas are coeducational including those marked (M/W) except those specifically marked (M) for men and those specifically marked (W) for women.

It is remarkable that a program of this overall scope can be provided with the limited facilities available at present. However, athletic facilities have been upgraded with additional lockers, resurfacing of the football field, track, and baseball infield, and the addition of a steeplechase water jump to the track.

About 200 undergraduates competed in twelve intercollegiate sports. Nearly 400 undergraduates participated in one or more of the seven intramural sports. A number of undergraduates also were involved in the sports clubs—the men in hockey and sailing clubs and the women in soccer and volleyball.

GRADUATE STUDIES

Lisa Anderson, a graduate student in environmental engineering science, examines a juvenile sporophyte of the giant kelp *Macrocystis pyrifera*. She uses the plants in experiments to test their reaction to varying levels of trace metals in artificial seawater.

Cornelius J. Pings, Dean of Graduate Studies

This report is for the academic year 1979–80, but comments will be included about admissions to graduate study for 1980–81. For the first time in seven years the Institute registered a slightly smaller graduate student body in autumn 1980 than for the preceding year.

Admissions for 1980-81

The number of graduate applications for 1980–81 was an all-time high, 4 percent higher than the previous year. Applications were down by 5 percent in the sciences, but up by 11 percent in engineering, a trend noted also last year.

This year 24 percent of the applicants were offered admission compared to 27 percent last year; the number of offers was down from 591 to 545. The acceptance rate was 42 percent, the lowest since 1975. The combination of a decrease in offers and a lower acceptance rate led to an entering class of 229, the smallest since 199 accepted for the autumn of 1975. Although these changes are small and within normal fluctuations of the process, the situation obviously will be watched carefully for any trends in the next year or so.

Student Support

Fellowships and traineeships financed by the federal government continue the slow decline noted in these reports over the last several years. However, the Institute continues to attract significant numbers of individuals who have won NSF Graduate Fellowships. The decrease in fellowship support has been compensated by growth in the number of graduate research assistantships, which are almost all paid for from the budgets of research grants and contracts awarded on behalf of individual faculty members.

College work-study funds from the federal Department of Education were available in substantial amounts during 1979–80, and were used to reduce expenditures for both teaching and research assistantships.

Enrollment

The graduate student enrollment for 1979–80 was 898, the highest in Caltech's history. There has been a growth in enrollment averaging about 4 percent per year since 1973. However, 1980–81 figures show a slight decrease from the previous year.

For 1979–80 the percentage of foreign students was 28 percent, slightly higher than the five-year average of 25 percent. The distribution is 19 percent in the sciences and 41 percent in engineering.

The total number of graduate degrees awarded in June 1980 was 297, up significantly from 250 in June 1979. The number of PhD degrees was 125, second only to the maximum of 127 in 1972. The average residence time for those receiving the PhD degree in June 1980 was 4.95 years as compared to 4.74, 4.71, and 4.89 in the three preceding years.

Summary

The quality of applicants and admittees for graduate study at Caltech continues to be excellent. There was a slight decrease in the size of both the entering class and the total graduate student population in autumn 1980, but the changes are not likely to be significant.

Enrollment by Program for the Past Five Years

Option	1975–76	1976–77	1977–78	1978–79	1979–80
Astronomy	26	20	22	19	20
Biology	86	80	82	74	76
Chemistry	143	158	167	164	165
Chemical Engineering	46	51	44	52	60
Geology	81	81	81	77	74
Mathematics	16	18	22	18	17
Physics	99	121	119	114	119
Science Totals	497	529	537	518	531
Aeronautics	33	42	40	47	46
Applied Mathematics	23	21	19	22	27
Applied Mechanics	11	16	15	14	15
Applied Physics	46	51	54	58	60
Civil Engineering	22	30	20	31	31
Computer Science	—	—	—	—	32
Electrical Engineering	39	38	55	51	57
Engineering Science	26	28	31	36	10
Environmental Eng. Science	22	23	20	20	20
Materials Science	1	0	1	1	0
Mechanical Engineering	26	21	30	31	47
Engineering Totals	249	270	285	311	345
Social Science	15	19	20	23	22
TOTALS ALL FIELDS	761	818	842	852	898

INSTITUTE RELATIONS

The opening of Caltech's Alumni House in September 1980 was greeted enthusiastically by alumni, including Professor Bob Sharp; Phyllis Jelinek, executive director of the Alumni Association; and Jim Workman, association president.

