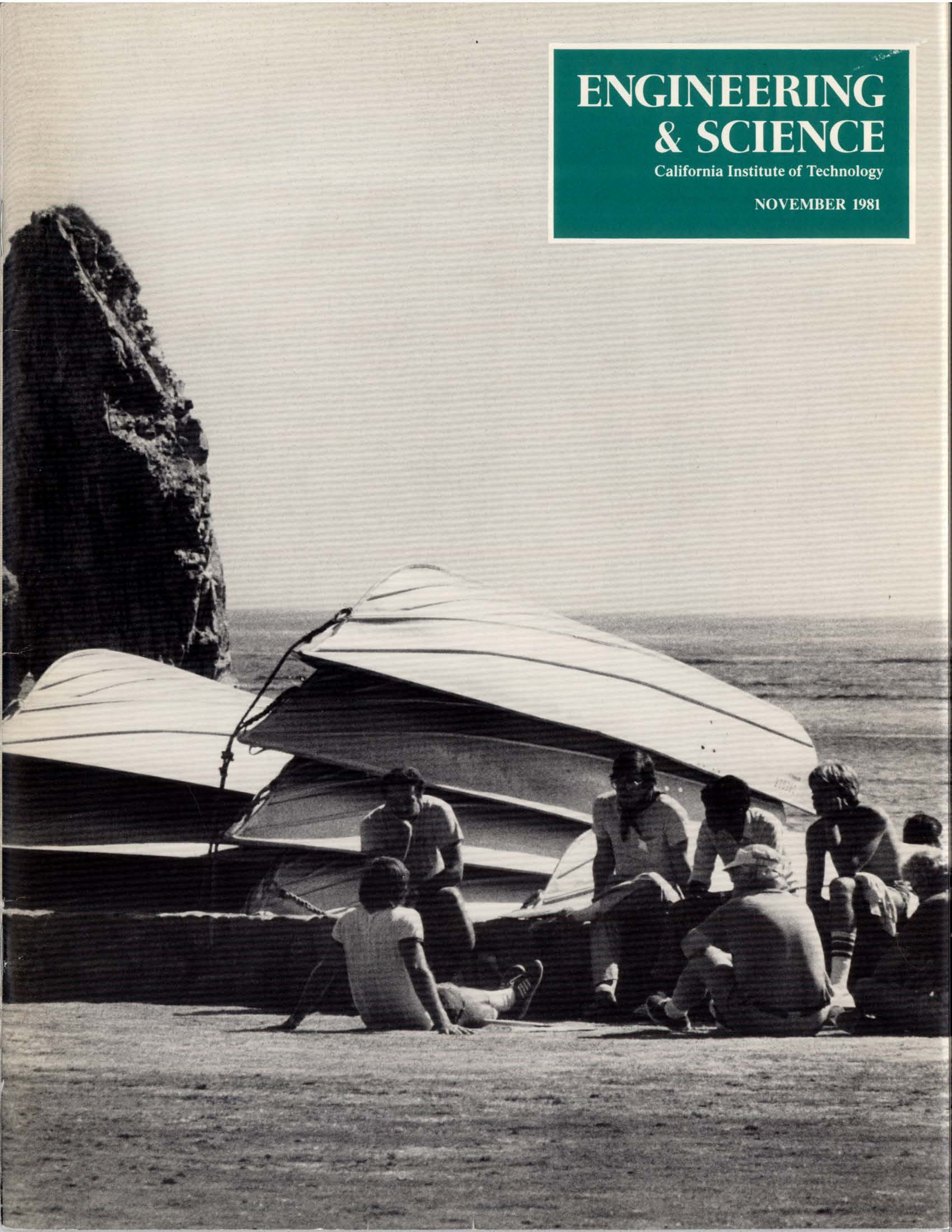
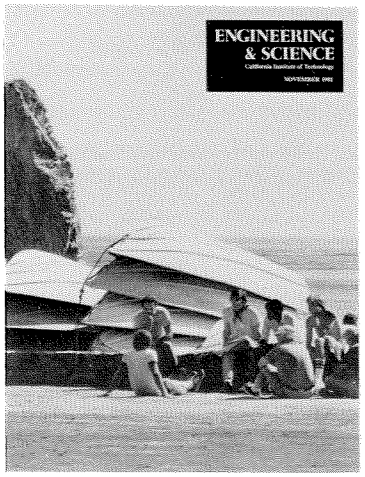
ENGINEERING & SCIENCE

California Institute of Technology

NOVEMBER 1981



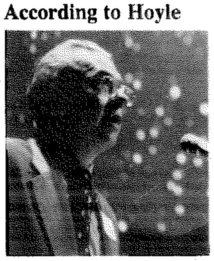
In This Issue



Catalina 1981

On the cover — one view of Freshman Camp, with boats, the beach, and people to get acquainted with. For more pictures, see "Camping In" on page 18.

According to Hoyle



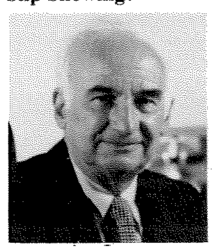
No stranger to controversy, Sir Fred Hoyle got his apology "out of the way right in the beginning" to those who he presumed would disagree with the views expressed in his Seminar Day address to the general session last May. That talk, "The Universe: Past and Present Reflections," a section of which (mostly the present reflections) is excerpted on page 8, did indeed present a daring and original view of the origin of life, one quite at odds with generally accepted theories. But this is the Hoyle style; his steady-state theory of cosmology has been exciting controversy ever since he proposed it in 1948.

No stranger to Caltech either, Hoyle first came here in 1952, has been here off and on ever since, and will be a visiting associate here again this year. It was with Institute Professor of Physics William A. Fowler that he developed the well-known theory on the origin and evolution of the chemical elements.

Hoyle's academic home for most of his distinguished career has been Cambridge University, where he founded and became the first director of the Institute of Theoretical Astronomy in 1967 and was Plumian Professor of Astronomy and Experimental Philosophy from 1958 to 1972. Currently he is associated with University College, Cardiff, Wales.

Hoyle was knighted in 1972 and has received the Gold Medal of the Royal Astronomical Society and the Royal Medal of the Royal Society among numerous other honors for his scholarship.

Slip Showing?



"The rapidity of technological advance — because of our inability to adjust to it, realize its benefits and minimize its negatives — is presenting us with dilemmas and critical choices." In "Gods' Gifts or Devils' Doings?" on page 13, Simon Ramo discusses those negatives and the anti-technology attitude they have bred — and the future benefits, which make it essential for the United States to maintain its strength in science and technology. The article is the introductory chapter to Ramo's latest book, *America's Technology Slip,* which goes on in subsequent chapters to offer some solutions to the dilemmas. It is reprinted here with permission of the publishers, John Wiley and Sons.

Ramo himself has played an active role in the rapid advance of American technology. With a PhD (EE 1936) from Caltech, he contributed to a number of research fields from microwaves to missiles before co-founding Ramo-Wooldridge Corporation in 1953. A subsequent merger with Thompson Products made the company, now known as TRW Inc., one of the world's largest technological corporations.

Although he "officially" retired in 1978, Ramo remains as director of TRW Inc. and chairman of the board of directors of The TRW-Fujitsu Company. He has been a Caltech trustee since 1964.

Mutual Interests

Paul J. Nahin is an associate professor of electrical and computer engineering at the University of New Hampshire. He is also a Caltech alumnus with a 1963 MS in electrical engineering (sandwiched by a BS from Stanford and a PhD from UC, Irvine). Nahin has worked for Beckman Instruments, Hughes Aircraft, General Dynamics, and the Institute for Defense Analyses; and he has taught at Harvey Mudd College and George Washington University. Currently he is on leave to the electronic warfare faculty at the Naval Postgraduate School in Monterey, California.

In addition to his academic activities, Nahin is a devotee and writer of science fiction and a freelance journalist. He was in Pasadena not long ago gathering material for an article about the Caltech football team (to appear soon in *Omni* magazine) and took a long-awaited opportunity to interview another Caltech alumnus, electrical engineer, and science fiction writer and fan. The result, "An Interview with John Pierce," is on page 22.

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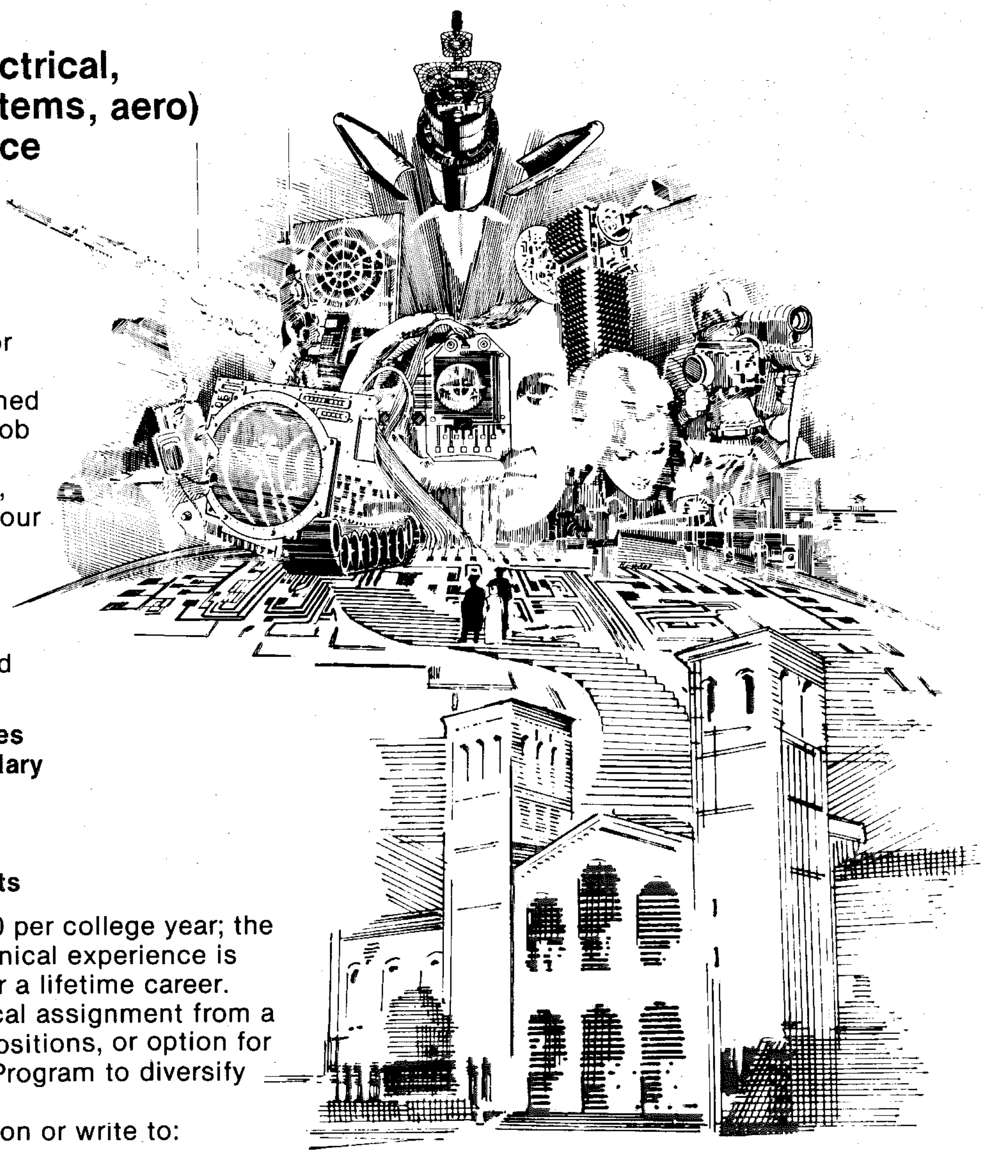

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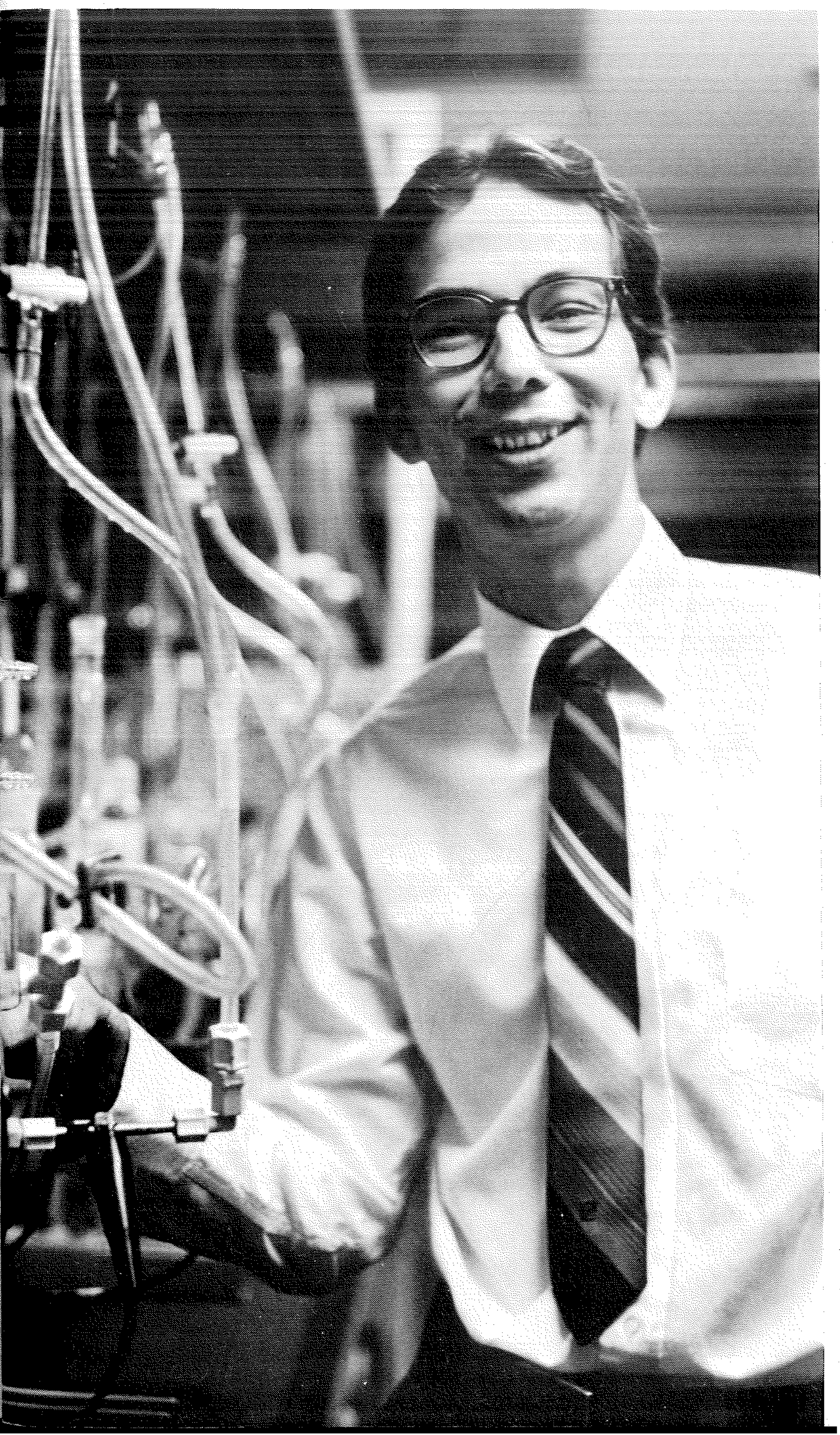

