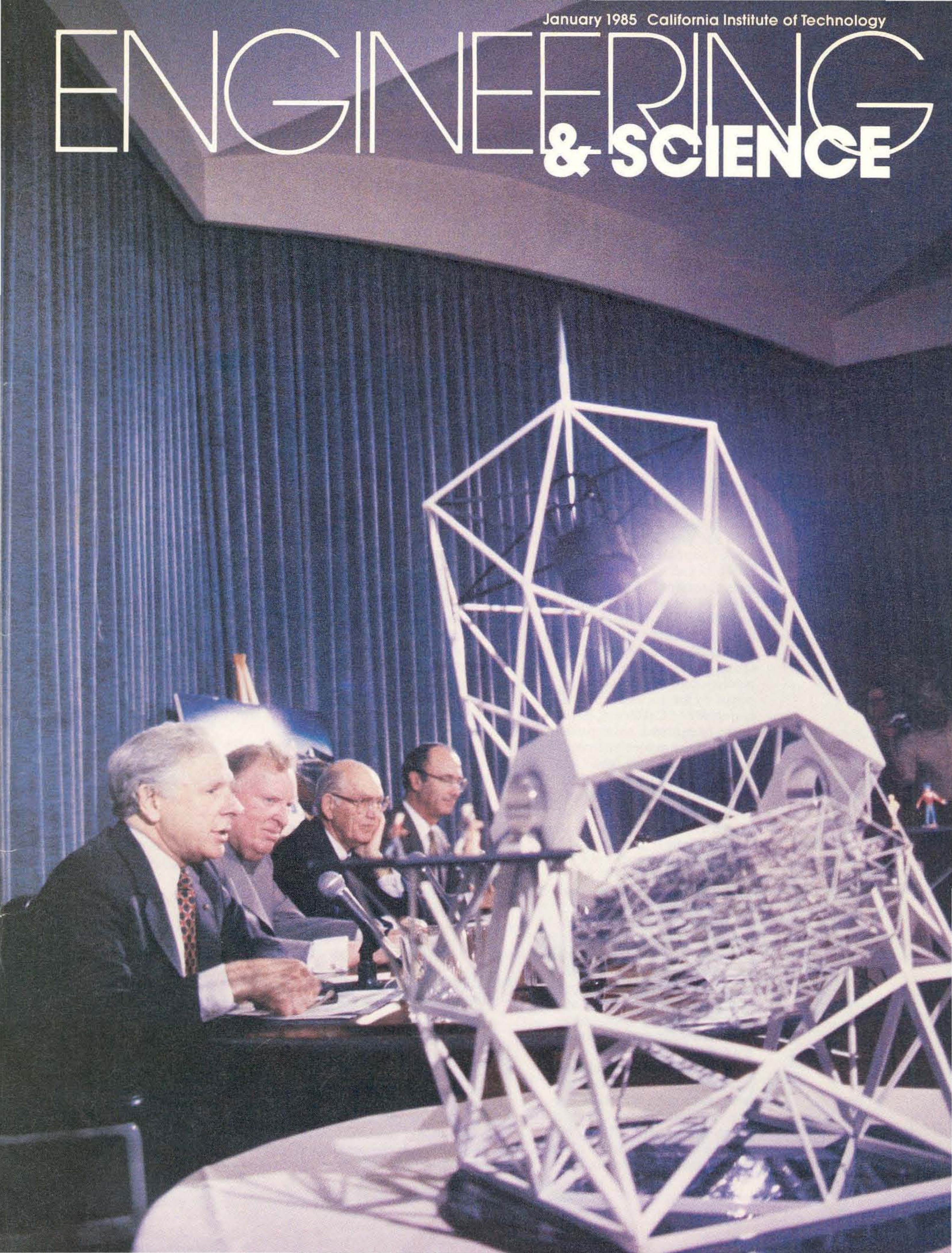
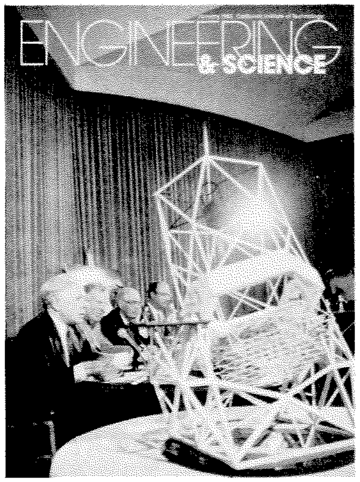
January 1985 California Institute of Technology

