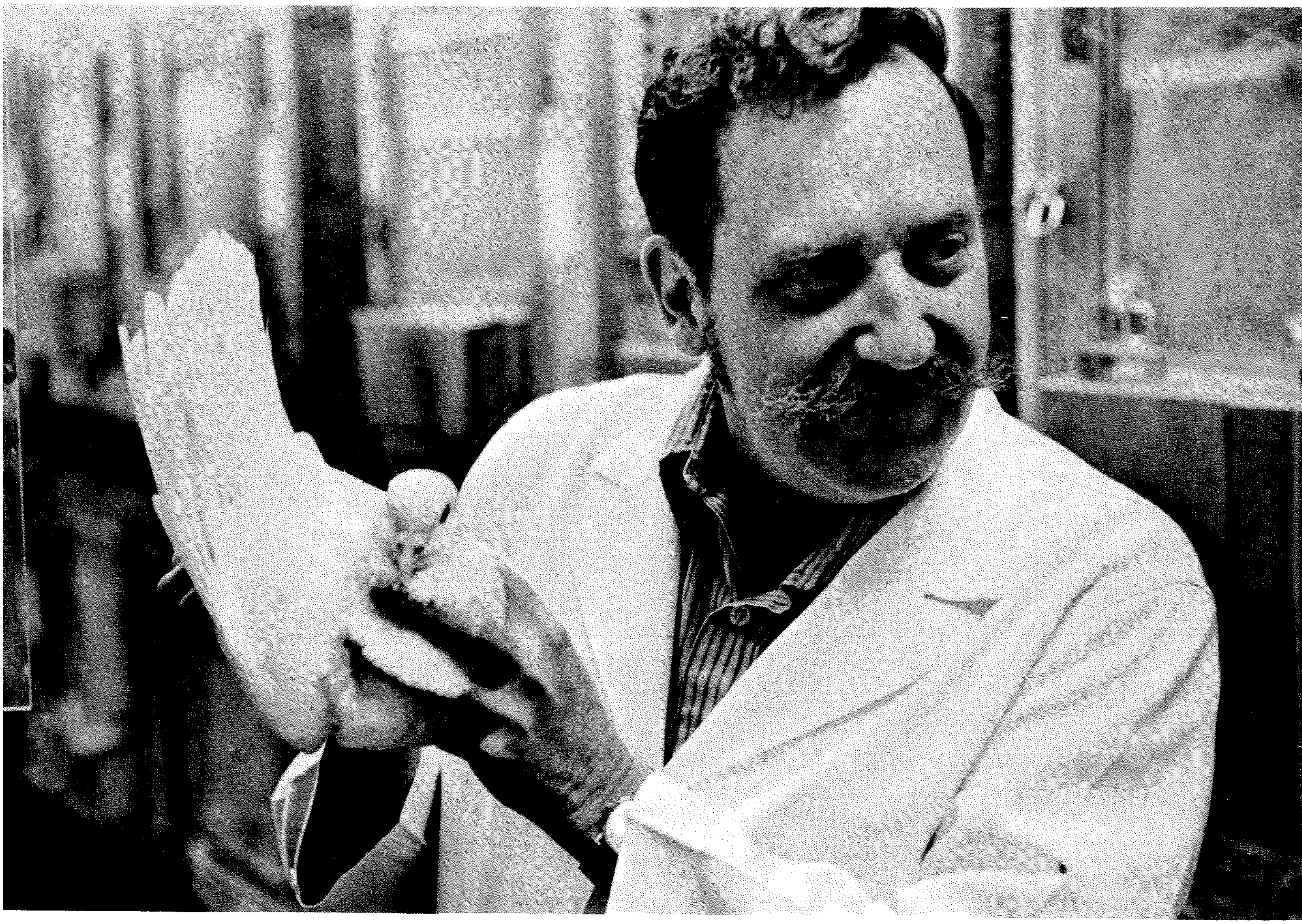
Engineering and Science

WHAT'S GOING ON HERE

The division chairmen report on recent research and developments in Caltech's six academic divisions

DIVISION OF BIOLOGY

Ray D. Owen*



*Ray D. Owen, professor of biology, substitutes for the current chairman of the division of biology, Robert L. Sinsheimer, who is on leave at the University of Zurich. Owen was chairman of the division from 1961 to 1968.

Among alumni, biology must be remembered as a relatively unpopular option, at least for undergraduates. It used to have about as few as geology, didn't it? Four biology majors was once a good year for the division. But things have changed. For third-term registration this past year there were 15 seniors in biology, 28 juniors, and 36 sophomores—a total of 79 undergraduate majors in biology. There were 46 chemistry majors and 13 chemical engineers—59 in all, as compared with 79 in biology. Eighty-nine physics majors were listed—10 more than in biology—but among the sophomores there were 31 in physics and 36 in biology. There were 32 sophomores in the engineering division—not counting the applied physicists—as compared to 36 in biology.

So student preferences have changed pretty fast, and you can see by the sophomore-junior-senior distribution just how fast they have been changing. Eleven of the 27 sophomore girls and 13 of the 32 graduate women are biologists. That is part of the reason the option is attractive, I think.

There are, of course, other reasons for the switch. It isn't only a Caltech phenomenon; in respectable circles everywhere much more attention is paid to biology these days. One reason is the growing conviction that biology is where the action is. And it's true; we are experiencing the fruits now of several decades of phenomenal progress in the understanding of life. Caltech has been an important part of that. Biology as a whole is big and at Caltech biology is little, but we have been very fortunate in the choices we have made of particular fields to emphasize. What was picked was genetics, biochemistry and biophysics (molecular biology), and neurobiology. These words represent much of the excitement of the last three decades in biology, and Caltech was lucky enough to be right at the heart of it. Even more important—to our chemists, physicists, and engineers, as well as to our biologists—we are in a most remarkably fortunate position as we approach the coming decades; we are where the action will be. Among the questions that excite people today in science are: How does the brain work? How does it develop so that it functions like the remarkable organ that it is? Are you going to change genes—or develop clones of people? If so, how? A large fraction of disease problems have their seat in the genes; will we develop gene therapy to correct the genes? Or in other problems of health and disease, like cancer: What goes wrong in a cancer? How can you correct it? These kinds of questions are the kinds of things we are, or can be, productively concerned with here at Caltech.