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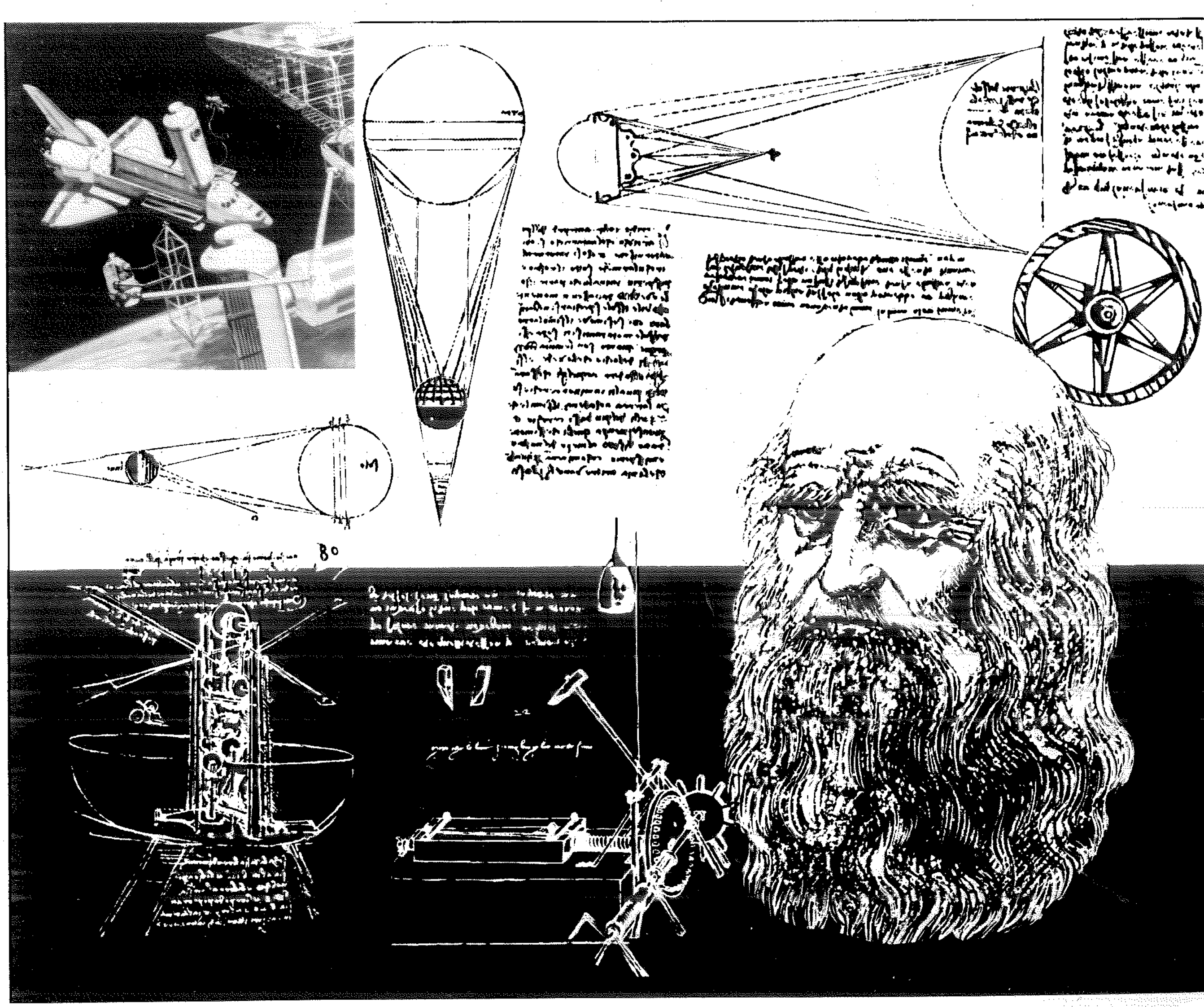

ALUMNI FLIGHTS ABROAD 1980–1981

This program of tours, originally planned for alumni of Harvard, Yale, Princeton, and M.I.T., is now open to alumni of California Institute of Technology as well as certain other distinguished colleges and universities. Begun in 1965 and now in its sixteenth year, it is designed for educated and intelligent travelers and planned for persons who might normally prefer to travel independently, visiting distant lands and regions where it is advantageous to travel as a group.

The program offers a wide choice of journeys to some of the most interesting and unusual parts of the world, including Japan and the Far East; Central Asia, from the Khyber Pass to the Taj Mahal and the Himalayas of Nepal; the surprising world of South India; the islands of the East, from Java and Sumatra to Borneo and Ceylon; the treasures of ancient Egypt, the world of antiquity in Greece and Asia Minor; East Africa and Islands of the Seychelles; New Guinea; the South Pacific; the Galapagos and South America; and more.

REALMS OF ANTIQUITY: A newly- expanded program of itineraries, ranging from 15 to 35 days, offers an even wider range of the archaeological treasures of classical antiquity in Greece, Asia Minor and the Aegean, as well as the ancient Greek cities on the island of Sicily, the ruins of Carthage and Roman cities of North Africa, and a comprehensive and authoritative survey of the civilization of ancient Egypt, along the Nile Valley from Cairo and Meidum as far as Abu Simbel near the border of the Sudan. This is one of the most complete and far-ranging programs ever offered to the civilizations and cities of the ancient world, including sites such as Aphrodisias, Didyma, Aspendos, Miletus and the Hittite citadel of Hattusas, as well as Athens, Troy, Mycenae, Pergamum, Crete and a host of other cities and islands of classical antiquity. The programs in Egypt offer an unusually comprehensive and perceptive view of the civilization of ancient Egypt and the antiquities of the Nile Valley, and include as well a visit to the collection of Egyptian antiquities in the British Museum in London, with the Rosetta Stone.

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EAST AFRICA—KENYA, TANZANIA AND THE SEYCHELLES: A distinctive program of 5 outstanding safaris, ranging in length from 16 to 32 days, to the great wilderness areas of Kenya and Tanzania and to the beautiful islands of the Seychelles. The safari programs are carefully planned and comprehensive and are led by experts on East African wildlife, offering an exceptional opportunity to see and photograph the wildlife of Africa.

THE SOUTH PACIFIC and NEW GUINEA: A primitive and beautiful land unfolds in the 22-day EXPEDITION TO NEW GUINEA, a rare glimpse into a vanishing world of Stone Age tribes and customs. Includes the famous Highlands of New Guinea, with Sing Sings and tribal cultures and customs, and an exploration of the remote tribal villages of the Sepik and Karawari Rivers and the vast Sepik Plain, as well as the North Coast at Madang and Wewak and the beautiful volcanic island of New Britain with the Baining Fire Dancers. To the south, the island continent of Australia and the islands of New Zealand are covered by the SOUTH PACIFIC, 28 days, unfolding a world of Maori villages, boiling geysers, fiords and snow-capped mountains, ski plane flights over glacier snows, jet boat rides, sheep ranches, penguins, the Australian "outback," historic convict settlements from the days of Charles Dickens, and the Great Barrier Reef. Optional visits can also be made to other islands of the southern Pacific, such as Fiji and Tahiti.

CENTRAL ASIA and THE HIMALAYAS: An expanded program of three itineraries, from 24 to 29 days, explores north and central India and the romantic world of the Moghul Empire, the interesting and surprising world of south India, the remote mountain kingdom of Nepal, and the untamed Northwest Frontier at Peshawar and the Punjab in Pakistan. Includes the Khyber Pass, towering Moghul forts, intricately sculptured temples, lavish palaces, historic gardens, the teeming banks of the Ganges, holy cities and picturesque villages, and the splendor of the Taj Mahal, as well as tropical lagoons and canals, ancient Portuguese churches, the snow-capped peaks of the Himalayas along the roof of the world, and hotels which once were palaces of maharajas.

THE FAR EAST: Itineraries which offer a penetrating insight into the lands and islands of the East. THE ORIENT, 30 days, surveys the treasures of ancient and modern Japan, with Kyoto, Nara, Ise-Shima, Kamakura, Nikko, the Fuji-Hakone National Park, and Tokyo. Also included are the important cities of Southeast Asia, from Singapore and Hong Kong to the temples of Bangkok and the island of Bali. A different and unusual perspective is offered in BEYOND THE JAVA SEA, 34 days, a journey through the tropics of the Far East from Manila and the island fortress of Corregidor to headhunter villages in the jungle of Borneo, the ancient civilizations of Ceylon, Batak tribal villages in Sumatra, the tropical island of Penang, and ancient temples in Java and Bali.

Prices range from $2,350 to $4,500 from U.S. points of departure. Air travel is on regularly scheduled flights of major airlines, utilizing reduced fares which save up to $600.00 and more over normal fares. Fully descriptive brochures are available, giving itineraries in detail and listing departure dates, hotels, individual tour rates and other information. For full details contact:

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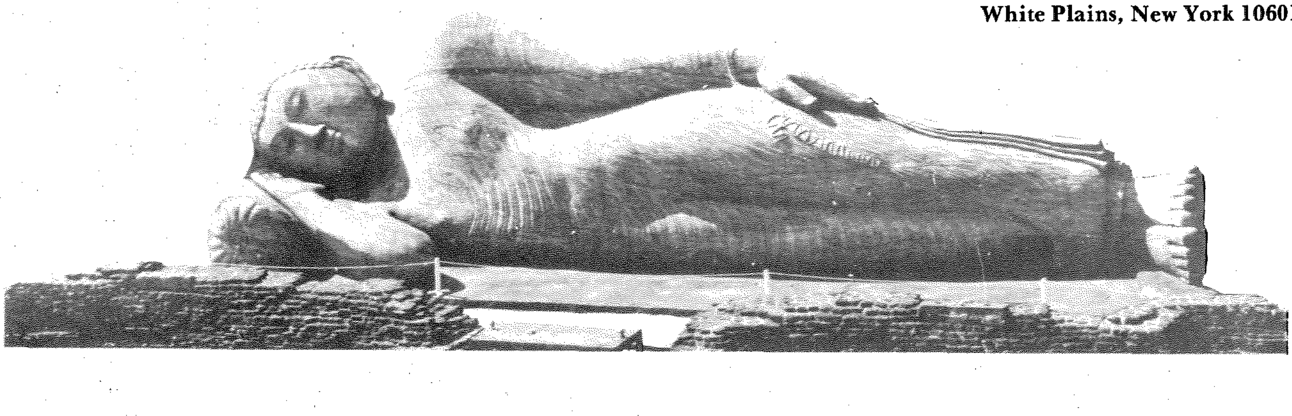
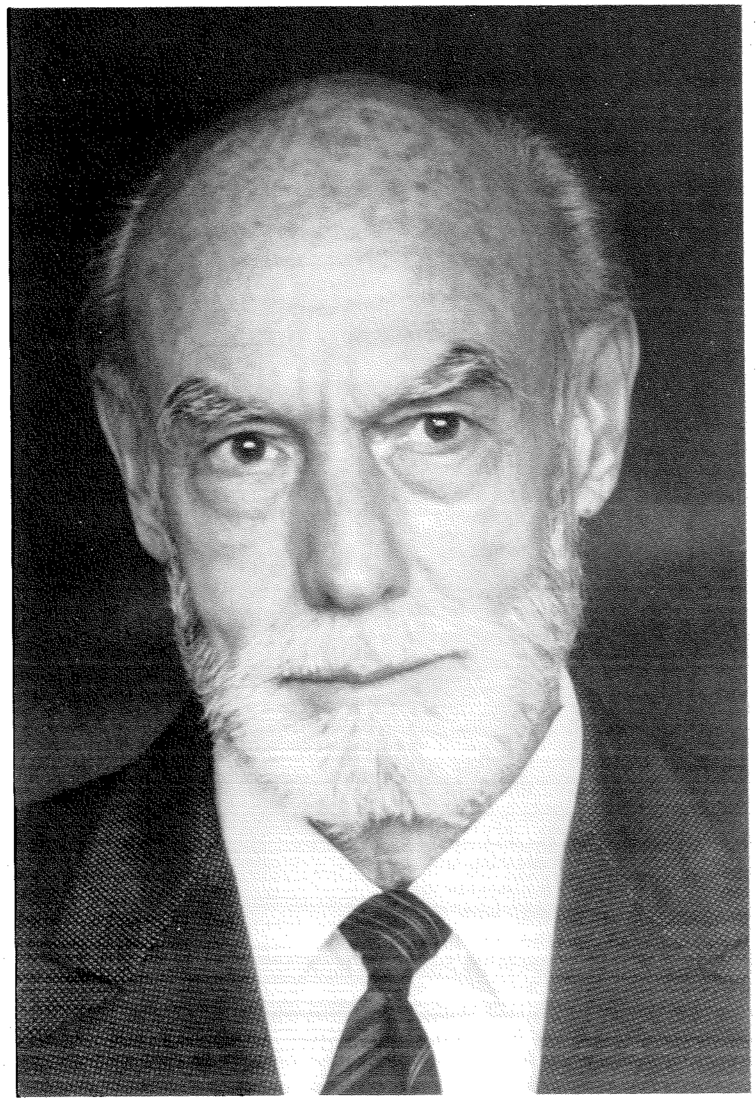




Roger Wolcott Sperry

Nobel Laureate 1981

On October 9 Roger Wolcott Sperry, Caltech's Hixon Professor of Psychobiology, was awarded the 1981 Nobel Prize in Physiology or Medicine for his discoveries concerning "functional specialization of the cerebral hemispheres." His work with split-brain patients, whose nerve fibers connecting the halves of the brain had been surgically severed, provided evidence that each brain half has its own perception, memory, and consciousness. Each hemisphere has its own character and function — the left half being verbal and mathematical and dealing with analytic and sequential reasoning, while the right half is spatial, conceptual, mute, and specializes in visualization and creativity. Sperry's research has shown that the functions of the right hemisphere are as important as those of the left, which had long been thought dominant. The greater understanding of the brain resulting from his work has relevance to education and philosophy as well as medicine.

Sperry's general field of behavioral biology (much less psychobiology) did not exist at Caltech in 1938 when Mrs. Frank P. Hixon established a fund in her husband's memory for studies of "salient and fundamental biology directly concerned with human behavior." Although she had been uncertain that money given to Caltech for her original purpose of "the correlation of mental or spiritual training with the scientific" would be fruitful, Mrs. Hixon was persuaded by Max Mason, then a member of the Caltech Executive Council. He wrote her that "this unique place" was just the right one to pursue fundamental *scientific* knowledge of behavior — that in the long run it was most promising to direct "the great forces of natural science into the new science of Man." Mason's foresight was confirmed when in 1954 a faculty committee headed by George Beadle brought Roger Sperry to the Institute to occupy the Hixon chair.

Sperry brought an already substantial reputation with him. Born in Hartford, Connecticut, in 1913, he attended Oberlin College (which also produced Robert A. Millikan, Caltech's first Nobel Prizewinner) where he was captain of the basketball team and also played varsity baseball, football, and track. He was quoted at the time he entered college as hoping to specialize in some area of science or medicine if he could find something of sufficient interest. He received his BA (English) from Oberlin in 1935 and MA (psychology) in 1937. In 1941 he earned his PhD in zoology from the University of Chicago, also another way station in Millikan's career. Sperry spent a year as a National Research Council Fellow in biology at Harvard and from 1942 to 1946 was a research associate at the Yerkes Laboratories of Primate Biology. During the war he also served as consultant to a government research project on the surgical repair of nerve injuries. He returned to the University of Chicago as assistant professor of neuroanatomy in 1946 and became associate professor of psychology there in 1952. In

1952-53 he also held a joint appointment at the National Institutes of Health as section chief for neurological diseases and blindness before his research attracted the attention of the Caltech committee looking for someone who fit both the Hixon description and Caltech's demands.

At Oberlin he had been a graduate assistant to R. H. Stetson, an international authority on the physiology of speech, who emphasized the biological aspects of psychology. Sperry's earliest publications in psychology were concerned with muscle coordination. Other early research dealt with the plasticity of the brain and functional recovery after injury to the nervous system. With experiments in nerve transplants in lower organisms he disproved the long-held theory that nerves are interchangeable and can learn new functions. He studied the developmental patterning of brain pathways, in which he demonstrated that neural networks are prewired according to a strict, genetically transmitted mapping system that is not subject to functional influence. Behavior (in the sense of visual perception) was shown to correlate precisely with these patterns of nerve connection. To explain these prewired networks Sperry developed the theory that growing nerve fibers are chemically "labeled" early in development and form connections with each other by recognizing complementary labels on their surfaces.

In the mid-1940s his interest turned to the organization of the mammalian brain, and he adapted to cats and monkeys the delicate microsurgical techniques he had developed earlier to study amphibian brains. With graduate student Ronald Myers, Sperry, now at Caltech, grew particularly interested in the corpus callosum, a cable of 200 million nerve fibers connecting the two halves of the brain. The function of this cable was unknown until Sperry and Myers began their experiments on the possible role of the corpus callosum in transferring information from one hemisphere to another in the brain of a cat. With their corpus callosa surgically split, cats trained to respond to information shown to one eye did not react when the image appeared only to the other eye. The corpus callosum apparently transferred at least visual information from one hemisphere to another. Subsequent experiments revealed an even more extensive function.