Eugene R. Wilson, Vice President for Institute Relations

As of September 30, 1980, I have resigned my position as vice president for Institute relations to return to the Atlantic Richfield Foundation as its executive director. I have enjoyed my involvement in Caltech's fund-raising and public relations activities and have appreciated the opportunity to be part of the Caltech family.

I am pleased to welcome Dwain N. Fullerton as the new vice president for Institute relations. Fullerton comes to Caltech from Stanford University. During his career at Stanford he served as director of the annual fund mail appeal, associate director of Stanford's International Center for the Advancement of Management Education, and director of corporate relations. In his most recent position as associate vice president for medical development at Stanford University Medical Center, he designed and executed development programs for the medical school, the hospital, and the university clinics. His expertise and enthusiasm will serve Caltech well.

Funding Projects

The construction of two new buildings, the Braun Laboratories in Memory of Carl F and Winifred H Braun, and the Thomas J. Watson, Sr., Laboratories of Applied Physics, is currently under way. Both buildings are scheduled to be completed in early 1982.

The ornate Gates Laboratory, built in 1917, which has stood empty since it was damaged in the 1971 San Fernando earthquake, will be renovated to become Caltech's main administration building, eventually housing the offices of the Caltech president, the provost, the vice presidents, and other administrative and support personnel. The project is being started by a grant of $1,000,000 from the Ralph M. Parsons Foundation of Los Angeles. The building will bear the name of Ralph M. Parsons. Additional private gifts are being sought to complete the renovation.

During 1979–80, fund raising efforts emphasized the Institute's need for unrestricted support. Such basic grants provide the monies for library acquisitions, sophisticated laboratory equipment, improvement of physical facilities, and salaries for faculty and staff. Funds for general support enable the Institute to continue the increasingly complex operation of a modern research university. In response to these needs, IBM granted $1,500,000 in unrestricted funds to Caltech.

Various programs of research and education at the Institute are also receiving substantial support from the private sector. A $1,000,000 grant from the Weingart Foundation will be used to establish the Weingart Fund for Special Programs. The fund will enable the Institute to initiate important projects, which could include a human gene isolation facility, an x-ray fluorescence facility in resource geology, and an astronomy data processing center. Chevron U.S.A., Inc., has endowed the Chevron U.S.A. Professorship of Chemical Engineering, a chair expected to be filled by an expert in an energy-related field of chemical engineering.

Additional notable gifts include a $600,000 grant from the Jones Foundation to establish a campus computer network that will not only link the Institute's many computers but will provide communication with a variety of computers at other universities and research centers, thus becoming a model for other institutions and for the computer industry.

The Andrew W. Mellon Foundation awarded Caltech a $480,000 grant to support postdoctoral fellowships in the humanities. These fellowships enable outstanding young humanists to develop their teaching and research skills while at the same time providing substantial benefits to Caltech by widening the scope of our activities in the humanities.

Ten major corporations are now sponsoring the Institute's Silicon Structures Project. The project is a Caltech-industry cooperative program, which focuses on the efforts of industrial representatives, faculty, and students in the design of very large scale integrated circuits.

Public Relations and Publications

The year was one of change for public relations and publications. James B. Black, director of those activities for the Institute since 1972, resigned to become vice president for university affairs at the State University of New York at Stony Brook. Institute Relations is grateful for his many outstanding contributions to public relations, publications, community relations, and the alumni association. Black wore many hats, and he wore all of them with a flourish.

Edward Hutchings Jr. retired after 31 years as editor of *Engineering and Science* magazine. Hutchings was largely responsible for the awards, the respect, and the reputation for impeccable editorial standards garnered by *E&S* through three decades. His post has been filled by managing editor Jacquelyn Bonner.

The alumni publication *Caltech News* acquired a new look when it was redesigned and converted to newsprint. Other regular publications—*Around the Campus*, the *Directory of Institute Personnel, Facts about Caltech*, the *Faculty Roster, Information for Students*, and *The President's Report*—made their scheduled appearances as did a new booklet for recruitment of women undergraduates.