There are many examples of "relevance" that help to explain why young people are going into biology these days. Think, for example, of population problems, of world food supply, the fertility of the people, the quality of the environment. These problems are related to the possibility of constructive social action—partly through biology, partly through engineering, and partly through social and behavioral science. So not all biology is in the biology division. Divisional and disciplinary boundaries don't exist on this campus. It's easy to get into effective interaction with engineers, chemists, geologists, physicists, and mathematicians with a minimum of administrative interference here. Caltech is really a unique place for that kind of freedom, and that is part of the reason we have been so successful.

What do we need money for? We haven't had much trouble in getting research grants for the well-developed programs we have in progress. The big problem is finding unrestricted gifts that can be part of general funds and can be used for things that don't fit into the immediate confines of the governmental grant and contract programs in support of research. The biology division, like the other divisions, depends very strongly on general funds. We need money for student support at both the undergraduate and graduate levels. All kinds of costs are going up and—unless we increase our base of funds—as the cost per person supported increases, the number that can be helped is sure to decrease. The problem is particularly critical at the graduate level these days, as a result of the almost total disappearance of federal fellowships that carry tuition support and, now, the threat to manpower training programs—particularly in the health-related sciences. Our students contribute at least as much as they take from Caltech by the research they do, and the part they play in our teaching. They are an integral part of the Institute and, considering their quality, we get their services pretty cheap.

Faculty salaries are in a somewhat similar situation. It is conventional for every faculty member who can do it, and we expect almost everybody can, to get a substantial fraction of his salary out of his research grant. That's fine but as funds begin to tighten elsewhere, the feeling of independence of this kind of salary support begins to disappear. We then run a danger of getting into a spot

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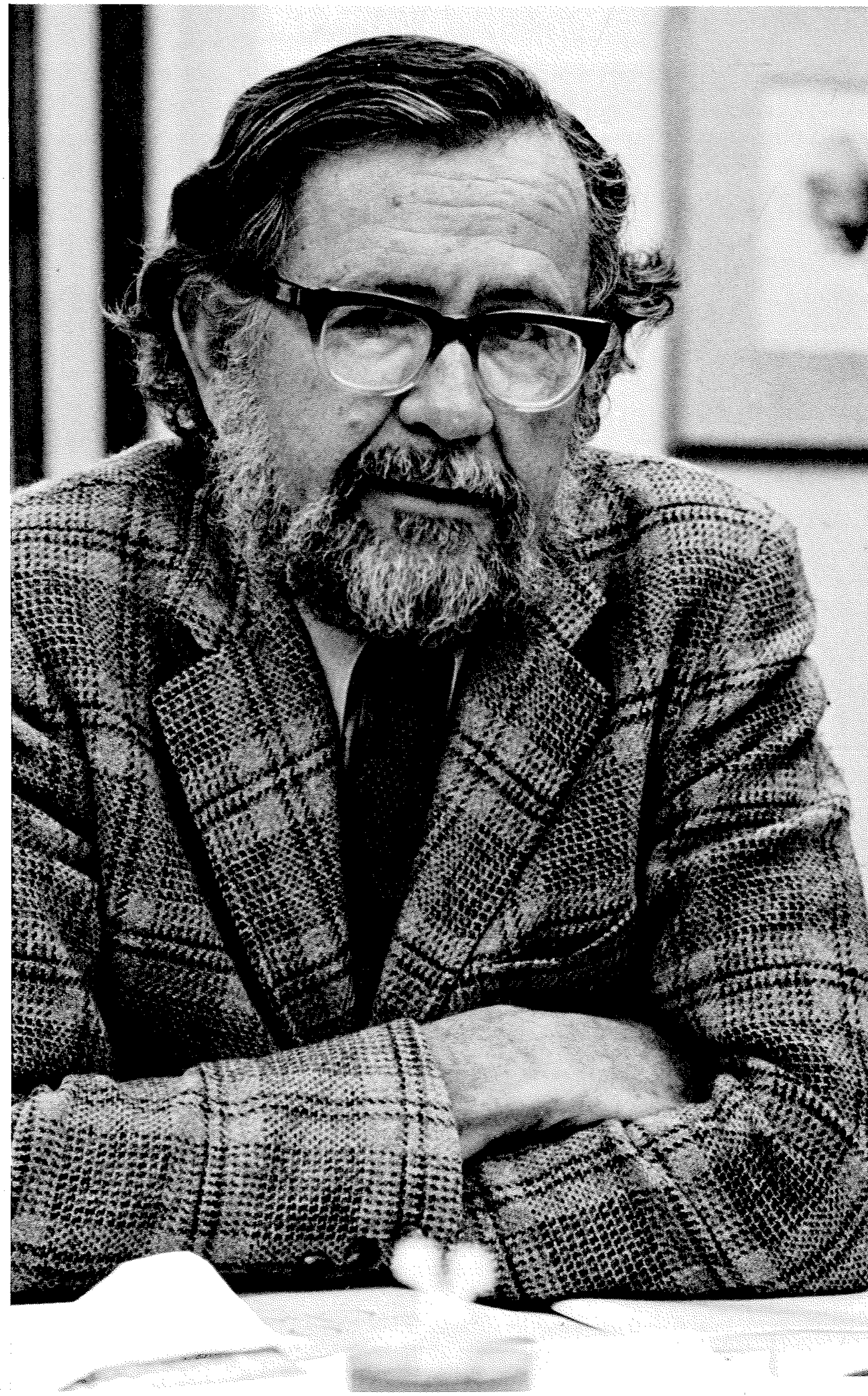
DIVISION OF CHEMISTRY AND CHEMICAL ENGINEERING

John D. Roberts
acting chairman



Twice in the last ten years, Caltech's Division of Chemistry and Chemical Engineering has been ranked as number two in an allegedly impartial national survey; behind Harvard and ahead of Berkeley, Columbia, and Stanford—whom I regard as our principal competitors. Harvard has some aging problems, and you might say that we have some youth problems. In chemistry we have only two professors now who are over 60, four in their 50's, and most of the rest of the present staff is under 40. Hardly a predominantly gray-haired group—for a long time to come. We've long been known for innovative teaching. And we're still at it, although the knowledge explosion makes it increasingly difficult to know what are the best things to teach in the decreasingly available time.

I think it's clear that chemistry still is very much alive, because many of the things that are being done in the field right now are things that we would really like to have time to tell students about in our elementary courses. I suspect this is less the case for physics and mathematics, but very much the case for astronomy and biology, as well as chemistry.