In humans it was thought that epileptic seizures traveled across the corpus callosum from one half of the brain to the other. Adapting Sperry's microsurgical techniques still further, Drs. Joseph E. Bogen and Philip J. Vogel succeeded in limiting the seizures of acutely debilitated epilepsy patients by severing the connecting cable between the hemispheres. Sperry's subtle experiments with these split-brain patients, who seemed in most respects to function perfectly normally, led to the dramatic demonstrations that the two brain hemispheres in humans are distinctly different.

Over the past two decades Sperry's group has tested many split-brain patients. Differences in understanding and response from the two unconnected sides of the brain to visual, aural, and tactile clues disclosed the astonishing dissimilarities that are now well known. Continuing investigations have shown that the right side does have some language ability; implications of right- and left-handedness, as well as differences in thinking between the sexes, have also emerged from the research.

Sperry's work has attracted the interest of popularizers, and "left-brain" and "right-brain" have become common even to schoolchildren's vocabularies. Sperry finds this more amusing than troublesome, say his colleagues. He's an interesting teacher but prefers small lectures and is not a showman in class. Though a number of graduate students have worked in his laboratory, he does not work with large teams and is basically an individual researcher. It is characteristic that, when the Nobel Prize was announced, Sperry and his wife were camping and fishing in a remote part of Baja California and could not be reached for several days. The announcement, when it reached him, cannot have been too big a surprise, however; among his dozens of honors and awards, two years ago he received the Wolf Prize in Medicine and the Albert Lasker Basic Medical Research Award, which is often considered the harbinger of a Nobel.

In recent years he has turned more and more toward writing on the mind-brain relationship and the role of consciousness (and free will), which he perceives to have evolved as a directive and causal force in brain function. The unifying, functional role of subjective experience, according to Sperry, brings ethical values into the domain of science. He wrote this year in the *Annual Review of Neuroscience*:

> Ideologies, philosophies, religious doctrines, world-models, value systems, and the like will stand or fall depending on the kinds of answers that brain research eventually reveals. It all comes together in the brain.

In 1968, 30 years after her original gift to Caltech, Mrs. Hixon wrote that Roger Sperry's work was leading exactly toward the goal she had hoped the Hixon fund might reach — "a knowledge of the 'why' in human behavior."□ *–J.D.*

The Universe: Past and Present Reflections

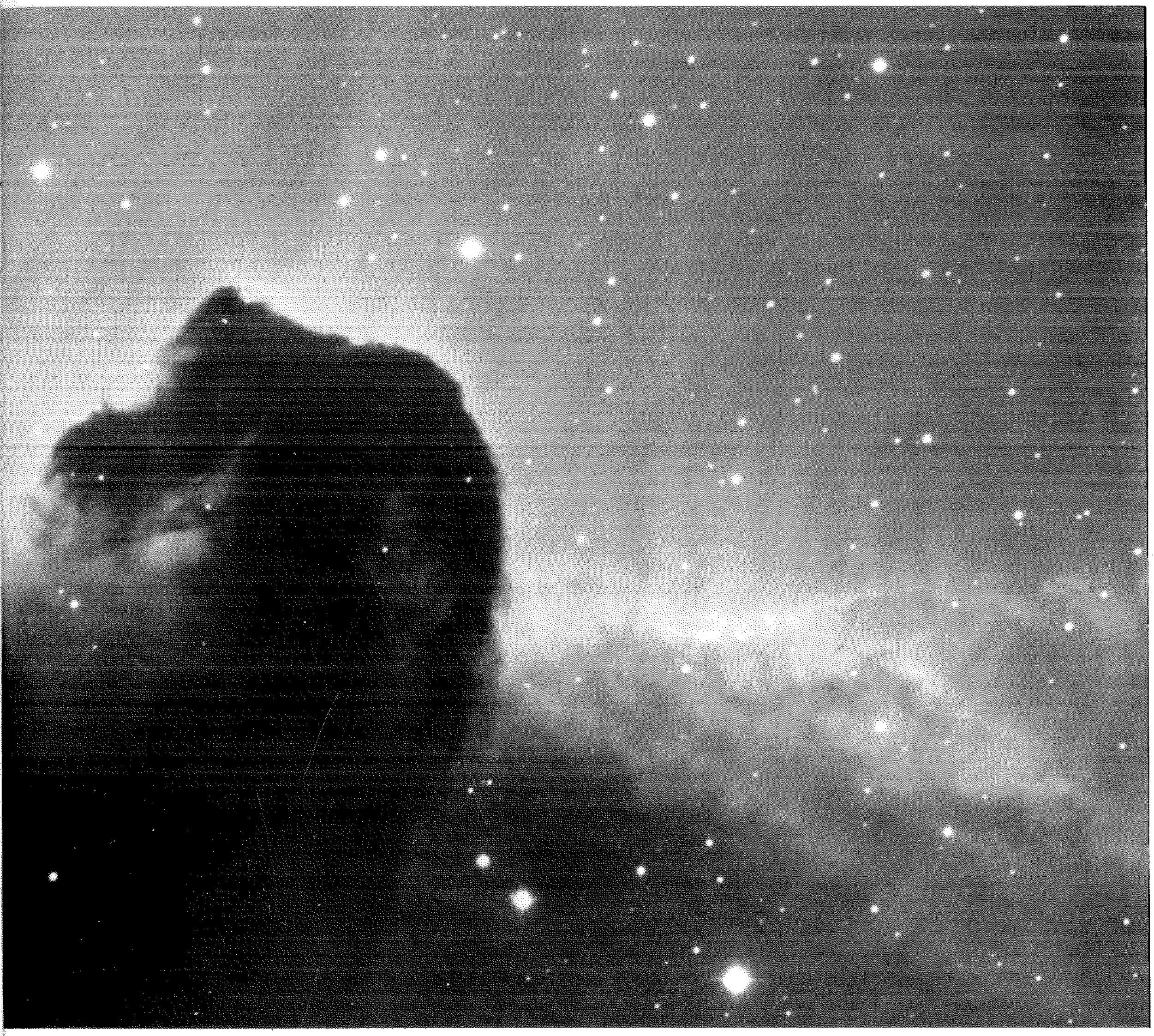
by Sir Fred Hoyle

DEFINING the universe to be everything there is, manifestly we cannot be expected to understand it exactly, since to do so we would need both a complete command of the laws of physics and the fantastic calculating power to work through the detailed properties of assemblies containing very large numbers of particles. What then are astronomers doing in their studies of cosmology? Obviously, we are beavering away to give an imperfect answer to an imperfectly defined problem. The issue is the quality or otherwise of our approximations. I suppose nine astronomers out of ten work on the presumption that our approximations are quite meritoriously good. In this essay I shall presume to hint that it may be otherwise.

The nebulosity of nebulae, for example, is due to small particles, or grains, which act to produce a fogging of the distant light. In fact, sometimes the fogging is so extreme that we don't see the stars that lie behind the nebulosity. Sometimes this fogging effect produces apparent rifts that are really due to the material of the grains blocking out the light of the stars that lie behind. Measurements of the properties of the grains indicate that they are remarkably similar in their physical properties, in their sizes. Whatever observations are being made, they always seem to turn out the same.

The problem of the nature of these grains began for me in a very innocent way but ended in unexpected results. In the 1950s, when I was much of the time here at Caltech, astronomers believed the interstellar grains to be water ice. Nothing at all was riding on this issue for me, and I would gladly have accepted the conventional point of view if calculation had shown it to be viable. The trouble was that interstellar grains are constantly changing their positions in relation to the stars. Even the briefest exposure of a water-ice grain to a temperature no higher than $-150°$ C will cause it to evaporate. I didn't find in my calculations that, once evaporated, water-ice grains would recondense by themselves under any conditions that seemed plausible. I chanced on this difficulty as long ago as 1955 thinking then that the grains must consist of some more refractory substance than ice as, for instance, graphite. But the matter rested so lightly with me that I did nothing more about it until some five years later when I had a graduate student, named Chandra Wickramasinghe, in need of a problem.

It was an encouraging indication that there might be something right about the idea when it turned out that the physical properties of graphite happened to be such as would give a reasonable approximation to the observed fogging that the grains produce in the visual light of distant stars. Furthermore, the behavior of the physical properties with respect to frequency, to wavelength, enabled us to predict that graphite would produce enormous fogging in an ultraviolet waveband cen-



The fogging effect in nebulae – as shown in this photograph of the Horsehead Nebula in Orion in our own galaxy – is due to small particles, or grains. On the following page the same effect can be seen in the central region of the galaxy M33, much farther away. Measurements of interstellar grains show them to be remarkably similar in physical properties regardless of where they are observed. Both of these photographs are from the 200-inch Hale telescope at Caltech's Palomar Observatory.

tered at about 2000 angstroms. When this predicted large extinction was actually discovered about a year later from rocket firings, it seemed certain that there really must be something right with the graphite idea. However, it's one of the incorrigible features of science that, whenever you have a theory that appears at first to be correct, you eventually find trouble in fitting all the other details that come along subsequently. And so it was with our graphite particles.

By 1965 enough was known of the reflectivity of interstellar grains for us to see that the reflectivity of graphite was too low. Graphite was too absorptive, too black. It seemed therefore that, while there was something right about graphite, the graphite theory could not be all right.

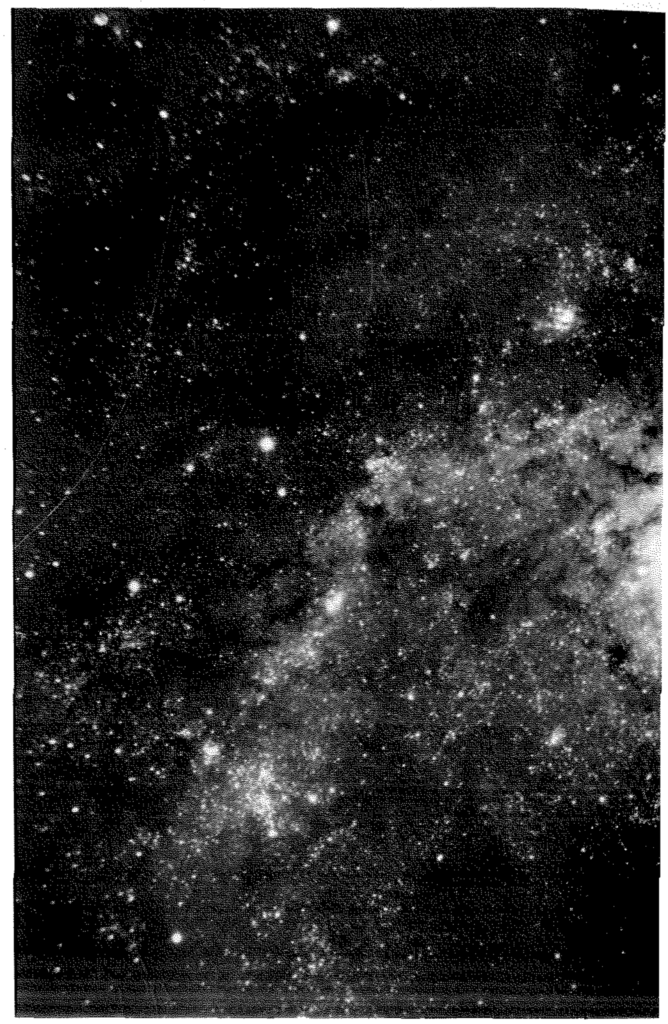
The next step was to try a composite model for the particles, a model with graphite cores and water-ice mantles. This composite core-mantle theory was a parameter-fitting enthusiast's delight. The shapes and sizes of the particles could be varied, as well as the relative proportions of graphite and ice. With so many parameters available, a moderate correspondence with all the data was inevitable and could not therefore be considered much of an achievement. The important thing was to obtain a really good correspondence with the data, and this holy grail eluded us with maddening persistence. Starting from a moderate agreement with all the data, we would tune up the parameters to get some particular feature almost exactly right, only to find the correspondence with the rest of the data had become worse. Gradually it was borne in on us that we had a wrong theory on our hands.

So it came about that in the later 1960s we began thinking of what other kinds of particle there might be. We tried metals and silicates as well as graphite. However, by 1970 the total quantity of interstellar gas had become quite accurately known. Supposing all the refractory material, such as magnesium oxide, silica, calcium oxide, and iron to become condensed out of the gas into grains, one could calculate that the amount of the grains was insufficient to explain the observed degree of fogging of starlight by a factor of about three. And then only if the sizes of the grains were chosen to give maximum opacity. Because this maximum opacity condition was quite unlikely to be satisfied everywhere throughout our galaxy, the prudent conclusion was that the amount of metals and of magnesium aluminum silicates was in deficit by a factor of at least five.

This result forced the conclusion that the grains have to be composed of elements with cosmic abundances an order of magnitude greater than magnesium, aluminum, silicon, and iron. It forced the conclusion that the mass of the grains had to come largely from carbon, nitrogen, and oxygen. But since by now we were fully convinced that the graphite-water ice mixture couldn't be correct, what otherwise could the grains be? All inorganic solids built from carbon, nitrogen, and oxygen, perhaps together with hydrogen, could easily be seen to evaporate much too readily. So with an initial sense of bewilderment, Wickramasinghe and I reached the conclusion that the grains had to be made up largely of organic material.

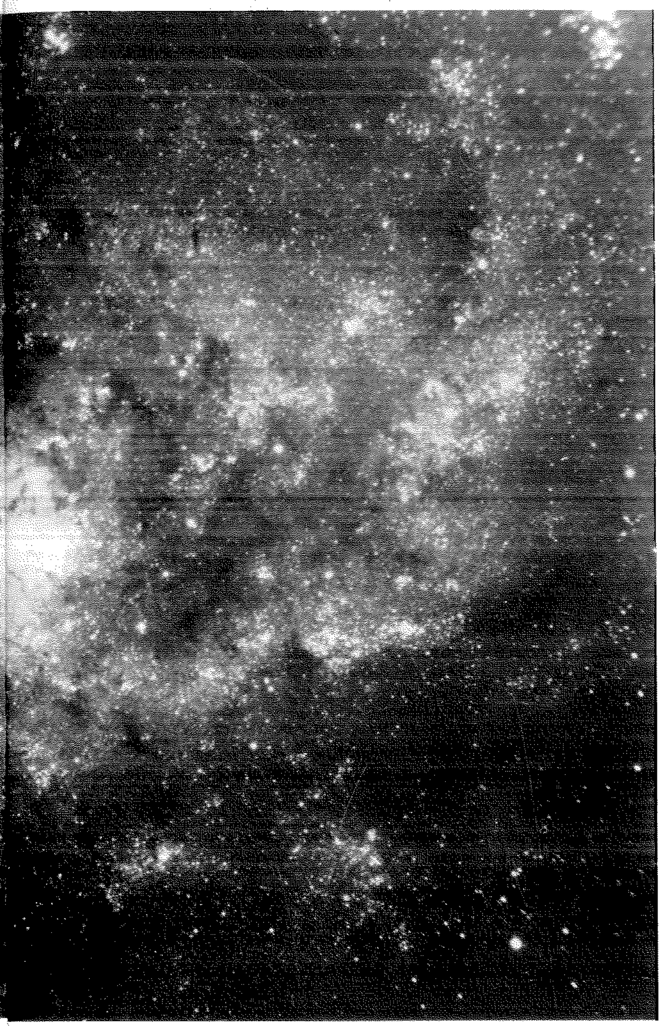
An interesting question forced itself on our attention. With the realization that the interstellar grains are largely organic, one sees that the material of the early solar system must have contained an enormous quantity of organics, at least 3000 earth masses of it. Much organic material would be destroyed by the heat of the solar nebula, but much would survive in the comparatively cool outer regions of the solar system, especially in the regions of the distant comets. And since at subsequent times a fraction of comets have developed orbits of high eccentricity, bringing them to the inner regions of the solar system with a part of the material that is constantly evaporating from them enmeshing the terrestrial atmosphere, there was a known process for transferring organic materials from the outer distant regions of the solar system to the earth. Could this potentially very large and still continuing source of organic material have formed the basis for the origin of life rather than the comparatively tiny quantity of organics generated in terrestrial thunderstorms and other purely local events?