ENGINEERING & SCIENCE



In This Issue



New Year News

On the cover — At a January 3, 1985, news conference, Caltech President Marvin Goldberger (left) introduces Howard Keck (second from left), chairman and president of the W. M. Keck Foundation, who was about to make "a truly momentous statement." That turned out to be the announcement of a proposed $70 million grant to Caltech to build the world's largest optical telescope. A model of the ten-meter telescope, whose revolutionary design was conceived by astronomers from the University of California, stands in the foreground. Also participating in the news conference were (next to Keck) Julian von Kalinowski, a director of the Keck Foundation, and David Gardner, president of the University of California.

The grant is the largest private gift ever made for a single scientific project. W. M. Keck, the founder of the Superior Oil Company, established the foundation in 1954. Since then it has been particularly dedicated to educational funding for the earth sciences, natural resources and engineering, and to medical research. Most of its awards have been to organizations and institutions in southern California.

Goldberger read a number of congratulatory telegrams at the news conference, including one from President Ronald Reagan, which said in part: "This joint venture by the University of California and the California Institute of Technology excites the imagination of anyone who has ever looked up at the stars in wonderment. The Keck ten-meter telescope high atop Mauna Kea in Hawaii will open windows on parts of our universe that have never before been seen. I commend everyone associated with the W. M. Keck Foundation for exceptional generosity, and I offer my best wishes for a new year that has started off with a truly 'Big Bang.'"

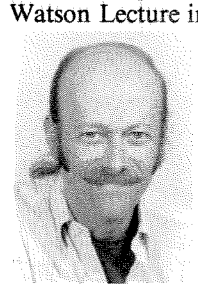
Construction of the telescope is expected to begin next year. "The W. M. Keck Observatory," beginning on page 5, describes some of the innovative technology of its construction and some of the windows it will open.

Auspicious Beginning

Robert Finn joined the *E&S* staff the day of the news conference and makes his debut in this issue with the article on the Keck Telescope. Bob has an AB in biology from the University of Chicago and earned his MS in psychobiology at UC Irvine. He has published in his own field and for three years wrote and edited instructional materials for Beckman Instruments. As a science writer he has contributed feature articles and news stories to *Science Digest, The Genetic Engineering News,* and *Science Books and Films.*

Nurturing Neurons

When asked, after his Seminar Day talk last May, what "nature vs. nurture" was doing in its title, Paul Patterson replied that it was there to draw a crowd, which it did. But the phrase does indeed have meaning in Patterson's subject — whether embryonic neurons are predestined for a certain identity or whether they are influenced in their choice by signals that might perhaps be manipulated by researchers. Recent studies have shown that neurons' chemical identities can indeed be "nurtured," which may have enormous significance in diseases involving premature death of neurons or chemical imbalances in the brain. So the somewhat curious title still graces Patterson's article, "Nature vs. Nurture in Building the Nervous System," which begins on page 11. It was adapted from the Seminar Day talk and from his Watson Lecture in November.



Patterson came to Caltech as professor of biology in 1983 after ten years on the neurobiology faculty of Harvard Medical School. His BA is from Grinnell College and his PhD in biochemistry from Johns Hopkins University.