In teaching, we find it really very difficult to get agreement as to the proper balance to strike between theory and practice, between facts and principles, among students, among staff, among alumni, and among the people who hire our students. Thirty years ago quantitative theories of chemical structure really were not worth very much discussion at the elementary level. Now, to a great extent because of the success of Caltech research, theories of structure are so well developed that in our elementary courses we can spend practically full time on theory. Yet, chemistry is really not that theoretical. Almost all of us still find out more from experiments than from calculations. But the problem is to decide what kind of approach we should take for our bright young undergraduates who are often very theoretically inclined. I can assure you of one thing—that our best people are heavily involved in undergraduate teaching. And when George Hammond, who was our immediate past division chairman, decided that he was going to revolutionize the teaching of chemistry for undergrads, probably the worst problem that he encountered was that the rest of the members of his staff had their own strong ideas about how this should best be accomplished.

In research, I think we're in very good shape, although we can see some difficulties ahead. A very important one has to do with space. Because of earthquake damage in 1971, the Gates Laboratory has been condemned for use by chemistry. So we've had to pack the former occupants into our other buildings, and we've constructed a small temporary building adjacent to the Noyes Laboratory for use as an undergraduate laboratory. Since the plumbing and hoods in this new building are alleged to have only about a five-year life span, we need to get going on plans for a new laboratory to house our undergraduate facilities as well as expanded research effort.

Twenty or so years ago our research was oriented toward determining molecular structures and theorizing about them. This was correctly perceived by Linus Pauling to be the most productive research area at that time. We're still in the structural chemistry research effort, but we have greatly expanded in other directions in the area of what one might call molecular dynamics—that is, the way in which molecules react. And we have research which ranges from the study of reactions between ions and neutral molecules in the gas phase, to the mode of action of digestive enzymes and the action of antibodies in living systems.

The biological end of our research spectrum is now receiving particular emphasis. We have professors who are working on the way in which light striking the retina of the eye is converted to nerve impulses, on the details of how cellular membranes function, on the nature of the hereditary mechanisms of tumor viruses, on the way hemoglobin molecules change shape when they absorb oxygen, and on the mode of action of metalloproteins in photosynthesis. These activities may not sound like chemistry at all, but I can assure you that the approaches that are being taken to them are fundamentally chemical approaches. And they are in especially fruitful areas for the application of chemical principles—with, of course, many profound and important implications for the health and welfare of humanity.

Chemical engineering at Caltech has also changed drastically in the past few years. Twenty years ago the emphasis in research was on the thermodynamic properties of petroleum hydrocarbons—a very important subject to the petroleum industry at that time. But now we've expanded our work to include the engineering aspects of artificial kidneys, combustion mechanisms, solid-state catalysis, structures of liquids, polymer properties, reactions in plasmas, and reactions that go on in air pollution. And again, as in our chemistry effort, we have on the average a very young, vigorous faculty.

Of one thing you can be sure—we are not doing the same old things we've always done. We're moving—we're moving very fast.

DIVISION OF ENGINEERING AND APPLIED SCIENCE

Ours is called the Division of Engineering *and* Applied Science, and we take the responsibility for both components very seriously. It was in 1959 that the Ford Foundation gave Caltech a multimillion-dollar grant for the development of graduate work in engineering. It was, I think, partly based on the success aeronautics had had at the graduate level over the years. Other areas of engineering wanted to strengthen their graduate programs, and the Ford grant enabled Caltech to develop one of the finest graduate schools in engineering in the country.

Concurrent with this was the decision to put an increasing emphasis on applied science. In the sixties we saw the emergence of a strong group in applied mathematics here at Caltech. It grew out of the excellent theoretical work we had done earlier in fluid mechanics and related areas. This effort enjoyed a growing national reputation. Applied mathematics at Caltech has ties with both the Division of Engineering and Applied Science and the Division of Physics, Mathematics and Astronomy.

More recently we have seen the reemergence of a program in applied physics, which had existed here during the years before World War II. It somehow was discontinued, and in more recent years students who came here wanting to do various kinds of applied physics had to undertake work under the title of theoretical physics or particle physics, or electrical engineering, or geophysics. So we established a formal program in applied physics, and I think it is now showing great progress. It, too, cuts across divisional boundaries. It has ties with electrical engineering, materials science, fluid physics, physics, chemistry, chemical physics, and geophysics.

It is my own view that the pendulum perhaps swung too far in giving greater emphasis to applied science and to graduate work. I believe that now is the time for us to strengthen the engineering component of our work and to give greater attention to our undergraduate program. We have already made a few moves in that direction. In 1969 we launched a substantial program in environmental engineering. The vigor of this activity is exemplified by the recent major undertaking of a half-million-dollar contract with Bechtel Corporation, Pacific Gas and Electric, and Southern California Edison to study thermal diffusion, wave defense, and off-shore conditions for two large nuclear power plants—one at Mendocino and the other at San Onofre. The program's vigor is also exemplified by, for instance, the work of Wheeler North in restoring the giant kelp beds off the southern California coast. And it is exemplified by the work that Sheldon Friedlander, Rudolf Husar, and James Huntzicker are undertaking in a major study with the Air Resources Board for characterizing and studying the aerosols in the southern California atmosphere. The program in environmental engineering is a growing one. Graduate enrollment is rising, and so is undergraduate interest.

Along with this academic program on the environment, we have undertaken a challenging new experiment—the Environmental Quality Laboratory, which is not in the direct academic line. It is an action-oriented laboratory set up to play an influential role in environmental affairs at the local, state, and national levels. Those who believe we should do something of social relevance will, I think, applaud the activities of EQL Director Lester Lees—his work with the legislature, with various industries, and on the national scene on various aspects of the environment. Those of a more conservative bent will view with some alarm this Caltech move into the political arena, where—if we are not careful—we may get our fingers burnt. There has been a great deal of debate here at Caltech about this matter. We are trying to find our way in this new area where science and engineering can play an influential role in bringing to the public a fair and unbiased analysis of environmental alternatives, and still not overstep the bounds of advocacy and political involvement.

We have increased our work in earthquake engineering. At the time of the February 9, 1971, earthquake, we had established a strong-motion network here in southern California against the day when a great earthquake would occur. From it we hoped to obtain for the first time strong-motion data as to what happens around an epicenter in the urban areas that are affected by it. The San Fernando earthquake gave us more data on strong motion than had been accumulated in all the rest of history up to that time. Fortunately, it occurred at a time, a strength, and a place where there was no major loss of life or property. But it did awaken all of us to the possible damage that a great earthquake might cause in the Los Angeles area. Caltech now has a major program of analyzing these data and relating them to needed changes in building codes and structural design. More recently Caltech has become a national information center for earthquake engineering.