Wickramasinghe and I answered this question affirmatively, and so we arrived at a temporary equilibrium point in our thinking: The organic basis of life was interstellar, a position that some others I think are favoring nowadays. It was at



this stage that we began our technical readings in biology, fully expecting the usual picture of the terrestrial origin and evolution of life to be amply confirmed by the facts.

But this first resting point did not survive those early readings, as it was quickly apparent that the facts point overwhelmingly against life being of terrestrial origin. Although we were quite released from what I now regard as a conceptual millstone, my own brain made no profound leap toward freedom. It just plodded its way, small step by small step, first to the comets. Because comets must have experienced break-up and reformation with material interchanged between them, and because the material would be organic, in our view, it was possible to think of the whole ensemble of comets, many billions of them, as a life-generating unit. And because a few comets are breaking up and scattering their contents all the time, the process was not relegated to the remote past. This was a big plus mark, since theories that relate to current events stand in my view much above those that are concerned only with situations that are long dead and done



with. There was therefore much of interest to be worked through in this first shift from the earth to comets, and the investigation of a number of side issues deluded us for a while into thinking that the main problem — the origin of life — had been faced.

The big problem in biology, as I see it, is to understand the origin of the information carried by the explicit structures of biomolecules. The issue isn't so much the rather crude fact that a protein consists of a chain of amino acids linked together in a certain way, but that the explicit ordering of the amino acids endows the chain with remarkable properties, which other orderings wouldn't give. The case of the enzymes is well known. Enzymes act as catalysts in speeding up chemical reactions that would otherwise go far too slowly, as in the breakdown, for example, of starch into sugar. If amino acids were linked at random, there would be a vast number of arrangements that would be useless in serving the purposes of a living cell. When you consider that a typical enzyme has a chain of perhaps 200 links and that there are 20 possibilities for each link, it's easy to see that the number of useless arrangements is enormous, more than the number of atoms in all the galaxies visible in the largest telescopes. This is for one enzyme, and there are upwards of 2000 of them, mainly serving very different purposes. So how did the situation get to where we find it to be? This is, as I see it, the biological problem — the information problem.

It's easy to frame a deceitful answer to it. Start with much simpler, much smaller enzymes, which are sufficiently elementary to be discoverable by chance; then let evolution in some chemical environment cause the simple enzymes to change gradually into the complex ones we have today. The deceit here comes from omitting to explain what is in the environment that causes such an evolution. The improbability of finding the appropriate orderings of amino acids is simply being concealed in the behavior of the environment if one uses that style of argument.

As this enormous problem gradually dawned on us, we thought to transfer the origin of life from the comets of our own solar system to all the other star systems of our galaxy. In going from the earth to the comets we gained in scope by perhaps a factor of a million. And in going from the comets to the whole galaxy we gained a further factor of 100,000 million — which satisfied us for awhile. This was a transposition into biology of a diagram that William Fowler [Institute Professor of Physics] and I drew together many years ago to illustrate the origin and evolution of the chemical elements.

Returning to the problem of the organic nature of the interstellar grains, the question now suggested itself — could the grains be living cells together with the decay products of living cells? An entirely preposterous question on the face of it, but one that could be tested immediately. Apart from graphite particles, which are known from observations to have sizes of a few hundred angstroms, the other interstellar grains must have sizes mainly centered at about .7 of a micron. This again is a requirement demanded by the astronomical observations. And this is precisely the size of the most numerous kind of living cell — bacteria. Moreover, the grains are known to be remarkably similar over the whole galaxy, and it's the outstanding property of biological systems that they are reproducible. Inorganic grains are without any strong size-determining property.

In calculating the fogging effect that would be produced by the normal size distribution of bacteria and degradation products, the correspondence to observations is remarkable. Unlike the complex and unsatisfactory calculations we made in the 1960s, we obtained an almost perfect result in only a couple of days. Einstein is reported to have remarked that while God may be subtle, he is not malicious. If grains aren't organic with connections to living cells, it would certainly be incorrigibly malicious to have given us this excellent result with a wrong theory coming after a long history of poor results with the right theory.

The potentiality of a cosmic system of life was so enormous compared to an earth-bound system that it was possible to rest content with the situation for awhile. But eventually I came to wonder if the potentiality of even a cosmic system was really big enough. In thinking about this question I was constantly plagued by the thought that the number of ways in which even a single enzyme could be wrongly constructed was greater than the number of all the atoms in the universe. So try as I would, I couldn't convince myself that even the whole universe would be sufficient to find life by random processes — by what are called the blind forces of nature. The thought occurred to me one day that the human chemical industry doesn't chance on its products by throwing chemicals at random into a stewpot. To suggest to the research department at DuPont that it should proceed in such a fashion would be thought ridiculous.

Wasn't it even more ridiculous to suppose that the vastly more complicated systems of biology had been obtained by throwing chemicals at random into a wildly chaotic astronomical stewpot? By far the simplest way to arrive at the correct sequences of amino acids in the enzymes would be by thought, not by random processes. And given a knowledge of the appropriate ordering of amino acids, it would need only a slightly superhuman chemist to construct the enzymes with 100 percent accuracy. It would need a somewhat more superhuman scientist, again given the appropriate instructions, to assemble it himself, but not a level of scale outside our comprehension. Rather than accept the fantastically small probability of life having arisen through the blind forces of nature, it seemed better to suppose that the origin of life was a deliberate intellectual act. By "better" I mean less likely to be wrong.

Suppose a spaceship approaches the earth, but not close enough for the spaceship's imaginary inhabitants to distinguish individual terrestrial animals. They do see growing crops, roads, bridges, however, and a debate ensues. Are these chance formations or are they the products of an intelligence?

Taking the view, palatable to most ordinary folk but exceedingly unpalatable to scientists, that there is an enormous intelligence abroad in the universe, it becomes necessary to write blind forces out of astronomy. Interstellar grains, living cells, are to be regarded as purposeful tools, every bit as purposeful, if you like, as a garden spade. We know from astronomical studies that the grains are mysteriously connected with a whole range of phenomena: the rate of condensation of stars; the mass function of stars; magnetic fields; spiral arms of galaxies; and quite probably with the formation of planetary systems. Not one of these phenomena has been explained by astronomers in better than fuzzy terms, just as the views of the imaginary travelers in the spaceship would be fuzzy if they attempted to explain terrestrial fields, walls, and ditches as products of the blind forces of nature.

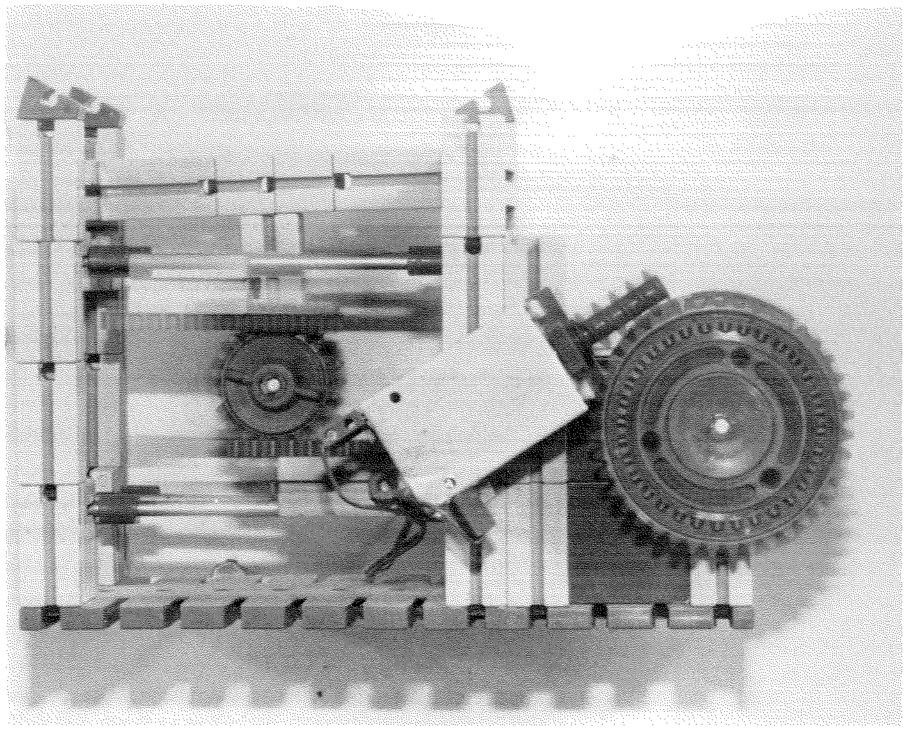
It would be necessary to calculate in full detail the properties of complex biopolymers in order to obtain the information required for the construction of a living cell. Such a project would be quite beyond our practical ability, but not beyond our comprehension. Indeed we are nearer to understanding what would be involved in it than a dog is to understanding the construction of a power station.

Now imagine yourself as a superintellect working through possibilities in polymer chemistry. Would you not be astonished that polymers based on the carbon atom turned out in your calculations to have the remarkable properties of the enzymes and other biomolecules? Would you not be bowled over in surprise to find that a living cell was a feasible construct? Would you not say to yourself, in whatever language supercalculating intellects use: Some supercalculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be utterly minuscule. Of course you would, and if you were a sensible superintellect you would conclude that the carbon atom is a fix.

From 1953 onward, Fowler and I have been intrigued by the remarkable relation of the 7.65 MeV energy level in the nucleus of ^{12}C to the 7.12 MeV level in ^{16}O. If you wanted to produce carbon and oxygen in roughly equal quantities by stellar nucleosynthesis, these are just the two levels you would have to fix, and your fixing would have to be just about where these levels are actually found to be. Is that another put-up, artificial job? Following the above argument, I am inclined to think so. A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question. □

Gods' Gifts or Devils' Doings?

by Simon Ramo



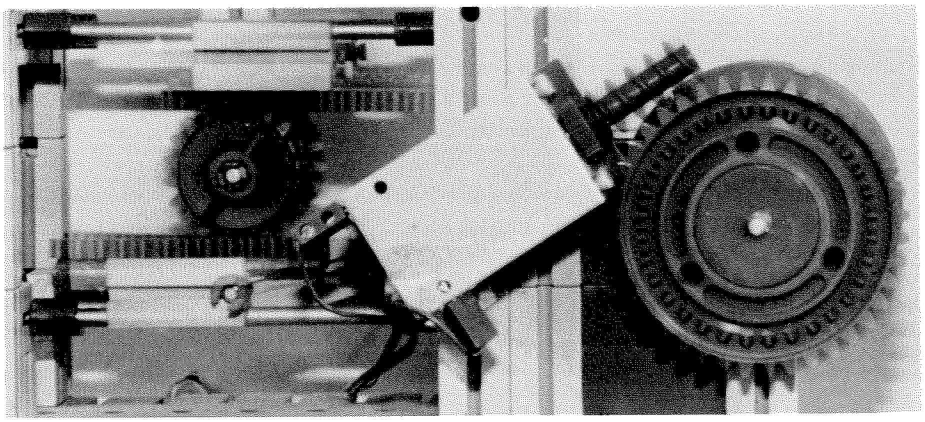
THE HUMAN species has not changed significantly in many thousands of years. No basic alterations have occurred in the inherent designs of the body and brain. If a live baby from 100 centuries ago could be deposited with a similarly rooted family of today, that child might grow up to be shorter in physical stature than the average or have a different susceptibility to certain diseases, but otherwise would exhibit little more deviation from the rest of the community than many of its members would show from each other.

The societies of humans, their organizations for ensuring survival and providing satisfactions, have been modified over the period of deducible history, but not because of changes in *Homo sapiens*. Social variations have resulted from people's accumulation of experience and knowledge about the physical universe and themselves, and from the use to which they have put this learning. Indeed, the know-how that human beings have accumulated up to the present moment can be described, with only mild fear of oversimplifying, by the words "science and technology." There has been disappointingly little progress in fundamental social dimensions.

Is the democracy of today's world more advanced than that of the ancient Greeks? Probably — in some ways. Yet, what about this century's ruthless dictatorships, the tribal wars fought in the midst of starvation, the repressive and inhumane acts inflicted by many existing governments on their own people? Brutality, fear, hatred, jealousy, distrust of the "other tribe" — these characteristics are discernible even among so-called educated and refined humans. Antisocial responses are inadequately contained by the thin veneer of accumulated behavioral advance; with provocation that need not be severe, they can quickly break out.

Thus it was only forty years ago that a major European nation, one highly developed technologically but not in all ways socially, committed mass genocidal horrors. More recently we could observe that after a mere half-hour of psychological pressure some automobile drivers in America, in disputes over their places in line while waiting to purchase gasoline, drew pistols and shot at each other. Speaking more broadly, we can hardly focus better on the limited social progress of humankind than with a contrast of two facts. First, we learned what atoms are made of and invented how to release such enormous amounts of energy from manipulating their constituents that it has become possible to wipe out most of the earth's population 30 minutes after a decision to do so. Second, we have not been able to follow this technological breakthrough, even decades later, with a degree of social progress that would preclude the possibility of such a catastrophe.

If 100 years ago, a thoughtful visionary group had gathered to conjure up a list of future human achievements to be prized as valuable and inspir-



ing, they might have included among others a specific pair: the ability to walk on the moon and permanent peace on earth. To the wiser of those engaged in the discussion, both feats might have appeared overly imaginative and impractical — conceivably realizable, but only a long, long time in the future. Startlingly, we have accomplished one. Not so startlingly, the other still remains as before: conceivably realizable, but only a long, long time in the future.

But if the species has changed physically hardly at all and the allowed behavior of humans, singly and in tribes, has been refined only slightly over a thousand generations, our knowledge of the environment, of the anatomy of our bodies, and of the means to put resources to work for our health, material needs, and comforts has recently exploded. In the past two centuries, our skills and tools have advanced more than in all the millions of preceding years. The first scientific list of the known elements was published by Lavoisier less than 200 years ago. His list included about 20 and, building on his giant step in understanding the basic nature of matter, scientists quickly added recognition of more chemical elements so they now number over 100. Throughout all of earlier recorded history, however, matter was thought to be made up of combinations of four elements: air, earth, water, and fire.

The changes that have occurred during recent centuries in the organizational and behavioral aspects of human society are almost entirely caused by the burgeoning of practical know-how. People and materiel can now be moved in hours from any point of the globe to any other. Electronics can keep the nations of the entire earth in instantaneous communication. We feed, move, inform, entertain, clothe, heal, and kill each other by means that did not exist two centuries ago. Divide the peoples of the world into two groups, one in which science and technology flourish, and the other in which the scientific approach is unknown and no wide employment of technological know-how takes place, and the societal differences between the two groups will be profound, more significant than the greatest of their dissimilarities owing to race, religion, or geographic location.

Imagine that we were to draw three curves, with time the abscissa for each, stretching over, say, 100,000 years. The ordinate of the first curve is to depict change in the basic makeup of the human species. We would see the curve as virtually flat, the alterations perhaps discernible to a minute degree only by the most expert biologists and anthropologists. The second curve is to measure social advance of the human race — progress in the relationships between individuals and among large and small groups of human beings. Perhaps this curve would have an observable, slightly positive slope designating improvement. But let us get to the third curve, the one that represents scientific discovery, technological change, and the modifications of the way of life and the physical structure of civilization that come from putting science and technological know-how to work. The ordinate would be minuscule, relatively speaking, for all time until a few centuries ago; then, and particularly in the past several decades, the curve would shoot up steeply, almost vertically, and off the chart.

No wonder we are experiencing the malaise, dislocations, and frustrations of an immense, almost uncontrollable imbalance between rapidly accelerating technological advance and lagging social progress. The more socially immature we are, the more difficult is our problem of social adjustment to the still further advance of technology. Our failure to make a harmonious merging of advancing technology with parallel social progress makes us a "disquiparant" society. In the theory of logic, a system is disquiparant if its definable, separate aspects lack a logical connection. If technological developments are not marching in step with social goals, how can there be logic in our employment of technology?