STAFF: *Editor* — Jane Dietrich
Writer — Robert Finn
Production Artist — Barbara Wirick
Circulation Manager — Lynn Healey
Photographer — Robert Paz

PICTURE CREDITS: Cover, inside front cover, 5, 6, 19, 32 — Bob Paz; 21 — Ares Rosakis; 23, 25 — Caltech Archives

Engineering & Science (ISSN 0013-7812) is published five times a year, September, November, January, March, and May, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual Subscription $7.50 domestic, $15.00 foreign, $20.00 foreign air mail, single copies, $1.50. Third class postage paid at Pasadena, California. Published by the California Institute of Technology and the Alumni Association. Telephone: 818-356-4686.
Postmaster: Send change of address to Caltech, 1-71, Pasadena, CA 91125.

ENGINEERING & SCIENCE

CALIFORNIA INSTITUTE OF TECHNOLOGY | JANUARY 1985 — VOLUME XLVIII, NUMBER 3

The W. M. Keck Observatory *Page 5*
Caltech's ten-meter telescope, when completed in 1992, will be the world's largest and most powerful.

Nature vs. Nurture in Building the Nervous System — *by Paul Patterson* *Page 11*
Nerve cells choose a particular identity by reacting to cues in the embryonic environment — cues that can be reprogramed.

A Special Relationship *Page 19*
Four industrial sponsors have joined Caltech in supporting the Program in Advanced Technologies — an innovative model for industry/academia relations.

Pump Lab Reminiscences — *by James W. Daily* *Page 23*
The Hydraulic Machinery Laboratory was set up in the 1930s to test the pumps for the Colorado River Aqueduct project.

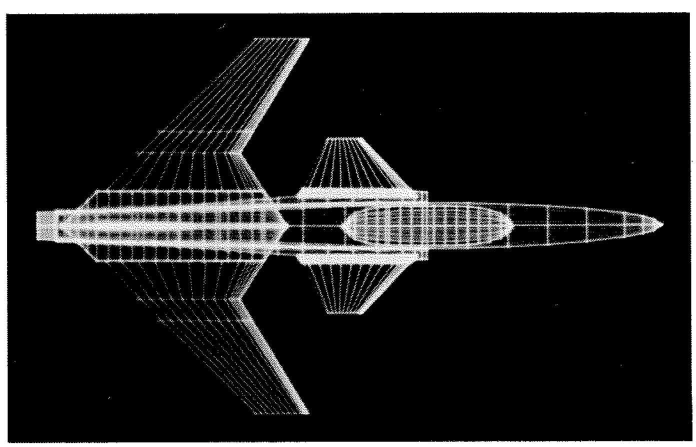
Departments

Research in Progress *Page 29*
Inside Information

Books *Page 31*
On Food and Cooking: The Science and Lore of the Kitchen by Harold McGee

Opinion *Page 32*
Frank Press

Engineering takes on exciting new dimensions in the Air Force



Developing and managing Air Force engineering projects could be the most important, exciting challenge of your life. The projects extend to virtually every engineering frontier.