Francis Clauser, chairman

As a result of our activity in studying the disastrous effects of earthquakes, we have reexamined our strengths in other areas of research on natural disasters. About two years ago we determined that there was need for a major review of the problem of wind loads on buildings. Our faculty called a national conference on this subject, and since then Caltech has played a leading role in research in this area. We took further stock and found that we had a group that had become well known for its work on fires—forest fires, fires in buildings, and fire storms. The same was true for landslides, for tsunamis, and for floods. All of the people working in these areas had a common interest—not so much for the technical aspects of their work as for the effect that the disasters they were studying had on society. They were drawn together because the results of their work led to such things as new building codes, new structural design requirements, new insurance laws, and revised needs for communications during a disaster, as well as the need for hospitals, police stations, and fire stations to continue to operate effectively during and after a major disaster. This common bond of interest has caused us to establish a center for the study of natural disasters.

The new Jorgensen Laboratory for computing and information science, given to us by Mr. and Mrs. Earle Jorgensen, will permit us to expand substantially our work in computing. As a first step we have rather clearly separated out the academic and research work in information and computer science from the responsibilities of providing service in computer programs on the campus. The Booth Computer Center will be the focus for the service, and the Jorgensen Laboratory will be the focus for the expanded academic program in computing and information science.

In another area, we brought John Pierce—one of our distinguished alumni, who was for many years at Bell Labs—back to the campus. He and Hardy Martel and others are now laying plans to establish a program in communications. The potentialities are great. We have close ties with JPL, of course, which I think is the leading practitioner of space communication in the world; with Hughes Aircraft Company, which has an outstanding reputation for its communications satellites; and with Bell Labs, the world's leading laboratory for communication research.

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DIVISION OF GEOLOGICAL AND PLANETARY SCIENCES

A prominent current development that involves the Division of Geological and Planetary Sciences is the construction of the new Seeley G. Mudd Building of Geophysics and Planetary Science. The building will house our group of planetary scientists and also the Seismological Laboratory, which will move to the campus from its present location in the San Rafael hills. This will bring the division's geophysicists into close contact with our geologists, geochemists, and planetary scientists, and we expect many beneficial results. The move to the new building is expected in 1974.

Research in the division has expanded into many new areas in the past few years, ranging from the earth's deep interior out to the moon, Mars, and beyond, with much of significance in between, right here on the earth's surface.

In trying to figure out what is going on deep in the interior of the earth, we ask such questions as what is the chemical composition of the material down there, what mineral phases occur, and what are the physical properties of these phases under the conditions of high pressure and temperature that prevail? The answers to these questions bear on the functioning of the earth as a great heat engine, whose activity causes faults to move, continents to drift, and mountains to be upraised. Because the interior can't be sampled, we have a problem of indirect interpretation, and it is difficult to get reliable answers. The primary evidence comes from seismology. Our geophysicists have been using modern data on the propagation of seismic waves through the earth, and on the elastic oscillations of the earth as a whole, to deduce in beautiful detail the layered distribution of density and elastic wave velocity in the earth's interior. Interpretation of this information now draws heavily on solid-state physics and chemistry. A combination of high-pressure experimental work and solid-state theory by Don Anderson, Tom Ahrens, and their colleagues is beginning to yield definite conclusions showing how—by a succession of phase transformations—the minerals known at the surface transform structurally to dense, unfamiliar forms as we go deeper and deeper into the earth. We are thus on the brink of a real understanding of what the earth's interior is all about.

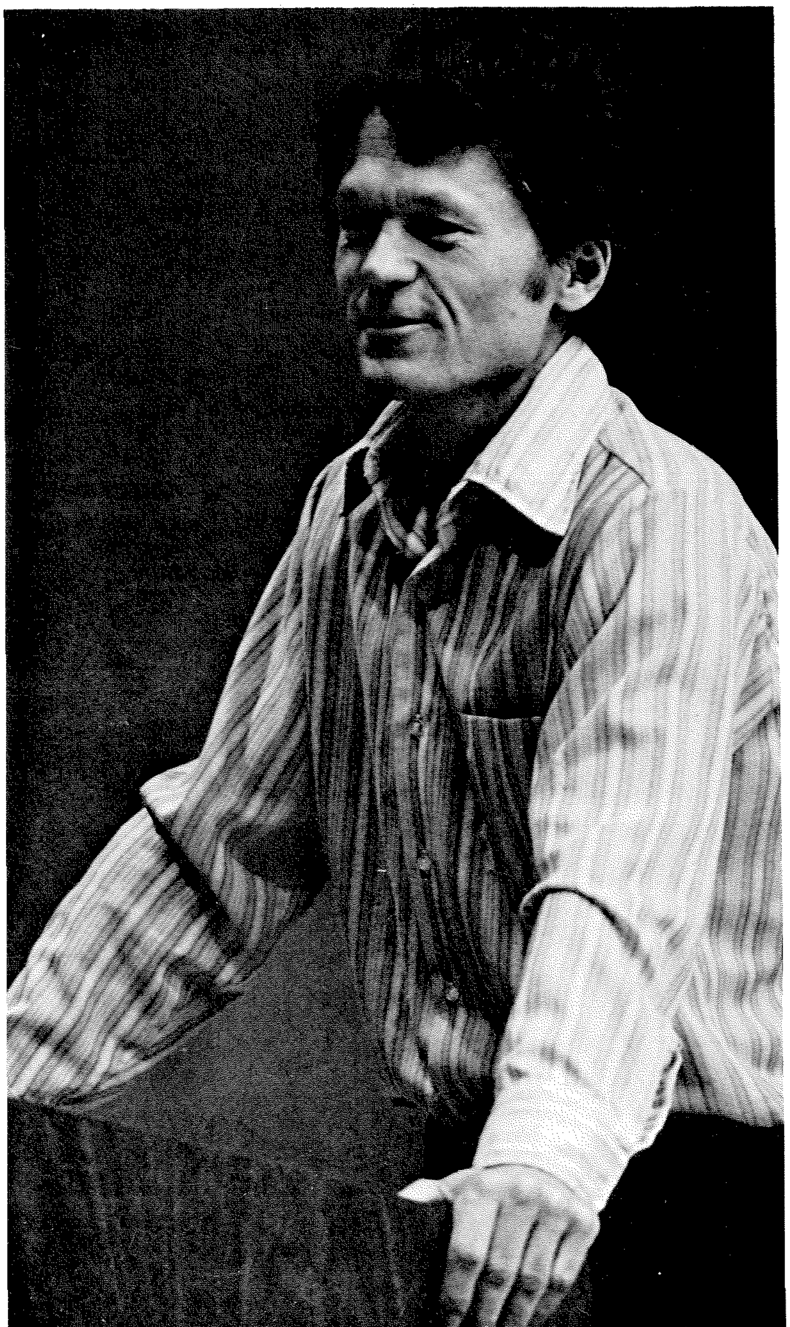
The study of materials at the extreme pressures of millions of atmospheres that occur deep in the earth is a very difficult experimental problem, which we are now tackling thanks to Tom Ahrens' application of the methods of shock-wave physics. His new shock-wave apparatus, which will be installed in the Lindhurst Laboratory in the new building, will be able to generate shock pressures up to more than one million atmospheres. Methods of measuring the internal energy, volume, elasticity, temperature, and spectra of rocks and minerals at high pressure in the shocked state are being developed. Caltech is leading the world in the application of these methods to the geophysical problems of the earth's interior.