Today a severe mismatch exists between the high potential of technological advance and the low rate of social-political progress. The reason for this mismatch is not science and technology per se. It is rather that our social organization cannot use these tools to the fullest. Critical and controlling are the interfaces between technology and such non-technological factors as setting goals, examining alternatives, and making balanced decisions. These factors are not now being managed, or they are being handled helter-skelter by people who lack understanding of the process.

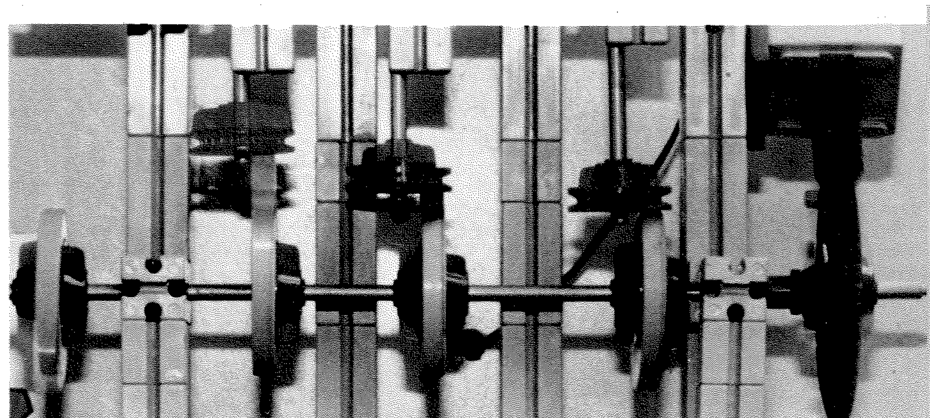
In choosing where and how to apply science and technology in America it would be helpful, for example, if we possessed clear national goals. When we find it hard to articulate and decide on what kind of society we want, it is understandably difficult to pinpoint the effective use of science and technology to help build it. Our society is not an assembly of related, essential components integrated into a harmonious whole.

Satisfactory decisions in any society cannot be made without an understanding of tradeoffs and options. For instance, we should be in a position to compare the good or benefit that can come from specific technological advance against its bad qualities or its cost. As to our employment of technology, we can be likened to a group of inept carpenters. Equipped with strong and ever sharper tools, they use them clumsily, often getting their fingers in the saws, hitting each other's heads as they bring their hammers back and their own thumbs as the hammers come down. They are not sure what they are trying to build. Confused, yet sensing an unsatisfactory situation from which they would like to extricate themselves, they meanwhile blame the tools.

A short while ago we were confident that the quickest, surest route to the better life was to acquire more scientific knowledge and expand our technology base. Scientific and engineering advances were regarded as limitless sources of higher living standards. These disciplines of the human brain were on a high pedestal. If scientific research and technological development were not worshipped, at least the highest level of such activity was revered and encouraged. To put science and technology at our service creatively and efficiently, a melting-pot form of Yankee ingenuity, an assumed innate ingredient of all Americans, was envisioned as available and ever growing. From time to time we might have to suffer a depression, some incompetents or crooks in influential places, a penalizing war or an annoying number of persistent social problems, but we Americans believed we could count always on one strong and favorable characteristic of our country: our advancing technology would steadily originate new and better approaches to meeting every requirement of our lives and would furnish us with continuing physical enrichment.

With more science and technology, we believed, we could do anything and ultimately would. And why should we not be so persuaded? In seemingly no time at all we had gone from horse-drawn carriages to automobiles, then to airplanes, with ever higher speeds and comforts such as four-speaker hi-fi in the cars and movies on the airplanes. Radio was invented and soon advanced to black-and-white TV, then color TV, cable TV, and intercontinental TV by satellites. To the early vacuum cleaners were added electric dishwashers, garbage disposals, and washer-dryers. We have found ways to collect, modify, and put to our use all matter of which we know the universe to be composed and have synthesized superior materials that do not appear in nature. We have created cities of weather-controlled structures and automated the mass production of physical goods. We are used to making low-priced long-distance calls by direct dialing. We have learned to so control insects and fertilize the ground as to grow far more food per acre than we can consume domestically. We have acquired nylon pantyhose, shatter-proof glass, frozen foods, and microwave ovens. A communication satellite weighing one ton now provides more channels of communication than 200,000 tons of cable laid under the oceans. During one year, a widebody airliner now moves more people back and forth across the ocean, at higher speed, than the largest ocean liner a thousand times heavier could carry. One of today's hand-held computers can make complex computations that at mid-century would have required equipment filling a room, with the costs proportionate to the equipment weights.

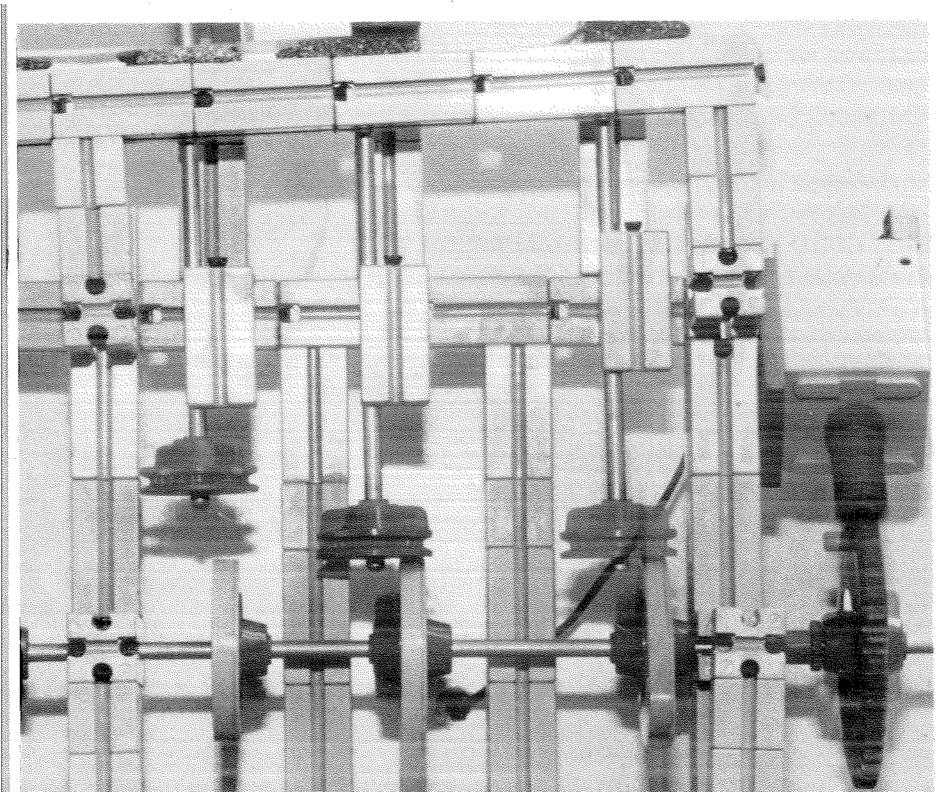
In not too long a time into the future, we have surmised, every individual will be able to push buttons on a wristwatch transmitter to call out a digital code that will establish radio contact with any other chosen person in the world. Soon our telephones should provide accompanying sight of those speaking, and our home TV should have a 3D picture. With advancing technology continuing to produce more for us with less effort, we should go from a 40- to a 30- or even to a 20-hour workweek. If we could walk on the moon in the '70s, then it seemed Americans should soon be able to visit Mars. If we should find ourselves,



a few decades from now, in contact with intelligent life elsewhere in the universe, this will not be regarded as incredible.

Microbiologists have broken the genetic code and begun pinning down the subtle distinctions between inanimate and living matter. We can overhaul the human heart and provide artificial kidneys. Vaccines have wiped out smallpox and polio while penicillin has curbed other diseases. Surely, then, a crash program to cure cancer ought to be successful, we assumed. Soon we should complete our conquest of disease, learn how to control aging, and perhaps even be able to use science and technology to alter the human species.

But if it was only yesterday when science and technology were adored as deities by the throngs — we could do no wrong no matter how avidly we applied these tools — it is only this morning we discovered the gods may be devils. An anti-technology wave has broken over us. A substantial fraction of our citizens now suddenly equate advancing technology with evil. As they perceive it, mass production jammed us into congested cities before we learned how to live together. To them TV means vapid, violence-loaded programs that miseducate our children. Gasoline refineries, needed to supply the automobiles, ruin the environment; those same automobiles, they note with revulsion, kill 80,000 people a year, foul the air, and force us to spend hours each day in traffic snarls. They now think we wasted money going to the moon. The atom bomb may destroy civilization and the nuclear reactor may poison the earth. We make our soil more productive but insecticides may do us in. The pill makes it easier to control the size of our families, but it promotes promiscuous sex among the young and is destroying the institution of the family. Many believe the computer is creating an automated robot society in which humans become slaves as digitalized signals and taped responses take over the society and personal privacy and freedom are lost.



It is not helpful to judge those holding these views to be a minority of extremists or, at best, careless listers of negatives who foolishly disregard the vast positives of science and technology. It is now clear to everyone that scientific research and technological implementations won't solve every problem and fill all needs. More powerful military weapons do not guarantee a peaceful world. No technological advances have come along to give us a lasting, plentiful supply of cheap, pollution-free energy to replace dwindling domestic petroleum and counter OPEC monopolies. We truly are impairing the environment and running out of certain resources. These and other facts about the present technological society are matters of legitimate concern. The nation is now aware that dis-benefits generally accompany all human efforts to produce benefits. Any country that understands this and yet fails to compare intelligently the gains and the accompanying harms deserves to have its policies protested. Such criticism is not unpatriotic and should be welcomed as a necessary prelude to realizing reforms that will adjust democracy and make it work in our technological era.

The desirability of carrying on large-scale research and development to accelerate further technological advance has become a controversial issue in the nation. Trends previously assumed to be clearly for the betterment of society are being challenged by new value judgments. Lower GNP (gross national product) is justified, some aver, if that goes with fewer cancer deaths, cleaner air, less congestion and noise, and a life with less pressure. In trying to find the right values, we are being forced to realize that there is no single truth to lead us to them. How do we arrive at limits on our rights to alter the world with technology? We interfere with nature when we dam up a stream or provide a heart transplant or drive an automobile and release its exhaust into the atmosphere or build pipelines or buildings or factories or sewer systems. When is what we do with technology a boon to mankind and when a detriment? Even the smartest people can't answer this query with an all-embracing guiderule. The difference between a wise man and a fool on this question is that the wise man knows that the values on which the answer can be based are not absolute, constant, and unique; they vary with people, situations, and time.

But if the omnipresence of rapid technological development is in part an evil, is it perhaps a necessary evil? Do we have a practical alternative to the technological society? Is it realistic to ban or even to greatly diminish technological advance? Is such a cutback too penalizing to accept for the American society because our values and social structures are so strongly based on a generous availability of the fruits of employing these disciplines? Experienced politicians assure us that no approach to our social and economic problems is politically viable if it contemplates the majority of citizens accepting a significantly reduced supply of goods and services. It is equally unrealistic politically to expect those now disadvantaged to abandon their aspirations for the higher living standards the majority enjoy. If these are political truths, then the tools of science and technology must be kept sharp and applied vigorously because such action is indispensable for a feasible approach to national problems.

While some want less technological development and more rules to regulate and minimize it, others are pointing to the available statistics and agonizing over evidence that America has developed a serious technology slip. They argue that we are realizing too little of what scientific and technological advance could yield. These advocates of more scientific research and speedier technological development consider that survival of the human race requires these extensions and applications. They think we need to choose between two options: one, a reasonably attractive and safe, albeit not perfect, environment with adequate but not infinite provisions for the human beings on earth; or the other, social instability, deep human misery, collapse of national economies, and wars based on scarcity of resources. They think the choice is easy. The real issue to them is how to use science and technology more fully, not whether to do so.

Of course, when we speak here of putting technology to work fully we do not mean the unthinking application of it, the misuse of technology on projects the public does not in the end really want and that are more harmful than beneficial. Problems of selection and organization arise here. Furthermore, even if we were to attain perfection in the choice and implementation of technological programs we still would not be guaranteed a healthy economy and a happy society. If we handle badly numerous non-technological decisions, we easily can have inflation, recession, high unemployment, wars, and other ills. Without a strong technological foundation, our minimum needs cannot be satisfied. Yet advances in science and technology are not by themselves sufficient. They are merely necessary.

Until very recently, we Americans took for granted that our country is the world leader in technology. This went hand-in-hand with our thinking we have the highest living standards in the world and are first in almost every scientific feat. It is true that some 20 years ago, when the Soviet Union sneakily abandoned the role of a technologically backward nation we had envisaged for it and launched the first Sputnik, our confidence was shaken. However, by sending men to walk on the moon while the Russians were having difficulty merely landing instruments there, we demonstrated to the world we were still champions.

But today we no longer can assume we are ahead. Contrary indications are all about us in the form of European and Japanese cars on our streets and foreign-made television sets and tape recorders in our homes. We are lagging badly in other fields and being overtaken in some areas where we still have a lead. Evidence is building that these trends are the result of some fundamental patterns that cannot be changed overnight. The United States, a country that previously had outstripped the rest of the world in producing goods and services for its citizens, has suddenly become highly concerned about its ability to go on providing a plentiful flow. More than just a handful of pessimists are asking whether the nation's store of resources and systems for deciding and doing things are up to the job of further increasing our living standards or even preserving the present level in the years ahead.

Have we lost our innovative ability and motivation? We enjoyed remarkable advantages over competitive nations in the century now ending. Maybe our organizations and habits of behavior were suited to the past but do not fit the future. Our presently decreased reaping of technological innovations suggests inadequate sowing some years earlier. The total United States expenditures on research and development are a decreasing fraction of our GNP while in Germany and Japan that ratio is increasing. We are investing less in improving our facilities, again as a fraction of our GNP, here off badly from the other developed nations. No wonder our rate of productivity increase has now dwindled to small oscillations around zero and is below that of all other developed countries.

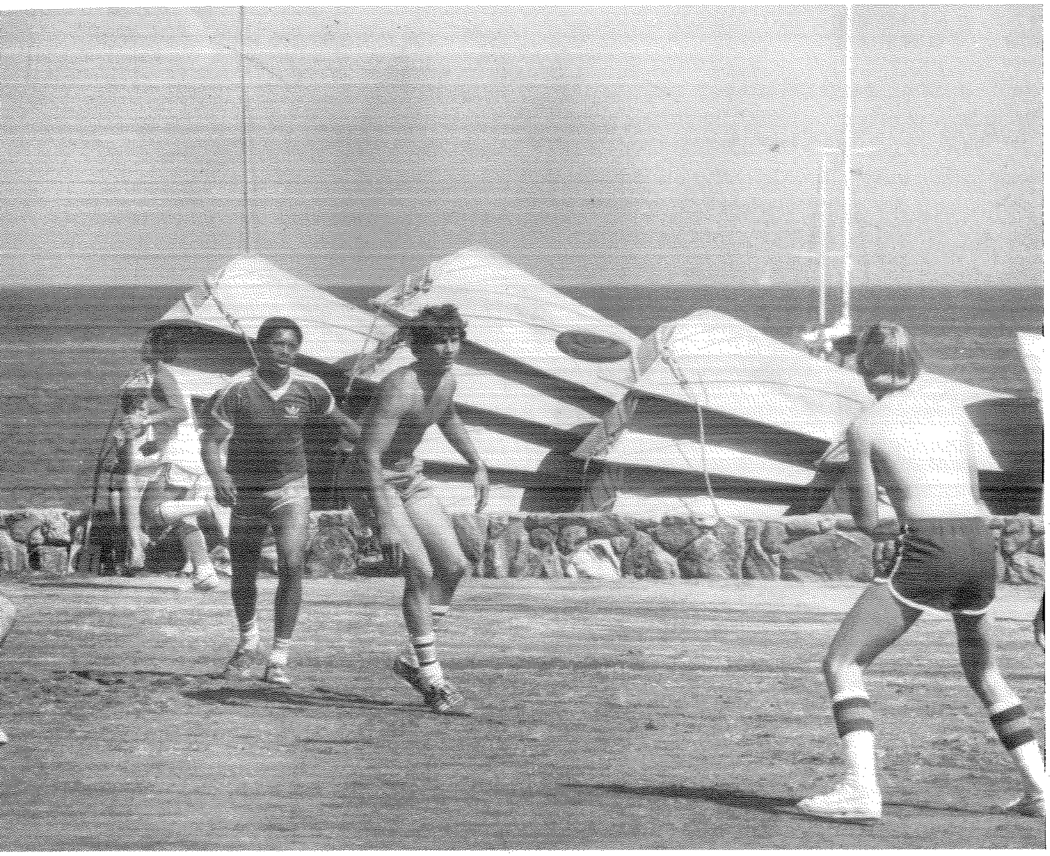
continued on page 30

Camping In

THE process of acquiring a higher education is punctuated with rites of passage — the getting from one status in life to another. For Caltech's freshmen the journey begins with registration, followed by getting away from it all for two and a half days of orientation to Institute people and traditions at Camp Fox on Catalina Island. That step begins with boarding a bus on Hill Avenue next to the Athenaeum at 7 a.m. on a Thursday morning in late September. Once at camp, everybody gets a chance to carry his or her luggage to an assigned sleeping space, as Chris Wood, assistant dean of students, demonstrates. For the next 48 hours there's lots of listening to speeches, including the always popular descriptions of the geology of the island and of California. One of those speeches was given by Tom Ahrens, professor of geophysics.