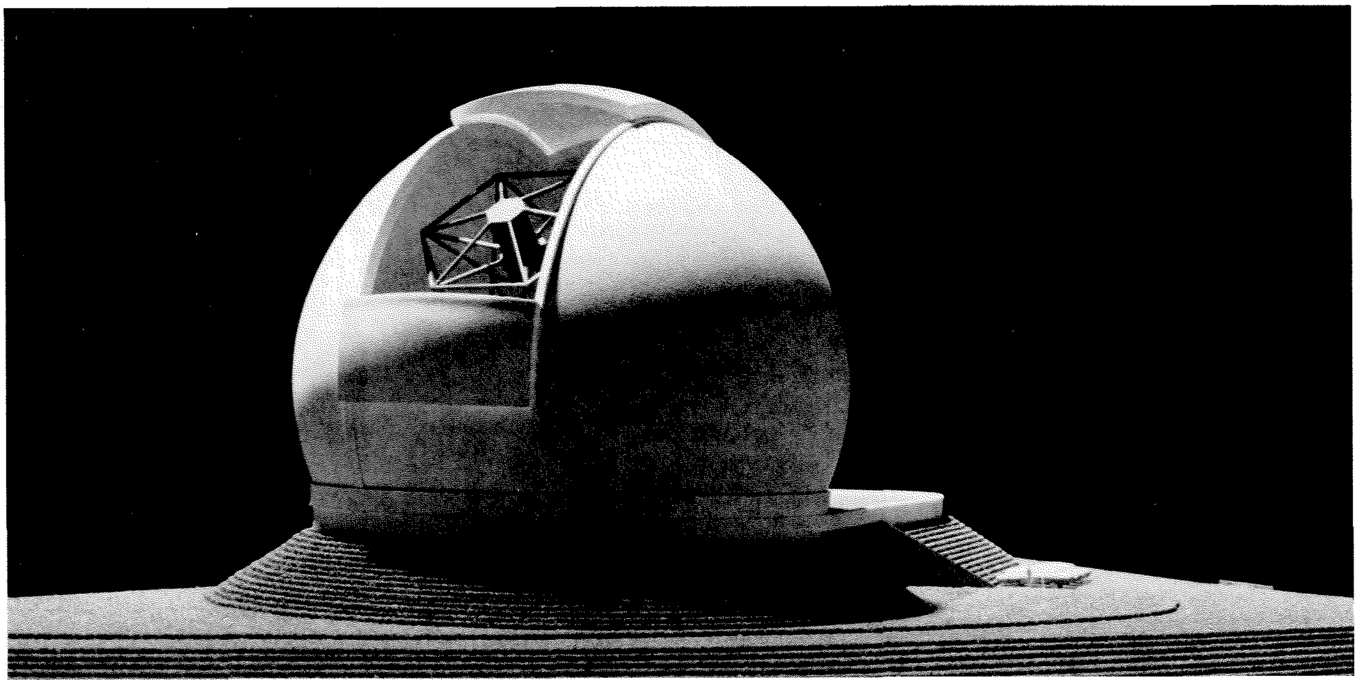
Engineering opportunities in the Air Force include these five career areas: aeronautical, architectural, astronautical, electrical and nuclear. Hundreds of diverse specialties are included in a wide variety of work settings. An electrical engineer may work in aircraft design, space systems, power production, research or communications. An aeronautical engineer might be involved in wind tunnel testing, designing cockpit displays and flight testing.

Most Air Force engineers have complete project responsibility early in their careers. A first lieutenant directed work on a new airborne electronic system to pinpoint radiating targets. Another engineer tested the jet engines for advanced tanker and cargo aircraft.

You may have the opportunity to join the team that moves the Air Force into the Twenty-first Century.

To learn more about how you can be part of the team as an officer, call toll-free 1-800-423-USAF (in California 1-800-232-USAF).
Better yet, send your resume to HRS/RSAANE, Randolph AFB, TX 78150. There's no obligation.

AIM HIGH
AIR FORCE
A great place for engineers.