The News Bureau maintained close contact with local, regional, and national media and established relations with several new science magazines. For example, on the occasions of the Voyager 1 encounters with Jupiter and Saturn, newspaper, magazine, wire service, and electronic media science writers in attendance from around the country were briefed by News Bureau personnel on other Institute research projects.

Placement Office

The Placement Office continued to assist undergraduate and graduate students, research fellows, and alumni of the Institute by offering employment listings, fellowship announcements, and job referrals. The staff provided employment services to 150 alumni in 1979–80. Campus interviews were conducted by 231 organizations—a 15 percent increase over 1978–79. The employment experiences of the June 1980 graduates for whom definite information is available show that 30 percent of the graduating seniors accepted employment at a median monthly salary of $1775, 34 percent of those earning masters degrees accepted employment at a median salary of $1950, and 94 percent of the PhDs accepted employment at a median salary of $2460. Approximately 50 percent of those students who received bachelors and masters degrees were continuing their educations in graduate schools.

As of October 1, 1980, the Placement Office was placed under the office of the vice president for student affairs.

Alumni Association

Caltech alumni moved into a new home this year when the Alumni Association acquired the handsome Institute-owned residence at 345 South Hill Avenue. Alumni House was renovated and furnished in colonial American style to become the center of alumni hospitality on campus as well as the gathering place for meetings, programs, social events, and business activities.

Phyllis Jelinek became the new executive director of the association when James B. Black left the post he had held since 1968.

Other firsts for the Alumni Association were the five-day exploration of Grand Canyon led by Caltech geologists Robert Sharp, Eugene Shoemaker, and Susan Kieffer, and the one-day tour of Palomar Observatory, highlighted by a lecture by astrophysicist Jesse Greenstein. These successful trips are the precursors of other adventures planned for alumni.

Alumni Seminar Day drew the biggest crowds of its 43-year history, and the San Francisco chapter held its second-year Mini Seminar Day. Other chapter meetings were held in 15 U.S. cities and in Paris, France.

Alumni participation in the high school relations program continued to be strong.

Support Groups

Many groups of friends and alumni of the Institute give generously of their time, energy, and money in support of the educational and research programs at Caltech. Among these organizations are:

1) the Alumni Association Board of Directors
2) the Alumni Fund Area Chairmen
3) The Associates of the California Institute of Technology
4) Earthquake Research Affiliates
5) the Industrial Associates
6) Regional Advisory Councils
7) Visiting Committees

Alumni Association
California Institute of Technology

OFFICERS

James W. Workman '57 *President*	Arne Kalm '56 *Treasurer*	Carel Otte '50 *Past President*
Philip L. Reynolds '58 *Vice President*	William J. Karzas '49 *Secretary*	Phyllis Jelinek *Executive Director*

DIRECTORS

Francis H. Clauser '34	Carl W. Hamilton '62	J. Steven Sheffield '72
Munson W. Dowd '38	Carole L. Hamilton '63	Donald L. Smith '71
Hubert E. Dubb '56	Frances E. Janssen '75	Donald P. Wilkinson '48
Vern Edwards '50	Herbert A. Lassen '43	Andrew B. Campbell '46
David E. Groce '58	Philip A. Naecker '76	Andy Gellman '81
		Albert Lin

The Alumni Fund

Under the leadership of Arne Kalm, '56, 1979–80 National Chairman, Caltech's Alumni Fund has surpassed its dollar goal and raised more money than any other year in its history. When the Fund year concluded on July 1, contributions from 4622 donors totaled $988,799, compared with $924,014 from 4655 alumni during the previous Fund year. For the fourth consecutive year, the Caltech Alumni Fund was recognized by the United States Steel Foundation and the Council for Advancement and Support of Education in the Sustained Excellence category for obtaining Alumni gift support. Tom Garrow, director of annual giving, accepted the award on behalf of Caltech.