THE program isn't all speeches by any means. There's a chance to sun yourself on the sandy — er, rocky — beach, and having a hands-on experience with live marine specimens caught and brought to camp by Wheeler North, professor of environmental engineering science.

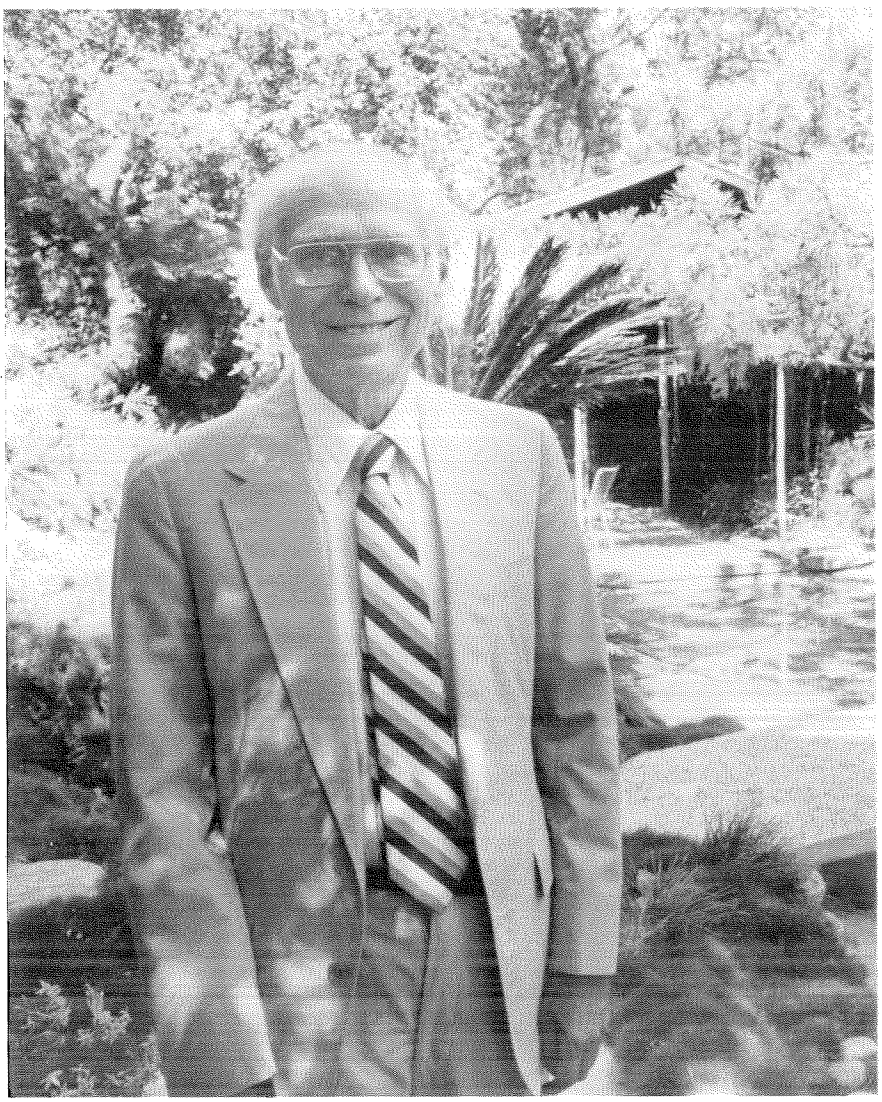
YOU can take a man- or woman-powered boat ride, do some one-on-one getting acquainted, or participate in the talent show.



THERE'S also tossing a frisbee, the interested presence of David Wales, dean of students, and finally, taking the ferry back to the mainland — a trip on which you can watch the world go by or rest up before getting into it for the next four years at Caltech.

An Interview with John R. Pierce

by Paul J. Nahin



AT THE age of 71, when most men have been comfortably retired for years, John Robinson Pierce is energetically into his third career. Retired since 1980 from his second career at Caltech (he is now professor emeritus of engineering), Pierce is chief technologist at the Jet Propulsion Laboratory, operated by Caltech for NASA in Pasadena. To this role Pierce brings decades of experience as both a research engineer and corporate executive at The Bell Telephone Laboratories.

Born in Des Moines, Iowa, in 1910, Pierce graduated from Caltech in 1933 with a degree in electrical engineering, and stayed on to take a master's in 1934 and a doctorate in 1936 in the same field. From then until his first retirement in 1971, he was employed at Bell Labs, finishing with the title of executive director of research, Communications Sciences Division. Even while busy at this demanding job, however, he occasionally found time to publish science fiction stories. The first appeared in a 1930 issue of *Science Wonder Stories*, and nearly two dozen more followed over the years (many at a time when to write speculative fiction wasn't nearly as "respectable" for scientists as it is today).

Pierce's skill with words isn't limited to fiction. He has written a large number of scholarly papers and books, mostly in the broad area of electronic communication devices and systems, and has made many important contributions to this field. His 1975 IEEE [Institute of Electrical and Electronic Engineers] Medal of Honor was awarded in part, for example, in recognition of his many innovative ideas in the design of high gain, large bandwidth traveling wave tubes, which in turn helped to make satellite communications practical.

His 1950 book, *Traveling Wave Tubes*, sits on the shelves of thousands of microwave engineers, worldwide. A more recent one, *Symbols, Signals, and Noise*, an introduction to information theory and electronic communications for laymen, is considered a classic of its kind. He is co-author of a new work, a textbook called *Introduction to Communication Science and Systems*, released last year by Plenum Press. It is based on his undergraduate teaching experiences at Caltech. Pierce is now at work on yet another book (with the working title *Science and Musical Sounds*) that reflects his long-time interest in the generation of synthetic sounds by digital computers.

During a recent visit with Pierce at his

Japanese-style home in Pasadena (complete with reflecting pool and waterfall), I heard him hold forth on a wide range of serious and speculative topics. One of the questions I asked him was how he came to be an electrical engineer rather than, say, a physicist or a mathematician.

Pierce: Originally, when I went to Caltech, the only technical person I knew was the father of a friend of mine who was a chemical engineer. So I thought I would be a chemist or a chemical engineer. Freshman chemistry cured me of that. It was disastrous, especially in the laboratory. And then, since I was building and flying gliders, I thought I'd be an aeronautical engineer. But in drafting my lettering was poor, and moreover we drew endless beams with rivets. So I looked for some sort of engineering that wasn't full of rivets. I became an electrical engineer.

I didn't become a physicist because in the catalog there was a language requirement that apparently would have debarred me. I found electrical engineering, which was largely power engineering in those days, not to my liking. But there was one professor on the faculty, name of Stuart Mackeown, whose field was electronics. I gravitated in that direction, taught a radio engineering course out of Terman's book when I was a graduate student, and Mackeown got me a job at Bell Laboratories.

My electrical engineering courses were about rotating machinery. The only rotating machinery I ever saw at the Bell Laboratories was the fan in my office. I was put to work on vacuum tubes, of which I knew nothing. From there on chance took over. I didn't find electrical engineering narrow and dull. It just went from one thing to another.

Nahin: Did science fiction play a role in your decision to become an engineer?

Pierce: Oh, yes, I'm sure it did! It excited me. I remember that after the first year of *Amazing Stories* I could look at the annual index and remember what each story was about. I thought that this was science and technology, in those days. I now realize it was really a sort of fantasy. It bears the same relation to the world of technology and science that legends of the saints do to the Christian religion.

But it's very inspirational. I have known so many people in whose lives science fiction played an important part. Detlev Bronk, who was president of the National Academy of Sciences for many years, and also of Rockefeller University. Also Lloyd Berkner, the radio pioneer and Antarctic explorer.

I found that they had been inspired by [Hugo] Gernsback, both by his science fiction and by his Electro-Importing Company that sold them radio parts when they were young. Indeed, at my suggestion, in Gernsback's later days, Detlev Bronk called Gernsback and told him of this, which greatly pleased Gernsback.

Nahin: The Cornell pop astronomer, writer, and newly emergent TV star, Carl Sagan, has said that science fiction does a good job of attracting youngsters to science, but not in sustaining that attraction. Do you have any reply to that?

Pierce: I think that an attraction is necessary. But a sustained interest in science or technology or engineering requires something of the individual. That he *do* something, rather than just passively read. Many individuals are disinclined or incapable of doing anything. It's often remarked that children show a great deal of curiosity and adults don't — most adults. The popular explanation of this is that something is done to the children to kill their curiosity.

I think it may be that some children are curious and find curiosity rewarding because they're capable of learning and finding something out. So they continue to be curious. Other children are curious, but never carry through the curiosity to resolving anything, and so they don't find curiosity rewarding.

It is the same, I think, with reading science fiction. It inspires some people to go and find out what science really is. Just as legends of the lives of the saints have probably inspired some people to become truly religious. For others it's just amusement and they pass on to something else.

Nahin: You've mentioned religion several times. To pursue that just a bit, in your book *Electrons, Waves and Messages,* you wrote, "To anyone who is motivated by anything beyond the most narrowly practical, it is worthwhile to understand Maxwell's equations simply for the good of his soul." Many other mathematicians and scientists who have also been struck with the elegant simplicity and beauty of the way Nature works have speculated it just couldn't all be an accident. That is, the universe has to be the handiwork of a higher spirit, a "God." Do you go that far?

Pierce: It's wonderful to admire Maxwell's equations, but a little presumptuous to bring God into it. Mathematics is just a game that people have made up and play. Unlike other games, say chess, it happens to be one that often can be related to the physical world. That's very natural, of course, because mathematics had its origins in very practical things, like building and surveying.

Not all mathematics is like that today, however. Modern mathematicians just love games with abstract rules that live all by themselves. That way they don't have to be physicists too!

Nahin: In his book, *The Character of Physical Law,* Caltech's Nobel prize-winning physicist Richard Feynman says he believes that C. P. Snow's "two cultures" are separated into people who have, and those who haven't, experienced an understanding of mathematics well enough to appreciate the machinery of Nature. Do you feel there is a widening gulf between those who understand technology and those who don't?

Pierce: Yes, and it may be because technology is getting more complicated.

Nahin: Do you think people are more self-indulgent now?

Pierce: Yes. I do feel many people don't want to think anymore in the organized and disciplined way you must in the natural sciences. Today, for many people, is a day for "feeling your own vibes" or "being yourself." It's not a day for hard effort for people who work outside of technology.

> "Science fiction bears the same relation to the world of science and technology that legends of the saints do to the Christian religion"

Technology, itself, may be partly to blame for this. Less than 15 percent of the population produce all the goods of society. All the rest do rather abstract jobs, and are far away from the things technology deals with effectively.

Nahin: Did the use of a pen-name, "J. J. Coupling," for your science fiction have anything to do with a concern about how that sort of writing might affect your technical image?

Pierce: No. When I started writing articles for *Astounding,* rather than stories, I used a pen-name because there was a release procedure for technical material written at Bell Laboratories. What I was writing had nothing to do with Bell Laboratories work, or very little, and I saw no reason to go through this tedious procedure. So I chose a pen-name.

The name "J. J. Coupling" comes from atomic physics. I didn't know what it meant when I chose it, and I'm a little uncertain now. Bill Shockley and Jim Fisk, who later became president of Bell Laboratories, had, while at MIT, founded the Institute for Useless Research. They had a letterhead printed. The president of the Institute was Isaac Neutron and the secretary was J. J. Coupling. I just picked the name up from the letterhead of the Institute for Useless Research.

> "I picked up the pen name J. J. Coupling from the letterhead of the Institute for Useless Research"

Nahin: Science fiction uses some seemingly impossible technical devices to help put stories in a "sense of wonder" setting. Some of these, like faster-than-light trips across galaxies, have recently been discussed as being accomplished with the aid of black holes. And professional scientists who are also SF writers, like Robert Forward of Hughes and Gregory Benford at the University of California, have written about time travel in a near serious manner. Do you think faster-than-light space drives and time travel can ever really happen?

Pierce: My authority on black holes is John Wheeler, and he doesn't believe in them for practical faster-than-light or time travel. There are certain paradoxical things that can happen on a very small scale. Science fiction writers want faster-than-light travel because they find it convenient to use other solar systems and civilizations in telling moral or adventurous tales. When Samuel Johnson wrote *Rasselas,* he could set it in Abyssinia because no one knew anything about Abyssinia. When Voltaire wrote *Candide,* he had all sorts of strange goings-on in the Americas.

But now all of our planet has been explored. There's no place on Earth about which to write romantic fantasy under the guise of possible fact. So the science fiction writers have been driven out of the solar system, almost. Some, like John Varley, still use the planets of our system, but most others have fled to the far corners of the universe. This is a sort of crisis.

Many science fiction writers are caught in the past. They think the exploration of space is going to be like the discovery of the New World by Columbus. They think Man himself will do it. I think it will be automatic machines that will do it, like Voyager. As far as I can see, the future just passed up these science fiction writers, and still does. Man is a terrible encumbrance in space, but it is a natural environment for a machine. A lot of science fiction seems not to have recognized this.

Nahin: To pursue the faster-than-light question, if we can't achieve it then Man will be isolated in his local region of space, and that bothers a lot of people. It has become almost a theological issue — if there really is a benevolent God, then such a cruel fate just couldn't be.

Pierce: Let me make a preliminary comment. Some of the people who don't believe in faster-than-light travel are very interested in SETI (search for extraterrestrial intelligence). My old friend Bernard Oliver, at Hewlett-Packard [vice president for research], is one. That's all right, but somebody once pointed out that maybe the reason we don't hear from anybody else is because everybody's listening and nobody's transmitting!

As to faster-than-light travel, that implies time travel, too, if you believe in relativity, and time travel has paradoxes. At the moment I don't believe in faster-than-light travel because relativity seems so simple and true. It follows from very direct and basic arguments and experiments. But I won't rule faster-than-light out, and I would hate to see it disappear from science fiction. All of space opera would be gone!

As to the isolation of Man, that is not inevitable. Way back, Robert Heinlein, who is a great hero of mine, wrote a story called "Universe." It was about a science fiction Noah's Ark. It *is* perfectly conceivable to have huge space ships that are self-sufficient worlds and that travel for generations. But not now. Not for many, many years. The time for the telegraph wasn't ancient Greece even though much of the beginning work for it was done then. In the same way, the time is not right for travel to the stars. It *will* come.

Nahin: You once wrote, "Computers look silly only when someone tries to make them walk on their hind legs and beg to be recognized. There should be a Society for the Prevention of Cruelty to Computers to deal with this abuse." In general, you seem to be quite negative about work in artificial intelligence, once having equated the development of computer algorithms for handling natural languages with the discovery of the Philosopher's Stone. Isn't that a funny position for a science fiction writer who thinks machines will explore space?

Pierce: Yes, but then I'm not a full-time science fiction writer. I've often been asked when computers will be better than Man. I always respond that from the very first moment computers have been better than Man at a lot of things. It's only when you ask them to do ridiculous things that they look bad.

You can liken a computer to an airplane. A bird is just wonderful. So is a 747. But a 747 doesn't land on a tree. And if you insist that flying machines flap their wings and land on trees, you'll get very poor flying machines.

Nahin: And dangerous ones, too!