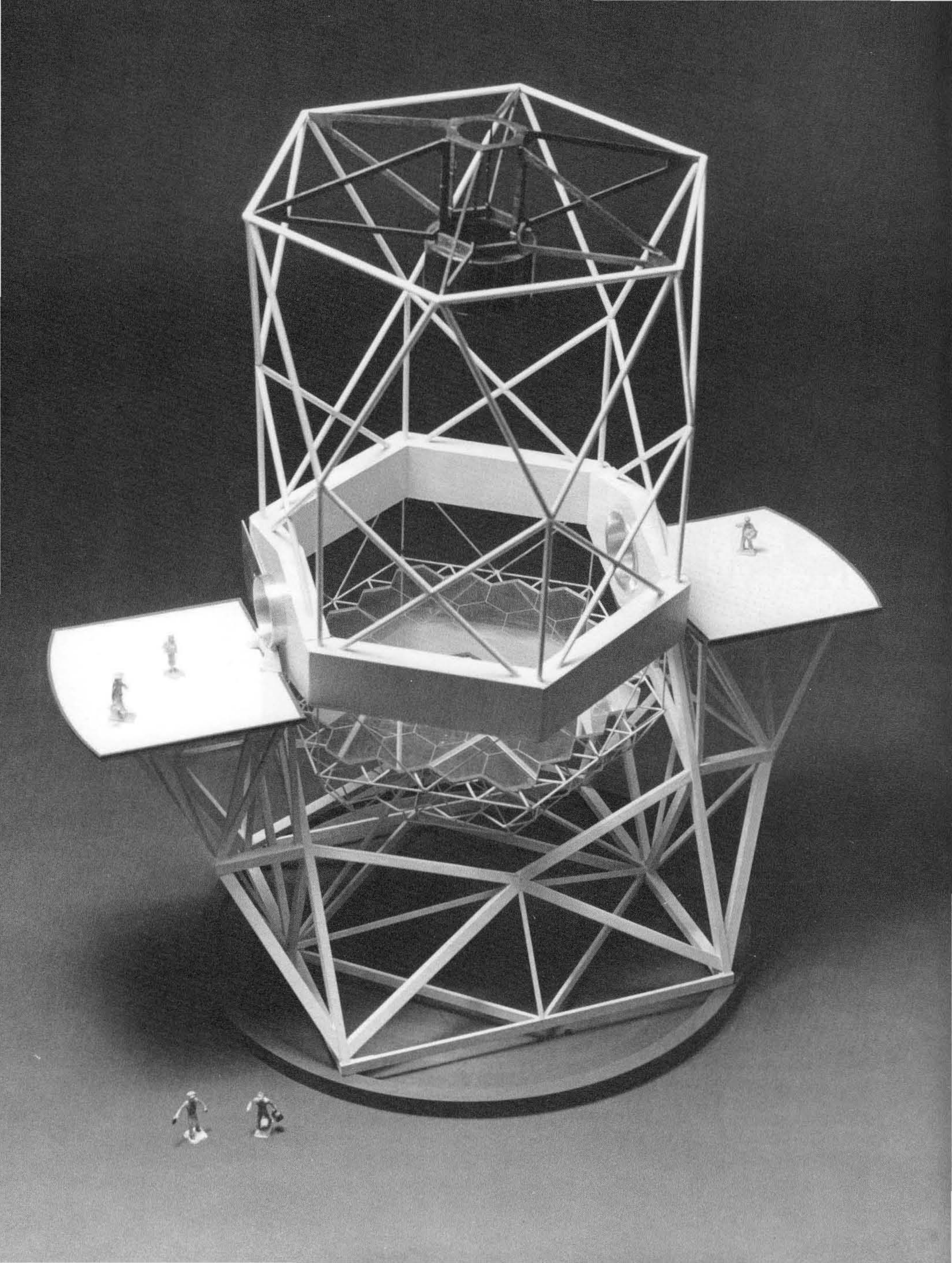
The W. M. Keck Observatory

IT WILL BE POWERFUL enough to see a single candle at the distance of the moon. But the Keck Telescope won't be looking at anything so mundane as the moon. Its faceted eye will look at the center of the galaxy to see if there's a black hole there. It will look at the clouds of hot gas that are the birthplace of stars. It will function as a time machine, peering 12 billion years into the past, three-quarters of the way to the birth of the universe. When construction is complete in 1992, this telescope, the most powerful in the world, will be set to answer fundamental questions in the fields of optical and infrared astronomy.

And it will do so from a most unworldly landscape — the remote high ridge of an extinct volcano already dotted with the white domes of observatories. Perched at the 13,600-foot level on Hawaii's Mauna Kea (White Mountain), a site that has some of the best "seeing," astronomically speaking, in the world, the Keck Telescope will be the culmination of a 15-year, $85 million project to design and build the premier weapon in the astronomical arsenal.

With the largest private gift ever made for a single scientific enterprise — $70 million from the W.M. Keck Foundation — Caltech will provide most of the funds for the observatory's construction. The University of California, whose scientists began designing the ten-meter telescope in 1977, will provide funds for the scope's continuing operation. Observation time will be split evenly between UC and Caltech astronomers, with a fraction of the time going to astronomers from the University of Hawaii, which is providing the site.