Dynamical processes in the earth's interior are probably responsible for what happens geologically at the surface, and we hope ultimately to understand in detail the connections between the two. A surface event of much importance locally was the San Fernando earthquake of February 1971, and we are still much involved in the geophysical and geological study of this event. Investigations are continuing of the mechanism of the earthquake, the fault movements involved, the origin of the rupture at depth and the details of its propagation to the surface, and the effects of the fault movements in producing regional patterns of strain, uplift, and subsidence. These studies aim to give us an understanding of the earthquake good enough to relate it to our best-known earthquake hazard, the San Andreas fault, and to allow an evaluation of the potentialities for similar events in the future. This is the kind of question that Clarence Allen is particularly concerned with.

Another example of a vigorous research area dealing with important phenomena of the earth's crust is the geochemistry of water. By isotopic analysis of oxygen and hydrogen in the rock-forming minerals, Hugh Taylor is able to detect chemical effects of the water that was associated with the intrusion of masses of molten rock into the crust and that to some extent escaped and reacted with the surrounding host rocks. Understanding the role of water in these igneous processes bears on questions such as the significance of primary magmatic ("juvenile") water, and the origin of ore-forming hydrothermal fluids. The isotopic geochemical study of water includes water at the earth's surface and water in the form of ice and snow, a field pioneered by Sam Epstein. His studies of samples from a core hole through the Antarctic ice sheet show the history of the isotopic composition of water deposited in the ice sheet, and give a record of world climate clear back through the ice age. The end of the ice age about 10,000 years ago is particularly striking in this record. This kind of investigation sheds light on current trends in worldwide climate and helps in the effort to understand their causes.

Important advances in studying the origin of rocks are being made by the technique of electron microprobe chemical analysis, which allows micron-sized regions of individual mineral grains to be analyzed chemically in

Barclay Kamb, chairman



great detail. Arden Albee's development of this technique has greatly increased its capabilities through use of new instrumentation and an on-line computer, so that you can now get a complete chemical analysis in about ten minutes. Such a powerful and efficient technique has many potential applications in the earth sciences and in science and technology at large. It is fair to say that Caltech now has the world's leading facility of this kind.

The electron microprobe is playing an important role in the study of the Apollo lunar samples, which is a very lively current research activity in the division. These samples are too small and too valuable for conventional chemical analysis, but can be analyzed in detail, non-destructively, with the microprobe. Such analyses are a basis for inferring the origin and history of lunar rocks.

Determining the ages of rocks by mass spectrometric measurements of radioactive elements and their decay products is one of the division's well-known fortes, which has been developed to a peak of perfection for the study of the lunar samples. The radiometric ages found for the lunar lavas are 3.1 to 3.8 billion years, older than any rocks known on earth (with rare exceptions), but distinctly younger than the age of 4.5 billion years inferred for the original formation of the moon. This points to a 1- to 1.5-billion-year period of ancient activity and development within the moon prior to its lapse into the state of inactivity that we see today. What is known of the basic chronology of events in the moon's formation and development is due almost entirely to work done at Caltech by Professors Burnett, Silver, Shoemaker, Wasserburg, and their colleagues. New measurements and ideas are being added almost daily in this vigorous research area. Piecing together the history and evolution of the moon, comparing it with the geological history of the earth, and trying to explain the behavior of these two planetary bodies on a common basis of understanding is the central current challenge in the scientific rewards of the Apollo program.

Spectacular results of hypervelocity impacts on the lunar surface are now recognized over a tremendous range of dimensions, from the microscopic, beautifully sculptured "zap craters" punched into exposed surfaces of lunar rocks by tiny particles traveling at great speeds, up to huge impact craters and entire mare basins, such as Mare Imbrium, blasted out by immense projectiles of asteroid size. The "gardening" of the lunar surface by all this impact activity is responsible for the widespread mantle of breccias and "soils," which contain the most

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DIVISION OF THE HUMANITIES AND SOCIAL SCIENCES

I suppose my career at Caltech is very much like the Division of Humanities and Social Sciences. I've had every odd job, and the division might well be called the Division of Everything Else at Caltech That Isn't Covered by Other Divisions. On our faculty we have 9 historians, 11 people in English literature, 9 economists, 3 political scientists, 3 philosophers, 3 psychologists, 1 anthropologist, 1 geographer, 1 professor of science and government, 1 information scientist, 6 people in languages; and working part-time, 1 sociologist, 1 senior research fellow in population studies, 2 art historians, 1 lecturer in science communication, and 1 linguist.

In its original conception the division was primarily concerned with adding an element of humanities studies to the education of engineers and, to a lesser degree, scientists—although the balance has now changed. That is still the division's primary function, but things have changed both in staffing and scope of work. Originally, the staffing of the division largely consisted of graduates of eastern colleges, at whose feet budding engineers could

Robert A. Huttenback, chairman

sit and gain some veneer of culture. (I don't mean to denigrate this, because I think our most influential and best teachers came from that tradition. I doubt if we ever had a more influential teacher at Caltech than Harvey Eagleson. It's a sad thing that such people don't even exist anymore.) But in our recruiting now we want not only excellent undergraduate teachers, but people with a great interest in research—the kind of interest that has made Caltech great in all the other divisions. In this we have been, to a large degree, very successful. In the humanities the young people we have recruited are people who have followed successful research careers. This is something we wish to continue to do.

Social science is relatively new at Caltech. I think the first branch of social science which was indulged in here was economics, and the prime function of economics originally was to teach engineers (many of whom went into business) some rudiments of business economics, or corporation work, or stocks and bonds. (Speaking of influential teachers, I must also mention Horace Gilbert, who recently retired from teaching economics here, and who had a major influence on many generations of Caltech students.) This is something we still think is very important, but we have added a whole panoply of social scientists who not only teach undergrads but also follow research careers in many important fields.