Pierce: Yes. Just like people, computers should have jobs they're good at.

I'm an engineer. I believe it's more important to get the job done than to be elegant. It's good to be elegant, certainly, but the bottom line is that it's gotta work!

As far as understanding how the human brain works, it's the biologists and psychologists who'll do that, not the artificial intelligence people. Here's a quote for *E&S:* "Artificial intelligence is real stupidity." I'll admit it's only a half-truth, but still, it's at least *half* true.

Nahin: In your 1968 book, *The Beginnings of Satellite Communications,* you wrote, "I wonder why I did not think of satellite communications. I believe that I just did not take space seriously, as Arthur C. Clarke had in proposing communications satellites in 1945. I read science fiction, and I wrote science fiction. I liked to talk about space travel — but I did not really see that space was near enough to be of serious concern." And yet, Clarke himself wrote the preface to your book and honored your contributions, and at least one recent book on communication electronics *does* credit you with proposing satellite communications in 1955. Is there some mix-up here, or are you being modest, or . . .?

Pierce: No, science fiction and space *were* one side of my thought, and before Sputnik and Explorer went up, I used to go around giving talks about space and space travel. I used pictures taken from V-2s which had been refurbished in this country. Then, in 1954, the Princeton section of the IEEE — it was the IRE [Institute of Radio Engineers] then, of course — asked me to give a talk on a space topic.

That woke me up. I thought that this man-in-space stuff, which is as old as Kepler or even older — remember Cyrano de Bergerac? — wasn't quite the right thing. I wondered what I could say that would be more serious. Since I was interested in communications, I thought of communication satellites. I didn't think of them as *my* idea. I hadn't yet read Arthur Clarke's article. Satellites were just in the air (figuratively speaking!) and I thought *everyone* had thought of communication satellites.

My job wasn't to invent them, but to analyze their possibilities. So I gave the talk, and later I was asked to write it up for publication. This got me thinking, but there wasn't anything to do about communication satellites then because there was no way to put anything up. When Sputnik went up and Explorer went up, I thought this was the time to do something. That led to Echo, and Echo did several things. It made the front page of the *New York Times*. It hit the people at AT&T, and that led to Telstar.

Nahin: It is no secret that NASA has had a public relations problem, and hasn't really succeeded in convincing the American people that its charter is essential to the country. Recently the agency's head, Robert Frosch, resigned over a failure to get the budget it needs. As a person intimately involved in the operation of a NASA lab, what do you think the future holds for our space exploration program?

Pierce: That depends on the health of the country, materially and mentally. As far as I'm concerned, one of the few good things that happened during the Carter administration was Voyager. It caught the attention of people, and it was a cheerful thing. It buoyed people up. America did something that everyone admires. Countries have to do some things beyond what is of day-to-day use. But of course the unmanned space program *has* done things of day-to-day use too. It does them for the military in surveillance of the Soviet Union, it does them in navigation through NAVSAT and through the Global Positioning System, it takes pictures that are useful in exploring for resources and for monitoring the weather.

If the country gets out of its doldrums, it *can* afford other less immediately useful things. Certainly, the poor will always be with us, but one doesn't live by bread alone. I regard this as a time in which the country wastes billions of dollars because we have so many Mammon worshippers who think they can cure any ill by spending a lot of money. That just isn't so. In their ill-conceived way Mammon worshippers overlook opportunities that could push Man's capabilities ahead, as I believe the unmanned space program does. NASA has a problem because Apollo went over so big. Well, Apollo was a dead-end in some ways. We'll not build such big and expensive rockets as Saturn V for a very long time to come.

The rockets that have actually launched all the commercial satellites are military derivatives of the Atlas, and the Thor, which became the Delta, and the Titan. NASA has persisted in believing that the way to appeal to the public is Man in Space. I think this has been an unhappy decision. It's a good thing to work toward, but you do that by improving technology. You don't do it by an all-out drive to replace all the unmanned launch vehicles, which have been so useful, with a manned vehicle where success and economy are so hard to attain.

Nahin: As a final question, what technical developments do you see in our future?

Pierce: The area that is really taking off now is biological science, with wonderful new advances coming almost daily in things like genetic engineering of bacteria. In electronics I think the very large scale integration of circuits is most exciting, and I could go on almost endlessly listing what that implies. But let me be somewhat more philosophical instead.

"I look for a digital future, but the thing that concerns me most about it is not privacy but accountability"

I look for a *digital* future, one in which the world will be much more under the individual's control. People, today, who comment on the future for a living, keep talking about *privacy,* and things like electronic snooping in personal data files. But the thing that concerns me most about the digital age is *accountability*. As T. S. Eliot said in "The Rock,"

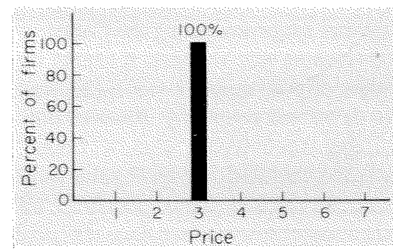
> Where is the Life we lost in living?
> Where is the wisdom we have lost in knowledge?
> Where is the knowledge we have lost in information?

And I add, where is the information we have lost in data? The government collects huge amounts of indigestible figures that don't mean anything to anyone, and spends billions doing so. Future developments in computers could turn this around and let the individual have meaningful access to these large data resources. *Before* they get manipulated in unknown ways by unknown people with unknown motivations. □

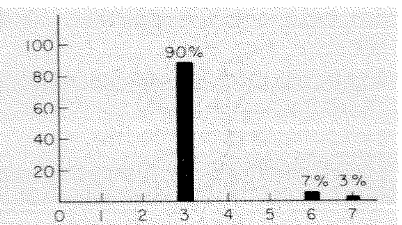
Research in Progress

Shopping Around

The bar graphs below illustrate how the market price of a homogeneous product changes as a function of the percentage (among all buyers) of shoppers who compare prices. From left to right the graphs represent a decreasing percentage of shoppers.



Case 1: Percent of shoppers sufficient to keep all firms charging the competitive price of $3.



Case 2: Percent of shoppers lower than case 1, but still enough to keep most firms charging competitive prices.

How much do consumers need to know to make intelligent decisions when purchasing goods or services? How much is enough consumer information to keep sellers honest without government intervention? Recent trends in consumer protection legislation have been based on the assumption that buyers need to know more facts than unregulated markets provide or to have them explained in a simple, uniform way to prevent sellers from taking advantage of them. Otherwise, regulation would be needed because competitive markets wouldn't work right if consumers were not well informed.

Perhaps — but perhaps not, say Alan Schwartz, Caltech professor of law and social science (and the Maurice Jones Jr. Professor of Law at the University of Southern California), and Louis Wilde, associate professor of economics, who have been jointly investigating the effects of imperfect information on markets. The unusual collaboration between these two arose after Schwartz, who is a specialist in contract law, discovered that a proper analysis of existing and proposed statutes regulating certain consumer product and financial markets required a sophisticated knowledge of economic theory. Coincidentally, Wilde's main interest as an economist happened to be information theory.

These two argue that most consumer protection laws have been passed or proposed without any real knowledge on the part of lawmakers of how markets really do behave when buyers don't know everything there is to know — when their information is imperfect. The problem was that no one knew; very little theory existed in the area, and what did exist was buried in specialized mathematical journals. Schwartz and Wilde set out to provide a theoretical basis for the study of this sort of market behavior and make it accessible not only to economic theorists but also in practical applications to the people who are responsible for regulatory interventions into markets. With theoretical models of market behavior available, lawmakers could look at a real-world situation and see if the features of a functioning competitive market were present. If they were, the large costs of regulation could be saved; if they were not, then perhaps some regulation would be necessary. Initial results from Schwartz and Wilde's work indicate that market dysfunction may happen much less often than previously thought.

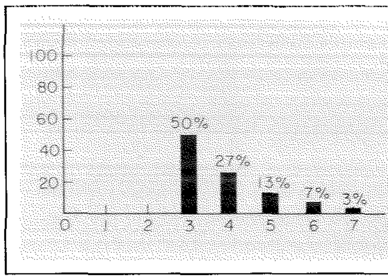
With support from the National Science Foundation, the two Caltech researchers have constructed mathematical models of markets that describe how different mixes of shoppers and nonshoppers combine with the technical characteristics of a market to yield various configurations of prices.

Their first model dealt with homogeneous "search" products, that is, markets in which every firm sells exactly the same thing, and all the characteristics of the product are observable. Money, for instance, is a "product" of this type and one that is also heavily regulated. When the Truth in Lending Act was passed in 1968, there was much debate about how much consumer information was necessary to keep interest rates at a competitive level. According to their model for homogeneous goods, Schwartz and Wilde have reason to believe that sufficient numbers of people were already shopping for credit and that the disclosure law was probably unnecessary. Credit consumers' awareness levels have risen since the law was enacted, but this hasn't affected the rates of interest they are actually paying. Regulation here has apparently not improved on the competitive market.

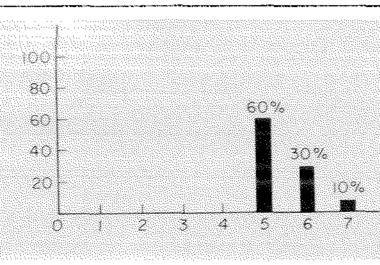
Another Schwartz-Wilde model concerns those products that differ from firm to firm not only in price but also in quality, but all of whose features can still be observed by consumers before purchase. Warranties, for example, differ greatly among firms, but a buyer can discover the features of the warranty by reading the contract. The Federal Trade Commission regulates warranties on the assumption that consumers have difficulty comparing the quality of guarantees. Although the Caltech research has not yet been finished for publication, preliminary findings suggest that the FTC may be going about consumer protection from the wrong angle when it forces firms to adhere to specific warranty disclosures. Schwartz and Wilde's models seem to indicate that firms often may not exploit consumer ignorance by offering low-quality guarantees, but rather by raising their prices to noncompetitive levels. In such a case, existing regulation may actually be working to the consumer's disadvantage.

In all of their model building so far, Schwartz and Wilde have had to rely on others' sometimes inappropriate data on shopping patterns to test their theories. They are applying for additional NSF funds to do their own empirical testing in real and experimental markets, so that they can state their findings more conclusively. In addition they plan to pursue models of other market situations, such as those involving products that have to be used to discern features that aren't immediately observable and services that involve diagnosis — by doctors or auto mechanics, for example. They also hope to look at the impact that new communication technology (for example, making all the grocery prices in Pasadena available on a home TV screen) might have on consumer decisions. Because this kind of market doesn't yet exist, their empirical work in this matter will rely exclusively on laboratory experiments. □

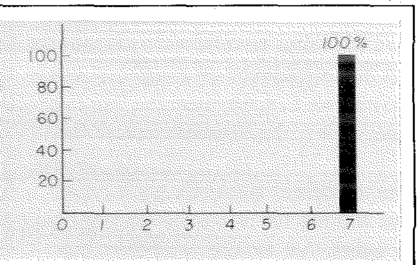
–*J. D.*



Case 3: Percent of shoppers substantially below case 1; half of the firms charge noncompetitive prices.



Case 4: Few shoppers; no firms charge $3; prices begin to cluster near the monopoly price of $7.



Case 5: No shoppers; all firms charge monopoly price of $7.

Tracking Smog

SMOG, like fine scotch and steaks, may arrive already aged (or, like old bread, stale) for residents of the San Gabriel Valley foothills and the low deserts east and southeast of Los Angeles. The first quantitative data concerning this finding emerged from a tracer gas study conducted during the summer by Professor of Chemical Engineering Fred Shair and a group of students — the Caltech "tracking team."

They found that the San Gabriel Mountains do not act as a barrier to smog; they merely redirect a portion of it. As a result of the study, communities in the foothills and low deserts will have to reconsider former assumptions on the sources of their ozone-level peaks and in particular the ratio of "old versus new" smog that they experience daily.

The four-week-long field study, part of a year-long investigation (with Meteorology Research, Inc., an Altadena consulting firm, as co-investigator), was aimed at determining where the smog-carrying wind leaves the Los Angeles basin, how much of the smog goes into the mountains, and where and how long it affects the desert. Funded by a $250,000 grant from the California Air Resources Board, the researchers released sulfur hexafluoride, an inert, harmless gas, from nine points in the Los Angeles basin and surrounding mountain passes. They then measured the concentrations in air samples collected in a 60,000-square-mile area ranging from the China Lake Naval Weapons Center to the Mexican border and from the Pacific Ocean to the Colorado River. This is the largest such field study undertaken to date.

Detecting these low-level concentrations over such a large area was made possible by a breakthrough in the design of an electron-capture gas chromatograph that can rapidly and accurately measure a gas in concentrations as small as one part in a trillion. The electron-capture detector had been invented in 1960 by British chemist James Lovelock, who in the early

"Tracking" team members Lillemor Hastrup and Eric Chang collect air samples in the field and replace syringes for the next test.

1970s was a consultant on the Viking Lander project at JPL. Shair, along with Lovelock and Peter Simmonds, then of JPL, developed the detector into a small, portable instrument for use in the field. Shair also recognized its applicability to investigating transport and dispersion associated with complex flows, and he and students from his freshman chemical engineering class conducted the pilot experiment in tracking smog in 1973.

The Los Angeles desert-impact study was conducted during July, a typically smoggy month that usually exhibits winds and other meteorological conditions favorable to the transport of smog out into the desert. Shair and his team of students released the sulfur hexafluoride gas into the air at nine sites (each on a different day) in downtown Los Angeles, the San Fernando Valley, the San Gabriel and San Bernardino Mountain passes, and further out in the desert. Each release involved about 100 pounds of the gas per hour for four hours. Air samples were then collected in small plastic syringes in 30 different stationary locations and by members of the study team conducting traverses in cars and airplanes. The portable analysis system allowed monitoring of the tracer gas in the field continuously so that planes and cars could be redirected to follow it. About 3,000 air samples were collected during each test.

The first test started with a release of tracer gas at Culver City on a morning when the wind at Glendale was coming from the southeast. The wind then carried the gas on a variety of routes. Initial analysis showed that 30 percent of it headed directly east, missing Pasadena, barely touching Azusa, and then traveling past Banning. The larger portion — about 65 percent — flowed northward into the San Fernando Valley; some of it then continued through the San Fernando Pass into the Antelope Valley. From there some of the tracer continued on through Needles. Most of it, however, headed east and then southeast, making its main impact in the Coachella Valley. The most surprising route was that taken by a portion of the tracer gas that was apparently driven from the Antelope Valley back into the San Gabriels and down through the mountain canyons, sloshing the next day into a five-mile-wide zone in the foothills of the San Gabriel Valley. It arrived at the same time that the ozone levels there began to peak.

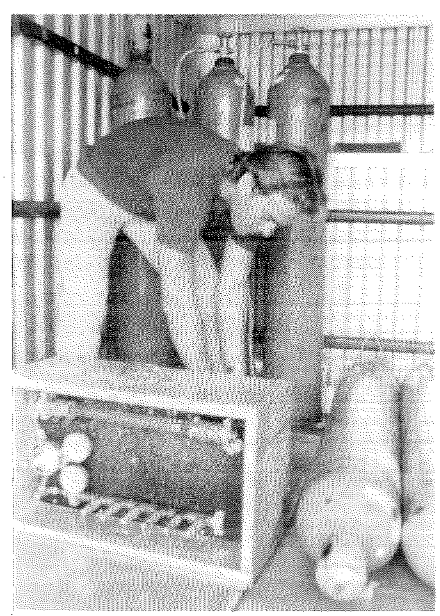
The study calls into question the interpretation of ozone profiles in the foothills and low deserts. Tracer gas from a single release was picked up three times (twice on the first day and once on the following day) in some areas in the Coachella Valley. Towns such as Indio do often have multiple ozone peaks in a day, but it had been assumed that some of them were totally locally generated; Shair's study indicates that this assumption needs to be re-examined.

Military concern about decreased visibility in the desert was an additional impetus for the study, and personnel at Edwards and Norton Air Force Bases and the China Lake Naval Weapons Center cooperated in the research. Also involved in the wide-ranging project were teams from Washington State University, UCLA, Santa Fe Research Corporation, JPL, and the Environmental Protection Agency.