The observations these scientists will make should help answer some of the most perplexing of astronomical riddles. One of these involves the large-scale structure of the universe. Galaxies cluster in groups ranging



from small ones only a million light years across, to superclusters, which span nearly a billion light years. Scientists link the small and medium-sized galactic clusters to tiny density irregularities arising among fundamental particles during the Big Bang. But they find the superclusters much more difficult to explain. Some scientists believe that superclusters owe their existence to primordial fluctuations in the density of as-yet-unidentified elementary particles, so particle physicists are vitally interested in the results of these studies as well.

Often superclusters occur in enormous filaments or chains, and the details of these structures that the telescope will reveal may provide important clues to their origin. Computer simulations indicate that the clustering process continues to this day. The ten-meter telescope will be able to trace this back in time by capturing light that's been traveling our way for billions of years. Present day telescopes, like the five-meter (200-inch) Hale Telescope on Palomar Mountain, are just barely able to make out the most distant (and hence the oldest) galaxies, but they can't collect enough light from them to determine their redshifts, a measure of astronomical distance. (The further away an object is, the faster it recedes from us. The faster it recedes, the further its light is shifted to the red end of the spectrum.) Redshift information is indispensable in mapping the structure of these ancient clusters. The ten-meter telescope, with its huge light collecting area, is admirably suited for this sort of work.

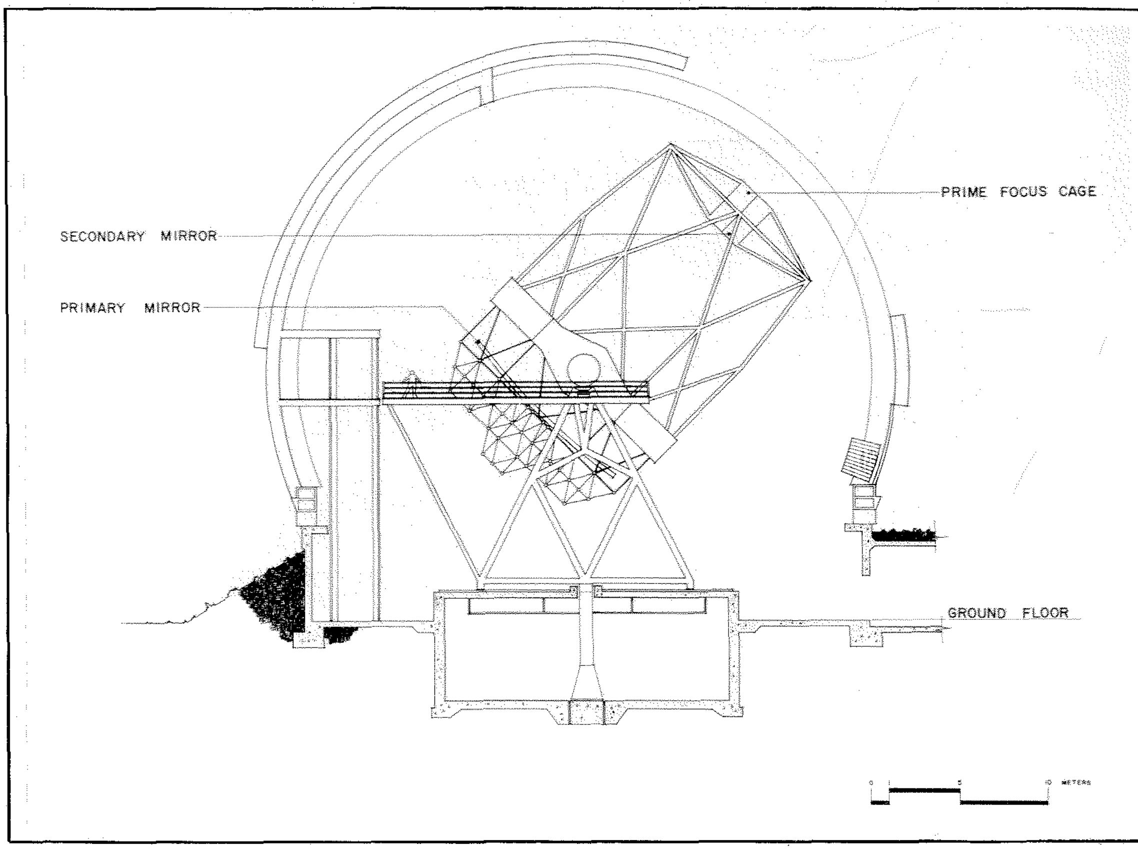
The telescope may also provide a solution to one of the major problems in astronomy — the question of why, where, and how stars form. Thick clouds of dust obscure most star-forming regions. But though the dust blocks visible light, infrared light gets through and the ten-meter telescope will be the biggest infrared instrument in the world, with a resolution three times that of its nearest competitor. The ten-meter telescope will be able to differentiate actual stars from nearby clumps of dust that scatter light and mimic stars. It will also be able to separate one nascent star from another in these densely packed areas. And the telescope may help solve the mystery within a mystery of certain small, young stars, which come into being as the result of an unknown mechanism operating outside the usual star-forming regions.