Last year, after careful scrutiny, a graduate program toward the PhD was approved in social science. This is the first graduate program in a nonscientific or non-engineering field to be approved at Caltech. This program is an interdisciplinary one. It doesn't attempt to give a degree in political science or economics or sociology, but it attempts to distill those important elements which the social sciences have in common and give a degree—which can be very valuable—in social science. In keeping with Caltech tradition it's essentially a very narrow program. It doesn't attempt to cover the whole waterfront. We intend to devote most of our interests to the area of social change. The program will be largely theoretical, but will have practical aspects and will be to a large extent quantitative. All students admitted to the program will be expected to have a high degree of sophistication in mathematics, and the outstanding faculty of social scientists we have recently recruited are all highly competent in mathematics.

This year, for the first time, we are starting both an undergraduate program in social science and a graduate program—and we now have our first graduate student. We are hoping for a program that will involve something like 5 graduate students a year, to a total—when it's in full swing—of about 20.

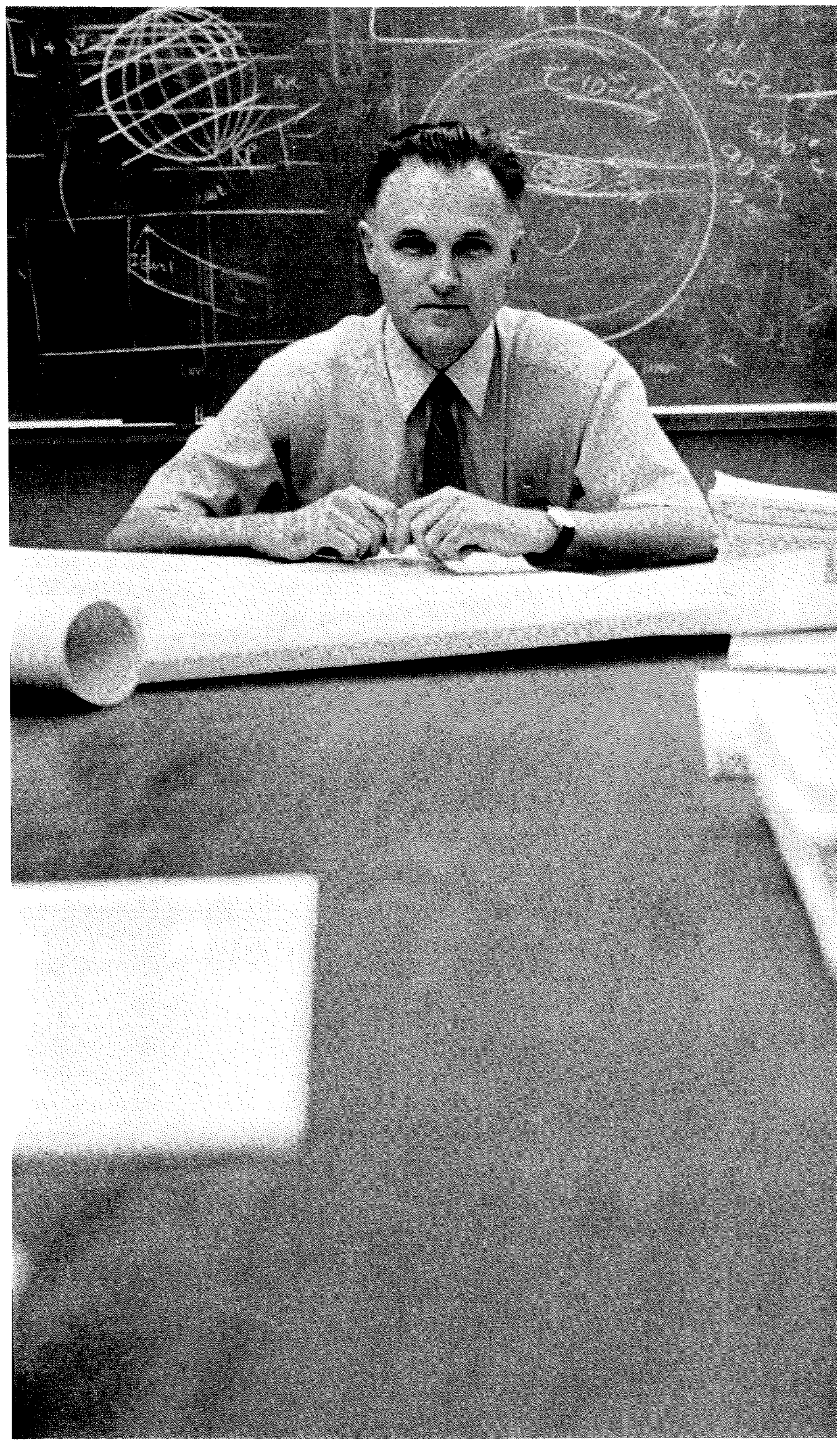
The research the social scientists do is considerable and diffuse. We have people interested in urban housing, health delivery systems, legislative behavior, and even the economics of professional sports. There's been a major attempt to cooperate with other divisions. Social scientists have been very active in the Environmental Quality Laboratory. And there's been a great deal of cooperation in the area of environmental engineering science. We have long hoped for increased cooperation with biology; and with the new behavioral biology building going up there's a real possibility of doing something in the area of child learning. (Jerome Bruner, who came under our auspices last year to give a series of lectures here, has been the catalyst in this direction.)

The prime function of the humanities in the division continues to be teaching Caltech students who major in science and engineering. We now also have four undergraduate major programs in economics, history, English, and social science. These draw—particularly economics—a fair number of people, but of course students do not come here initially to major in one of these fields. Research in the social sciences looks much more like research in the sciences, in that teams of people quite frequently work together on a project. This is not true in the case of the humanities, where the research is individual, making for serious implications for funding. Individuals can often obtain support for a year, but are very unlikely to get it over many years. So the humanities section lives very heavily off the general budget.

Another function has accrued to our division which I think is an Institute-wide responsibility. This is a cultural responsibility.

We have an art gallery, which has had some very significant exhibitions in the last several years. We've done some experiments with repertory theater. We've had a couple of poets in residence. We've funded a film-making program. We've had an artist in residence. All of these things have a significance, we feel, for the entire Caltech community. In the area of music, where I think there's probably more intrinsic interest by the Caltech community than in any other area of the arts, we fund a chamber music series and various other things. We were very fortunate last year to receive from the Mellon Foundation an endowed visiting professorship that should allow us to invite authors, musicians, and artists to the campus for periods up to a year. I think this will be a great enrichment of the whole life of the Institute. So we feel that we have a triple responsibility—to the graduates, the undergraduates, and the Institute community.