NATIONAL CHAIRMAN

Arne Kalm '56
Arcadia

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Delano A. Brouillette '55 San Diego	Harry J. Moore, Jr. '48 Rye, New York	Ernest Wade '43 Rancho Palos Verdes
Andrew B. Campbell '46 San Marino	Richard C. Nielsen '66 Whittier	William J. Williamson '48 Sherman Oaks
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Robert D. Boche '34
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William Broste '66
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Alfred B. Brown, Jr. '47
Eastern New Jersey

Ross Buchanan '44
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Roger Caputi '57
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Formed in 1926 by Robert A. Millikan and a group of distinguished southern California citizens, The Associates, an organization composed of friends of the Institute, assist in advancing Caltech's scientific research and education. Because the Institute relies heavily on unrestricted money to maintain current programs and to develop new research, The Associates, who have provided over $9,000,000 in unrestricted funds over the years, are a very special group of benefactors.

In 1979–80, 114 new members were welcomed to this enthusiastic part of the Caltech family, bringing the number of members up to 790. Membership in The Associates is by invitation and election; information about joining may be obtained from the campus office of The Associates or from any member.

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The Caltech Earthquake Research Affiliates program, formally established in 1967, was a natural outgrowth of the Institute's long-standing emphasis on seismology and earthquake engineering. The program is sponsored by public utilities, insurance companies, and corporations involved in civil engineering and construction, seismic instrumentation, and transportation. These organizations provide support for programs of research and education in seismology and earthquake engineering. Reports and publications on Caltech's earthquake studies are distributed periodically to the sponsors, and their representatives are invited to participate in conferences and field trips organized by members of the faculty from the Seismological Laboratory of the Division of Geological and Planetary Sciences and from the Earthquake Engineering Research Laboratory of the Division of Engineering and Applied Science. Sponsors of the program as of September 30, 1980, were as follows:

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The Industrial Associates Program functions to encourage useful communication between Caltech and the industrial research community. During the past year, the Industrial Associates staff has provided the following services: 100 faculty visits to corporations; 185 corporate personnel visits to the Caltech campus; 98 Caltech responses to requests for technical information; 2222 Caltech publications sent upon request. In addition, the Industrial Associates Program offers extensive library services to members and sponsors a variety of scientific conferences geared to members' interests.

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The fiscal year ended September 30, 1980, reflected increases in the levels of support for the programs conducted at the campus and the Jet Propulsion Laboratory. Revenues and expenditures were again in balance. Campus expenditures totaled $79.7 million—an 18.7% increase over fiscal year 1979. JPL direct expenditures, funded largely by the National Aeronautics and Space Administration, totaled $375.4 million—an increase of 17.7% over fiscal year 1979.

During fiscal year 1980 construction was started on the Braun Laboratories in memory of Carl F and Winifred H Braun and the Thomas J. Watson, Sr., Laboratories of Applied Physics. These buildings, when completed, will add 78,000 and 40,000 gross square feet of laboratory, classroom, and office space to the campus. They are scheduled for completion in fiscal year 1982. Construction was also started on a 4,000 square foot addition to the basement of the Kellogg Radiation Laboratory to house a new particle accelerator that will provide a wide range of applications in basic and applied nuclear studies. Funding for the accelerator and the building addition has been provided largely by the National Science Foundation and the W. K. Kellogg Foundation. Completion of this project is scheduled for the fall of 1981. In addition, a benefactor funded the refurbishment of the Dabney Gardens and the Winnett Center as part of a program to increase the attractiveness and cohesion of the campus. Finally, another benefactor provided funds to create a lounge in the Athenaeum.

At September 30, 1980, the market value of Caltech's endowment fund amounted to $197.4 million, its highest fiscal closing date performance.

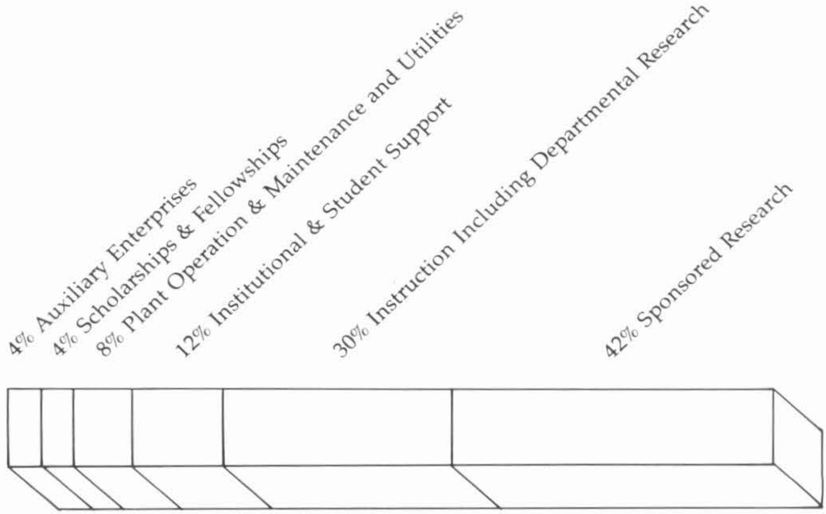
Summary of Operations
As shown on Exhibit 3, total current fund expenditures at the campus were \$79.7 million, an increase of 18.7%.