Shair's investigation exonerates Los Angeles from polluting the skies over China Lake. Most of the degradation of visibility over China Lake is associated with smog transported from the southern San Joaquin Valley over the Tehachapi Mountains, says Shair. He and his field study team have previously conducted tracer gas studies of this area as well as the Salinas Valley, the Sacramento Valley, the Sacramento River Delta region, and the Santa Barbara Channel. An earlier study of land and sea breezes off the El Segundo coast of Los Angeles gave the first quantitative information regarding the transport and dispersion associated with a "Yo-Yo" effect. Although night breezes blew elevated industrial pollution in that area out to sea, morning winds brought virtually 100 percent of it back over the land at ground level, affecting a coastal zone from Ventura to Corona del Mar.

In the current study Shair and his students have analyzed 24,000 air samples in the laboratory and are now combining this information with pertinent air quality and meteorological data. The physical and mathematical descriptions that will emerge from these data will give air quality planners a more realistic picture of the transport and dispersion of Los Angeles pollutants as a basis for effective clean air policy. □ *–J.D.*

Ardi Chang types information into a digital integrator to measure the concentration of tracer gas in an air sample.



Caltech senior John King adjusts the flow meter of the sulfur hexafluoride gas release system.

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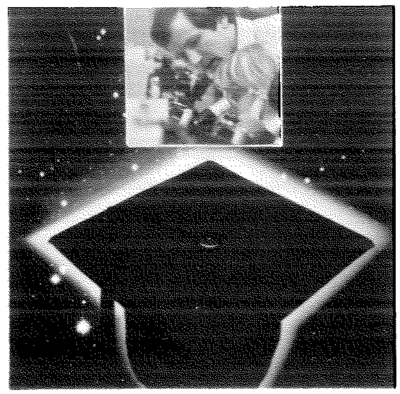

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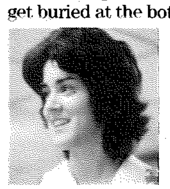

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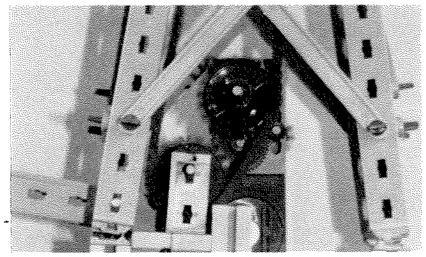

Some Americans believe the world is changing much too rapidly. Others want more and faster change. Everyone must agree technological advance is a forcing spearhead of change and that we are having great difficulty absorbing it. The rapidity of technological advance — because of our inability to adjust to it, realize its benefits, and minimize its negatives — is presenting us with dilemmas and critical choices. If stopping technological advance is not practical because we need the gains it brings, if curbing it is unacceptable for fear of risking the lowering of living standards and security, if the negatives of technological advance and the growing shortage of resources are real and serious, then we are surely stuck. We need to invent new policy-forming and decision-making techniques.

To illustrate, take the stubborn, ubiquitous problem of inflation. Ask the average American citizen which problem should be rated as worse, inflation or the penalties of rapid technological advance, and inflation would surely be named as the curse we most need to eliminate. But the two phenomena, inflation and advancing technology, are related. Indeed, the strengths of technology can be used to fight inflation. In this instance, inflation is the dragon. Technology, sometimes a positive and at other times a negative force, can serve here as the good knight.

To see how, let us first grant that a sound approach to curbing inflation includes limiting the expansion of the money supply. The government must reduce its spending to make possible politically acceptable conditions for curbing monetary growth and as a political practicality must somehow achieve this reduction without greatly increasing unemployment. But the public insists upon the government's supplying health, education, welfare, and numerous other services, and a strong national defense. This vehemence makes the reducing of government spending a near miracle. Under these circumstances, it is hard to exaggerate the importance or the difficulty of arranging for a higher rate of investment in technological innovation. Whether the problem is lowering the cost of national security or increasing productivity, the technological advance route offers real hope for progress. If the voters will not countenance a much lower supply of goods, we must look for ways to increase that supply at the same costs, that is, while using the same human and physical resources. If resources are dwindling, we must learn how to make more resources available economically. There is only one way to have a generally higher standard of living and to enhance the availability of goods and services to those now well below the average partaker. This is by increasing the quantity and quality of what we produce for each dollar of cost to produce it — a natural role for beneficial technological advance.

Scientific research, if avidly pursued, can discover new resources and teach us how to apply the laws of nature more effectively in using all resources. Advanced technology can be employed more broadly to develop economically and socially advantageous products whose manufacture would create new jobs to fight unemployment. Further R&D effort can lead us to superior methods for increasing supply and lowering costs as a counter to inflation, substitutes for materials in short supply, and ways of acquiring raw materials and manufacturing for our needs with less harm to the environment.

Now if, as some say, too much technological development is inundating us with hazards and detriments, then the present United States trend of slowing technology advance compared with some other nations could be a blessing. If we could rightfully equate technological advance to ruination of the environment and to a bad life generally, not a better one, then we should applaud our failure to develop more rapidly technologically. Let the other nations knock themselves out producing more material things, having the mere appearance of gain while actually lowering their real living standards. We, meanwhile, shall rise above such unsophisticated, misconceived, harmful contests.

But such extreme rationalizations will not satisfy the majority of Americans. True, we have all become familiar with the word "ecology." We all know the goals of life are not met by high production totals alone. We must protect our environment and preserve natural resources. On the other hand, we realize we need a plentiful supply of goods, energy, and services. We also feel intuitively that if we lose the ability to provide well for ourselves we are bound to become more dependent on other nations that exceed our performance record. Then both the quality of our life and our freedom to control it will diminish. While we struggle with working out a better match between the potentials of advancing technology and the needs and wishes of our society, inevitable competition with other nations affects us. Total isolation not being practical, our attempts to resolve our dilemmas are influenced by what the rest of the world does.

Imagine for a moment a planet with only two nations, Country A and Country B, each well endowed with human and natural resources. Also assume this two-nation world is a free one — money, products, resources, technology, and labor are allowed to flow freely between the two countries. Suppose that Country A gradually attains a superior, broader understanding of science and technology, is better organized to employ these tools, has greater productivity, and is more innovative. It discovers new ways to use resources, develops substitutes whenever natural resources threaten to run out, lowers the cost of manufacturing and distribution, invents means to diminish pollution of the environment, and continually designs and brings out new products that are socially and economically superior. It is generally more skillful and mature in matching what science and technology make possible to the needs and desires of the population.

With these assumptions, we know what will happen. The citizens of both nations will prefer the products of Country A because they will be cheaper and yet of better quality and more suited to their needs. The industries of Country A will prosper and employment will be high there. The industries of Country B will be in depression and its unemployment will rise. Temporarily, Country B can maintain its standard of living by selling its country's assets, its land and raw material resources, to the citizens of Country A. Country A will amass more capital, some of which will be used for these purchases. Soon Country A will set up, own, and operate plants in Country B. Some of Country B's workers may go live in Country A, where employment opportunities are better. In time, Country B, like an underdeveloped country, will supply lower wage labor for low technology products, descend to a lower standard of living, and be subservient to Country A.

Let us alter our assumptions somewhat toward political realism. As the trend we described begins to be felt deeply in Country B, its citizens probably will elect a government promising to create protective barriers. These will keep out or tax the products of Country A and restrict foreign investment and takeovers. It will subsidize Country B's industry when it is seen to be failing and charge its citizens high tariffs if they insist on buying the superior, foreign-made products of Country A. Country B can isolate itself as though Country A did not exist. The end result, however, will not be much different. Country A, with its advancing technology, will have a rising living standard. Country B, busily engaged in subsidizing its own backward technology industry, will produce less (and lower quality) products for its citizens to divide up.

Some in Country B may argue, "When all is added up we have not lost. We have benefited by not worshipping technology as has Country A. Yes, we produce less, but we have a simpler and better way of life, one that is less dependent on advancing technology." But if Country A has been properly described as superior technologically, it will use technology in a thoroughly optimum manner and the criterion for what is optimum will meet the value judgments of its citizenry. If Country A moves ahead unthinkingly instead and, in producing increasing volumes of products, spoils its environment and impairs the health of its citizens, then it would have to be reckoned as inferior, not superior, in its use of technology.

Similarly, Country B, defined as inferior technologically, is not automatically superior in another sense: it has carefully avoided employing that technology which provides more detriments than benefits. It is one thing deliberately to produce fewer shoes and thereby gain time to walk barefoot on the sands of a clean beach. It is another to walk barefoot because we can afford no shoes — especially if the beach is filthy. A sound definition of technological superiority is not merely to use advancing science and technology aggressively and avidly. It is to select appropriate areas for technological efforts. It is to create approaches that will generate the least negatives and the maximum positives. The objective is not to accumulate the biggest bag of technological tricks, winning a science olympics of discoveries and breakthroughs over other nations. However, if other nations excel on a broad enough front in science and technology, they will be the ones with the most options to set a society pattern of their choice.

How good and how bad for America is further advance of the technological age? By accelerating scientific research and technological developments in the United States, what do we gain and what do we lose and how do the two compare? Is it inevitable that we become an even more technological society? Can we arrange to reap the positives, or most of them, and eliminate the negatives, or most of those, of further implementation of advanced technology? Must we in the United States strive for a position of technological superiority or else lose out to other nations that move faster technologically?

These questions suggest a summary question. Are we in the United States using science and technology to the fullest on behalf of our society? This is not to ask whether we are following up every clue to nature's undiscovered secrets and are building every machine it is technically possible to build. These latter are very different and less sensible questions. We seek here rather to inquire whether our scientific and technological know-how is being applied adequately where there is evidence of high economic and social reward for the effort. If the American society is not now making proper use of science and technology tools, then why not? Are we becoming slower, more timid, and less innovative in applying science and technology? What stands in the way? Is Yankee ingenuity really disappearing? Is there something about the pattern, the rules, the organization of American society that is at fault here? Is our system of applying value judgments, making decisions and implementing them inadequate for the technological society ahead? Should it, must it, be changed?

In the competitive and highly interactive world society, advancing technology cannot be halted, but the movement can be influenced. If we do not understand and work at properly employing technological advance, our goals as a nation will not be met. We shall also then not make our proper, needed contribution to world social, economic, and political stability. This will be damaging for America. It will be equally bad for the world. □

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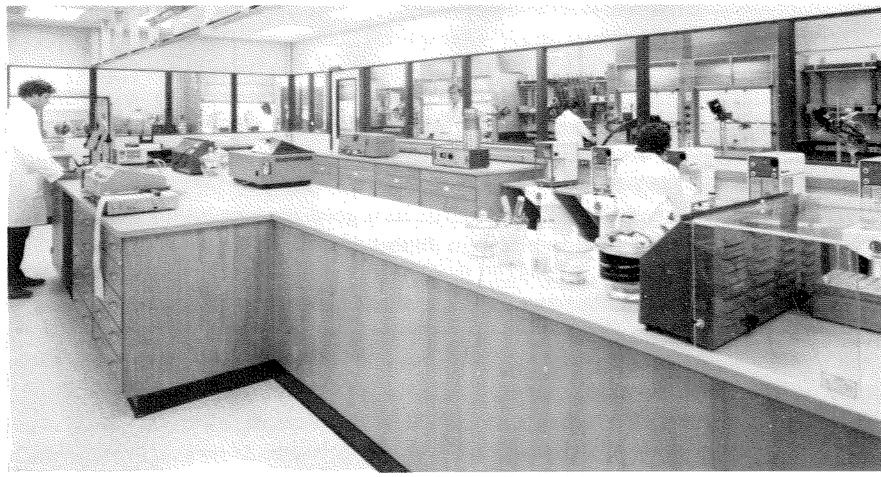


Chem 4 and 5 students now have these handsome facilities in the Mead Undergraduate Chemistry Laboratory.

Chemistry Lab

The earthquake of 1971 shook the Caltech campus hard enough to necessitate the removal of the undergraduate chemistry labs from their time-honored spots in severely damaged Gates Laboratory to a series of makeshift sites in buildings all over campus. Fortunately, it was possible to raise money for, design, and build an 8,000-square-foot minimum-amenity replacement building by the fall of 1972. It is into that building (just west of Noyes Laboratory) that the chemistry division has with increasing difficulty shoehorned several of its undergraduate lab courses ever since.

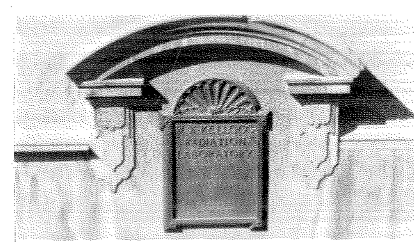
This fall, life in lab-land looks much better. The building, remodeled and refurbished, has become the Clifford S. and Ruth A. Mead Undergraduate Chemistry Laboratory; and it is now comfortably serving the needs of all those enrolled in Ch 3, 4, and 5 — up to a maximum of 180 students each term.

Happy Birthdays

A number of important birthdays were recently celebrated at Caltech, one of which was that of Lee A. DuBridge, president emeritus, whose 80th birthday was the occasion for a dinner at the Athenaeum on September 20. Hosts were President and Mrs. Marvin Goldberger and Provost and Mrs. John Roberts. Roberts presided after dinner, and the speakers included Goldberger, Trustee William Zisch, Jesse Greenstein (the DuBridge Professor of Astrophysics, Emeritus), William A. Fowler (Institute Professor of Physics), and DuBridge himself. A musical helping of nostalgia was provided by Kent Clark (professor of literature), who sang "Lee, Lee, Lee" from his own 1956 musical *Who Is This Guy DuBridge?* Gary Lorden (professor of mathematics) accompanied him.

Lee DuBridge's 80th birthday party brought out Mrs. Stanton Avery and W. A. Fowler, right, whose 70th birthday was honored a few weeks later. One gift Fowler collected early was DuBridge's autograph of a 1932 edition of Hughes and DuBridge's Photoelectric Phenomena.

Three birthdays crowded the first week of November, beginning on November 2. That was the 90th anniversary of the opening of the doors of Throop University. Those doors were in a building that became a part of the Green Hotel in Pasadena. Neither this name nor this location lasted very long, however, and several changes later the school wound up as the California Institute of Technology located on its present site. As a tribute to the school's origins, there was a luncheon for community leaders and an exhibit of some of the medals awarded to Caltech faculty over the years. On the day itself, there were birthday cakes and balloons for faculty, staff, and students.



Later in the week, on November 5 and 6, the W. K. Kellogg Radiation Laboratory celebrated its 50th birthday with a conference, a special dinner, and a grand finale "Kellogg Party" in Dabney Garden. One of the conference highlights was the dedication of the new accelerator laboratory built in the underground area between Kellogg and Karman laboratories.

Distinguished physicists and astrophysicists from all over came to participate as guests and speakers in the seminar and celebrations. One of those celebrations — the special dinner at the Athenaeum on November 5 — was billed as "Willy's Birthday Party." It honored the 70th birthday of one of Kellogg's most noted scientists, who is also among Caltech's most noted alumni — William A. Fowler.

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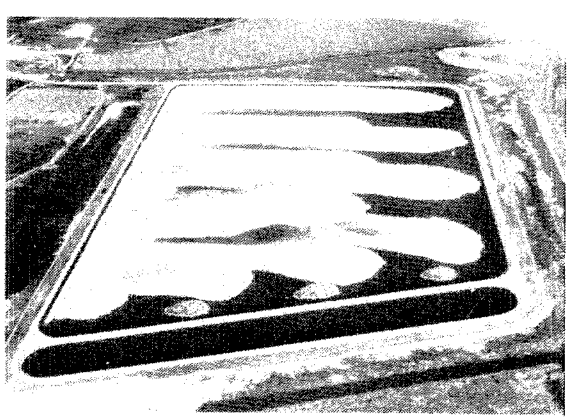

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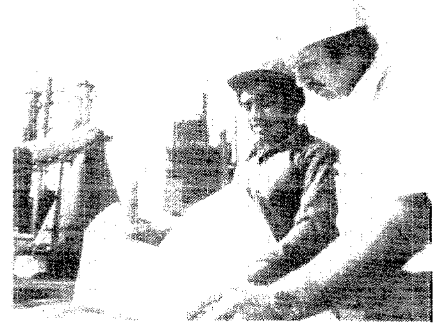

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