DIVISION OF PHYSICS,



Robert B. Leighton
chairman

MATHEMATICS AND ASTRONOMY

The names Ph 1 and Ph 2 have a special meaning to Caltech alumni. If they were to come back and sit in a class of Ph 1, even if they had been away for some decades, they would find that almost all the equations were familiar. Some of the problems might be a little difficult to solve, but that would not be a real change from the time when they were students here! It isn't so much that nothing has changed; it's that Newton's laws are still true and valuable, and it would be a shame to raise a generation of scientists to whom they were alien.

With respect to the number of majors in the Division of Physics, Mathematics and Astronomy, about half the undergraduates at Caltech major in one of the subjects under this division. And if we stop to think about it, 89 physicists—if that's the right number—is a lot of physicists. It may be surprising to learn that we have 20 mathematics majors per class these days. It used to be that mathematicians were here in 3's and 4's. They are still by some margin among the brightest of our students.

With regard to research, I'll have to tell you right away that I'm not going to say anything about research in mathematics—partly because I'm not competent at it and partly because they tell me that we should now regard mathematics as a fine art and put it in the Humanities Division.

A returning alumnus would find much of the research in physics and astronomy to be along the same lines as when he was a student here. The principal endeavors are still aimed toward study of the fundamental properties and organization of matter and of the cosmos. Some of us will remember that, in the 1930's and 1940's, Robert Millikan and Carl Anderson were analyzing cosmic rays to find out where those huge energies came from. Were they the birth pangs of the atoms? Charlie Lauritsen had reversed the polarity in the big high-voltage generator in Kellogg to accelerate protons instead of electrons—and so put Caltech in the nuclear physics business.

Ira Bowen, Fritz Zwicky, and the Mt. Wilson astronomers were busy delving into the cosmos. In that era, not long after the spiral nebulae were established as being external to our own stellar system, the expansion of the universe was discovered. It has been a key and prime line of research ever since.

Today, some activities have diminished, some have greatly expanded, and some are relatively new. Atomic spectroscopy is no longer the central thing that it was in the days when Ira Bowen was analyzing the spectra of complicated elements. But Ward Whaling is doing marvelous new things in Bowen's old laboratory. The fundamental properties of matter—what we used to call elementary particle physics—is still a central line of endeavor both experimentally and theoretically. However, experimental work has of necessity moved outside this campus—to Stanford's linear accelerator, to Berkeley's Bevatron, to Brookhaven, and now to the National Accelerator Laboratory (NAL) where there is a new machine operating at 300 billion volts that will power a number of experiments for our so-called users' groups.

Would you believe that the first of these experiments will involve a beam of neutrinos? The neutrino is about as close to intangibility as we can get in this world—the human soul, perhaps, being the next stage. A beam of neutrinos, it is calculated with reliability, could penetrate through *light years* of solid iron with a good probability of emerging at the other end without having hit anything! And yet they're going to have a *beam* of neutrinos (God bless them!)—enough neutrinos that, even with that small probability, some of them are going to hit something in a big stack of iron plates and spark chambers and do something to elucidate whether neutrinos are formed in the peculiar way that people now think, or, more understandably, through an "intermediate boson." (That's not a joke; that's one of the terms you hear in the esoteric world on the top floor of the Lauritsen laboratory here.)

Other Caltech people are studying what are called quasi-two-body reactions at NAL. When I was a student here, Millikan had just written his book with the red cover called *Electrons (Plus and Minus), Protons, Neutrons, Mesotrons, and Cosmic Rays*. If you were to write that book today, you would have to put in multitudes of hadrons, meson families, the leptons, and all that kind of thing. It would be a difficult thing to do. There are, in fact, more of these so-called elementary particles than there are chemical elements. Unlike the chemical elements, there is apparently no limit to finding new particle families.

One of the main theoretical endeavors at Caltech, as a matter of fact, is based on this business of families of particles. Richard Feynman, Murray Gell-Mann, and their colleagues who deal with these things have come down to a new idea of elementarity—you've heard of quarks? You probably could have been thrown out of Caltech back in the 1930's if you had seriously mentioned a particle that had one-third of an electron charge. Millikan would not have stood for it. And yet it seems possible that quarks are the fundamental things that compose matter. They come in three flavors—up, down, and strange; and in three different types—red, white, and blue. (This is the latest word from a conference recently held in Chicago.)

We have no idea right now whether quarks might have any practical application or not; nobody can say. Most likely not. And yet, is it inappropriate at a place like Caltech that significant effort should go into studying things like this? I think it adds to our appreciation of the grandeur of the universe to understand these funny little quarks—with their third-of-an-electron charge!

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BIOLOGY

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where our faculty might become dependent on, and identified with, the agencies that support their research and salary rather than the institution that needs their full devotion—not only as researchers but as teachers and citizens as well. Even in research, we cannot run the risk of subordinating our free-ranging and independent creativity to direction from external agencies.

The new laboratory of behavioral biology will be finished a year from now, with new functional research units to be staffed and equipped. It is harder to get an operation going than to keep it operating when you have it going well. The expenses are substantial, especially if you are interested in getting good young people who need help from unrestricted funds to get started. But it is not just a matter of new buildings; the old buildings are a problem too. Come visit Kerckhoff someday, and I'll show you what I mean; or see our experimental animal facility, which faces a big change in requirements for the amount and quality of animal care. And our marine station is operating at absolutely top capacity with the new kinds of emphasis in biology and engineering. Teaching is charged to general funds, but the way costs have been growing, we can hardly afford to continue to teach the way we should, unless increasing general funds become available.

I wouldn't make a pitch as a biologist for Alumni Fund contributions to the Division of Biology. We need as an institution—of which biology is one lively part—the general funds that will make it possible for the Institute to move with the times, to maintain its unique distinction in teaching and research. These are times of severe stress for our Caltech.

ENGINEERING AND APPLIED SCIENCE

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We have for years had a great deal of work going on in biomedical engineering. Derek Fender has been studying the stimuli associated with human vision. Gilbert McCann and his associates have had a long program of investigating the neural systems of insects. Harold Wayland has had a program on the flow of blood in veins and arteries, and he has recently received a major grant from the Hartford Foundation for his work. Friedlander has been doing work on the flow of air in lung passages. All of this work has had ties with biology and chemistry. At present we are actively exploring the possibilities of uniting forces with some of the people at JPL to establish a major program in biomedical engineering.