The most significant growth in campus activities continues to be in the area of sponsored research, supported primarily by federal funds, where expenditures increased \$5.8 million, or 21.3%, to \$33.1 million. Instruction, including departmental research, largely financed by the Institute and other private sources, also increased substantially by \$3.4 million, or 16.8%, to \$23.8 million.

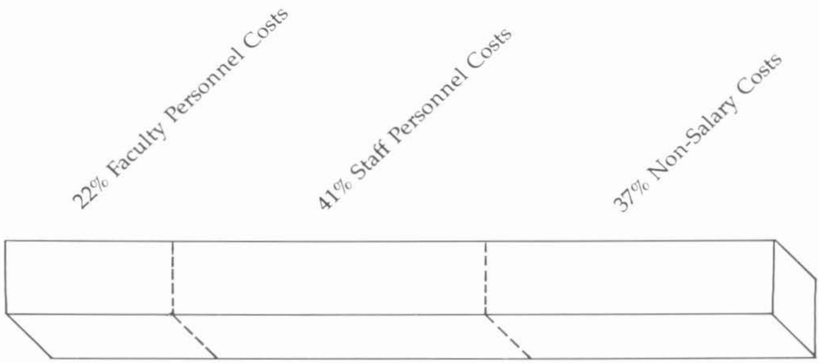
Campus plant operation, maintenance, and utilities increased \$1.4 million, or 27.6%, to \$6.6 million. Energy costs accounted for \$1.2 million of the increase. The cost of electrical power is the principal factor due to the sharp increase in rates from 3.76¢ to 6.51¢ per kilowatt hour during the year. In addition to its continuing conservation program, the Institute is conducting a feasibility study on cogeneration and the various alternatives of generating power to reduce energy costs.

The percentage distribution of operating expenditures is presented below:

Operating Expenditures by Program



Operating Expenditures by Cost Categories



As mentioned earlier, direct expenditures at the Jet Propulsion Laboratory increased 17.7% to $375.4 million. These expenditures are funded by the federal government principally through the National Aeronautics and Space Administration.

Laboratory operations included Voyager, Galileo, International Solar Polar Mission flight projects, operation of the Deep Space Tracking Network, research in space and earth science, and electrical energy programs related to development of low cost solar cells for direct solar conversion and solar thermal power systems.

Fund Groups
Caltech's financial accounts are grouped into self-balancing entities or funds. Besides the current fund, which was described above, there are four others. Their status is reported in Exhibits 1 and 2 and discussed below.

Loan Funds
Loan funds for interest-bearing loans to students amounted to $4.4 million at September 30, 1980. Of this amount $3.9 million represented outstanding loans to Caltech students with $2.7 million provided by the federal government under the National Direct Student Loan Program and $1.2 million from contributions by private donors. Loan principal payments in arrears for 120 days or more amounted to $142.6 thousand or 3.7% 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

The carrying value of the Institute's Endowment increased from \$156.0 million in fiscal 1979 to \$174.9 million in fiscal 1980. Corresponding market values increased \$23.5 million from \$173.9 to \$197.4 million. New gifts amounted to \$3.2 million.

Income from the Endowment amounted to \$12.4 million for the current year compared to \$10.7 million in 1978–79.

Portfolios having a market value of \$152.4 million or 77% of the Endowment are managed by three investment advisory firms. Included in these portfolios is a \$17.0 million fixed income fund which yields income of 11.9%. The other portfolios are invested in short term cash equivalents, fixed income securities, and common stocks. The distribution among these categories is constantly evaluated and adjusted to improve investment results.

Caltech's advisor-managed portfolios have traditionally produced total return performance (capital appreciation plus income yield) comparing favorably with that of other universities and institutional endowment and pension funds. Last year's results were particularly gratifying, with Caltech's three equity oriented portfolios ranking in the top 10% of the broad-based Becker "Funds Evaluation Service" at June 30, 1980.

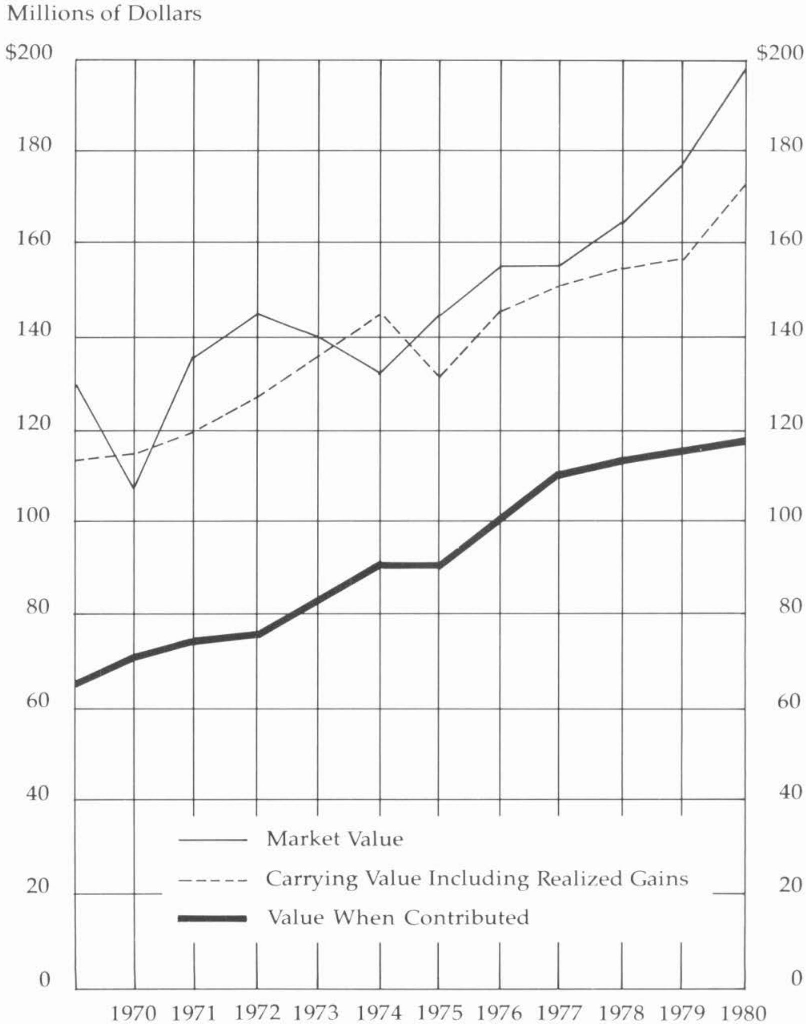
In addition to the endowment funds managed by the investment advisory firms, assets consisting of approximately 23% of the total are internally managed. These consist of real estate, securities that have special investment requirements or restrictions, and newly received gifts. Performance and income on these assets tend to reflect the characteristics of these investments.

Endowment fund investments at September 30, 1979 and 1980, are summarized below:

	Market Value (in thousands)			
	1979	%	1980	%
Bank accounts and short term commercial obligations	$ 11,049	6.4%	$ 38,015	19.3%
Fixed income securities				
Maturity 1–10 years	10,100	5.8	3,741	1.9
Maturity 11–20 years	3,564	2.1	4,791	2.4
Maturity after 20 years	29,120	16.8	33,967	17.2
	42,784	24.7	42,499	21.5
Common stocks	102,846	59.0	89,812	45.5
Preferred stocks and convertible securities	1,515	.9	10,540	5.4
Real estate, notes receivable and other	15,726	9.0	16,526	8.3
Total investments	$173,920	100.0%	$197,392	100.0%

The following graph plots the fiscal year end values of the Endowment since 1970:

Investments of Endowment and Similar Funds



Life Income and Annuity Funds
Life income and annuity fund balances amounted to $20.9 million at September 30, 1980, and represented some 130 trust and annuity agreements. These funds will become a major source of endowment funds upon termination of the agreements.