All through our work here there is a strong interdivisional activity that would be very difficult at most universities, where high departmental walls make communication difficult. But at Caltech the ease with which we can cross interdivisional lines is a pleasure.

We are also moving to establish closer ties with industry. Each year we have five or six major conferences through our Industrial Associates program, which give people from industry a picture of the research activities that are going on here at Caltech. In addition, we've taken steps to invite people from industry to serve as visiting professors. Leo Stoolman from Hughes has spent a year here; others are Paul Dergarabedian and James Broadwell from TRW; Martin Goldsmith from Aerospace; Hirsh Cohen from IBM; David Malk from Beckman Instruments; Guy Pauker and Cliff Shaw from Rand; Mahlon Easterling and Ralph Miles from JPL. And we would like to invite more. Industry is a fertile source of new ideas, and it is to our mutual benefit to have closer ties.

GEOLOGICAL AND PLANETARY SCIENCES

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diverse assortment of powdered mineral grains, rock fragments in all stages of shock disintegration, and glass beads, shards, and coatings generated by shock melting. The nature of this "gardening" activity, and its history and consequences are being studied in detail by Professors Burnett, Shoemaker, Wasserburg, and their students and collaborators. Burnett's lunar neutron probe experiment on Apollo 17 represents a beautiful application of nuclear chemistry in revealing the time scale of the gardening process. The importance of impact shock effects on the moon (and also on earth, where recognized by discerning observations) is prompting experimental studies of these phenomena in Ahrens' shock-wave laboratory, which is thus serving a dual purpose as research tool for both geophysics and planetary science.

Still another facet of the division's activity is the lunar field geology program —the adaptation of terrestrial methods for field study to lunar conditions as anticipated in the Apollo missions. This was initiated and developed by Gene Shoemaker and then further advanced by Lee Silver in his field geology training expeditions for astronaut crews. The participation of Jack Schmitt (BS Ge '57) in Apollo 17 as the first scientist-astronaut to fly a lunar mission is a cause for particular pride and involvement on the part of the division. Perhaps Jack's selection for this mission goes back to his undergraduate field geology, and it strengthens our belief in the value of strong field experience.

Beyond the moon is Mars and Mariner 9, a beautiful accomplishment in which several of our staff participated, particularly Bruce Murray and Bob Sharp. Analysis of the great amount of photographic information obtained in this mission is still under way and will continue for some time. And research in the division by no means stops here, for our planetary scientists are at work on Venus and Jupiter, on the jovian satellites, and indeed right on out of the solar system to interstellar masers, pulsars, and who knows what next?

PHYSICS, MATHEMATICS AND ASTRONOMY

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The Caltech staff in astrophysics has grown greatly since the time that Fritz Zwicky and Joe Johnson, and maybe one other, were the only astronomers on our staff; but it still numbers less than ten people. Much of the astrophysics that Caltech has carried on has been in conjunction with the Carnegie Institution under the title Hale Observatories (which represents the Mt. Wilson and Palomar Observatories, Big Bear Solar Observatory, and eventually, probably CARSO—the southern station of the Carnegie Institution in Chile). Many of the things you read about—quasars, redshifts, deceleration parameters, cosmological constants, evolutionary effects, and things like that—come from Caltech and/or the Hale Observatories. Maarten Schmidt is on one side of a controversy that is now boiling about whether quasars are cosmological or relatively local. Nobody is sure. Some bits of evidence indicate one thing—other evidence indicates something else. It's nice that most of the people who worry about these questions, even though they're polarized, can remain friends about it. And it will eventually come out one way or another; people don't need to get personal about it. In the end, the universe will be like it is and not how we might wish it to be.

In the past 15 years Caltech has moved strongly into radio astronomy. We have a major (probably for universities, *the* major) radio observatory at Owens Valley. It has two dishes 90 feet in diameter and one 130 feet in diameter, and they are used to probe the structure of the many radio-wave-emitting sources out in the universe. Some of our people are participating in what is called VLBI experiments—very long base-line interferometry experiments. They find that some of the radio sources are changing in their angular size at such a rate that, if you interpret it as due to a velocity in the plane of the sky at the distance we think these sources are, we come out with speeds greater than the speed of light! Well, don't get worried; we don't believe it. But of course the science-fiction people jump right in and say: "We told you so."

Actually, much of the current research in the Kellogg Laboratory has to do with astrophysical questions, and much of the research that goes on elsewhere in the division is also directed toward astrophysics. The light-element nuclear physics that still goes on in Kellogg, with Van de Graf generators up to 10 or 12 million volts, is now directed toward understanding the processes by which stellar energy is generated. The cosmic production of the heavier elements is studied theoretically and to some extent experimentally at Kellogg. Our staff there has also taken the lead in the study of super-massive objects—elliptical galaxies, which often have radio sources in their centers. Our suspicion is that there's something at the center of those galaxies, down in the deep gravitational holes where matter can be held together in amounts greater than a star has. (A star just heats up in the middle, makes nuclear energy, and blows out the extra mass. But when you get inside a galaxy where matter is held in, maybe there can be objects quite unlike anything we can now imagine, with masses of tens or hundreds of millions of solar masses.) The laws of physics must be able to cope with these things; and if they can't, then we have to figure out what laws can cope with them.

One of the big questions in Kellogg right now is: Where are the neutrinos? Neutrinos should be coming out from the sun. There's a detector down in a deep mine in South Dakota somewhere, with several thousands of gallons of chlorinated cleaning fluid to intercept neutrinos from the sun. There should be about six solar neutrino units (SNU's they call them) coming through the detector. But the measurements are down to less than half a SNU, and the number could be zero. There's no evidence of any neutrinos at all coming from the sun. That's a big problem.

We're still doing great things in cosmic rays, and Robert Millikan would be very proud of us. Remember, he was worried about where they came from and whether they were the birth pangs of atoms. We're still worried about where they come from. We still send up balloons just as he did, but now we also send equipment out in spacecraft and make *in situ* experiments. I think it's marvelous that Millikan's cosmic rays are still "in it" as far as our research is concerned.

As you can guess from the size of the things I've been talking about, much of this research is federally sponsored; much of it, of necessity, goes on away from the Institute; and much of it involves large budgets, time delays, and lack of flexibility. I should emphasize the importance of relatively modest, but readily available, funding. If we had as much as 1 to 2 percent of the divisional budget available yearly so that we could take advantage of an unanticipated opportunity—or start an activity which would lead to major funding from other sources, it would be a fantastic help. Only 1 to 2 percent! It isn't there. But we would like to see it.