Plant Funds
The plant fund balances increased 7.3% from $143.4 million in fiscal 1979 to $153.9 million in fiscal 1980 after provision for $2.1 million of equipment retirements. Gifts and transfers of $4.3 million and current fund acquisitions of $6.7 million comprised the major additions to the plant fund.

California Institute of Technology
Balance Sheet
(in thousands)

	September 30, 1979
	Total All Funds
Assets	
Cash (demand deposits)	$ 1,026
Accounts receivable:	
United States government (note B)	42,686
Other	1,654
Student accounts and notes receivable	4,394
Investments (notes A and C)	200,206
Interfund interest bearing advances	
Prepaid expenses and other assets	1,827
Campus properties (note A):	
Equipment	58,169
Buildings	68,555
Land	8,204
	$386,721
Liabilities and Fund Balances	
Accounts payable and accrued expenses (note B)	$ 46,985
Deferred student revenue	1,877
Funds held in custody for others	773
Annuities payable (note A)	2,084
Fund balances	335,002
	$386,721
Fund balances comprise (Exhibit 2):	
United States government grants refundable	$2,444
Institute funds—	
Unrestricted	2,491
Discretionary endowment	
Unrestricted	33,571
Restricted	18,691
Endowment principal	103,775
Other restricted funds	43,975
Invested in plant	130,055
	$335,002

See accompanying notes to financial statements.

Exhibit 1

September 30, 1980					
Total All Funds	Current Funds	Loan Funds	Endowment and Similar Funds	Life Income and Annuity Funds	Plant Funds
$ 805	$ 408	$ 15	$ 7	$ 374	$ 1
52,672	52,672				
1,945	1,945				
5,234	1,323	3,911			
220,964	10,949	483	175,728	23,476	10,328
	4,481			(448)	(4,033)
2,002	2,002				
64,493					64,493
75,536					75,536
8,977					8,977
$432,628	$73,780	$4,409	$175,735	$23,402	$155,302
$ 55,192	$53,409			$ 361	$ 1,422
2,190	2,190				
6,394	5,570		$ 824		
2,161				2,161	
366,691	12,611	$4,409	174,911	20,880	153,880
$432,628	$73,780	$4,409	$175,735	$23,402	$155,302
$ 2,669		$2,669			
1,750	$ 284				$ 1,466
33,719			$ 33,719		
22,751			22,751		
118,441			118,441		
43,810	12,327	1,740		$20,880	8,863
143,551					143,551
$366,691	$12,611	$4,409	$174,911	$20,880	$153,880

California Institute of Technology
Statement of Changes in Fund Balances (in thousands)

	Year Ended September 30, 1979
	Total All Funds
Fund balance at beginning of year (Exhibit 1)	$320,403
Revenues and other additions (notes A, D and F)	
Student tuition and fees	6,780
Investment income	13,766
Net gain (loss) on disposal of investments—	
Unrestricted	415
Restricted	819
Gifts and nongovernment grants	16,770
United States government grants and contracts—	
Reimbursement of direct costs	26,201
Recovery of indirect costs and management allowance	15,397
Auxiliary enterprises revenues	2,703
United States government advances	166
Plant acquisitions, etc. (including $6,668 included in campus operating expenditures and $8,845 included in plant acquisitions, payments on interfund advances and renewals)	8,913
Other	406
Total revenues and other additions	92,336
Expenditures and other deductions:	
Campus operating expenditures (Exhibit 3)	(67,157)
Plant acquisitions, payments on interfund advances and renewals	(6,373)
Retirement and disposal of campus properties	(2,657)
Interest on advances for plant purposes	(154)
Payment to life beneficiaries	(1,161)
Adjustment of actuarial liability for annuities payable (note A)	137
Other	(372)
Total expenditures and other deductions	(77,737)
Transfers among funds:	
Gifts allocated	
Discretionary endowment transfers to (from) current funds	
Allocations for plant purposes	
Other	
Total transfers	
Increase (decrease) for the year	14,599
Fund balance at end of year (Exhibit 1)	$335,002

See accompanying notes to financial statements.

Exhibit 2

Year Ended September 30, 1980

	Current Funds					
Total All Funds	Unrestricted	Restricted	Loan Funds	Endowment and Similar Funds	Life Income and Annuity Funds	Plant Funds
$335,002	$337	$ 11,109	$4,034	$156,037	$20,062	$143,423
7,562	7,562					
16,259	4,995	8,870	48		1,372	974
4,196				4,196		
12,095				11,311	475	309
16,958	2,951	7,745	76	3,243	387	2,556
32,187		31,325				862
17,183	16,056					1,127
3,087	3,087					
264			264			
15,513						15,513
950	146	78	70		95	561
126,254	34,797	48,018	458	18,750	2,329	21,902
(79,748)	(34,642)	(45,106)				
(10,789)						(10,789)
(2,134)						(2,134)
(221)						(221)
(1,372)					(1,372)	
(139)					(139)	
(162)		(60)	(102)			
(94,565)	(34,642)	(45,166)	(102)		(1,511)	(13,144)
	(195)	(615)		810		
	576	(1,569)		993		
	(46)	(80)		(1,573)		1,699
	(543)	630	19	(106)		
	(208)	(1,634)	19	124		1,699
31,689	(53)	1,218	375	18,874	818	10,457
$366,691	$284	$ 12,327	$4,409	$174,911	$20,880	$153,880

California Institute of Technology Statement of Operating Expenditures

Exhibit 3

(in thousands)

	Year Ended September 30, 1979	1980
Educational and general:		
Instruction	$ 20,369	$ 23,781
Sponsored research	27,327	33,139
Scholarships and fellowships	2,827	3,232
Institutional and student support	8,657	9,608
Plant operation, maintenance, and utilities	5,148	6,571
Total educational and general	64,328	76,331
Auxiliary enterprises	2,829	3,417
Total campus expenditures	$ 67,157	$ 79,748
Direct costs of sponsored research at Jet Propulsion Laboratory (fully reimbursed by the United States government)	$318,982	$375,378

See accompanying notes to financial statements.

California Institute of Technology
Notes to Financial Statements
September 30, 1980

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. 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. The participation of each fund is established on a pool share basis. 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 value 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, 1980 and 1979, 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,	
	1979	1980
Marketable securities (Approximate market value of $169,461,000 in 1979 and $166,355,000 in 1980)	$155,480,000	$150,420,000
Savings accounts and short-term commercial obligations	25,239,000	50,219,000
Settlements in process—		
Receivables for securities sold	4,320,000	4,720,000
Payables for securities purchased	(4,574,000)	(5,141,000)
Real estate, less amortization and accumulated depreciation of $3,301,000 and $3,431,000	15,144,000	16,114,000
Mortgages, notes and other securities	4,597,000	4,632,000
	$200,206,000	$220,964,000

Investments shown above include the investment pool as follows:

	September 30,	
	1979	1980
Investment pool assets at year end—		
At carrying value	$135,147,000	$151,654,000
At approximate market value	$147,564,000	$165,055,000
Pool share value at market	$ 10.08	$ 11.19
Annualized income earned per pool share	$ .59	$ .70

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 $9,000,000 at September 30, 1980 and 1979. The income derived from these funds amounted to $536,000 and $538,000 for the years ended September 30, 1980 and 1979, 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 $3,300,000 and $3,588,000 at September 30, 1980 and 1979, 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, 1980 and 1979, totaled $12,319,000 and $11,849,000, respectively, of which $9,398,000 and $9,006,000 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.

Note F—*Pledges:*

The Institute does not record pledges in its financial statements. At September 30, 1980, the Institute had pledges on hand (principally for restricted purposes) totaling approximately $22,700,000, of which $7,100,000 is expected to be collected in 1981. It is not practicable to estimate the net realizable value of such pledges.

REPORT OF INDEPENDENT ACCOUNTANTS

Price Waterhouse & Co.

Century City
West Los Angeles, California
January 9, 1981

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, 1980, 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, 1979, financial statements which are included in summary form for comparative purposes.

Price Waterhouse & Co.

Board of Trustees as of September 30, 1980