The telescope's infrared capabilities make it an ideal source of information about our galactic center, which is also obscured by layer upon layer of dust. Studies to date indicate that this is a most peculiar region, containing remnants of supernovae as well as chaotically moving clouds of ionized gas. Many astronomers believe that these constitute the gravitational signature of a black hole located precisely at the center of the Milky Way galaxy. The Keck Telescope will peer through the dust, searching for the high velocity regions that will distinguish a black hole from a compact star cluster, the other major candidate for the structure at the galactic center.

One technique that will be applied to the telescope is known as Multiple Object Spectroscopy (MOS), a process in which the spectra of as many as 100 objects from a single field of view are obtained simultaneously. One of the advantages of MOS is a lengthening of the maximum tolerable exposure. An astronomer may be willing to invest 10 or even 20 hours in a single exposure if 100 good-quality spectra will result. In other words MOS, coupled with the great light-gathering power of the ten-meter telescope, will mean a 600-fold increase in productivity over present telescopes.

Despite the Keck Telescope's high resolution, when construction is completed in 1992 it will not be the highest resolution instrument in use. The Hubble Space Telescope, scheduled for launch by the Space Shuttle in 1986, will have a resolution ten times better than any ground-based instrument because of its freedom from atmospheric blurring. The Space Telescope will also have advantages in ultraviolet spectroscopy (since most ultraviolet light is filtered by the ozone layer) and in certain parts of the infrared region that are attenuated by atmospheric water vapor. But the Space Telescope's primary mirror is only 2.4 meters in diameter. At more than 4 times the diameter and 17.4 times the area, the ten-meter mirror will be better able to provide the large amounts of light demanded by the exacting requirements of spectroscopy. Spectroscopy is needed in quantitative astrophysical studies to determine abundances of the constituents of stars and galaxies, as well as to determine redshifts. The two telescopes will therefore complement each other. The ten-meter telescope will often be used to conduct detailed spectrographic studies of objects first discovered or imaged by the Space Telescope.

Designing a ten-meter telescope, which



The latest design of the telescope and its dome is fairly traditional. The one-story building will be located immediately to the right at ground level.

must have a virtually perfect 76-square-meter optical surface, requires much more than merely scaling up a five-meter mirror like the one at the Palomar Observatory. According to University of California astronomer Jerry Nelson (Caltech BS 1965), who headed the design team, scaling these designs up by a factor of two introduces a number of formidable problems, most of them associated with the primary mirror itself. A ten-meter mirror blank has never been made, and even if it were possible, its cost would be enormous. Polishing such a blank would take a very long time and require extremely large and expensive machinery.

Perhaps even more difficult is the problem of properly supporting the mirror against the force of gravity, since the deflections of a ten-meter mirror are 16 times those of a five-meter mirror. These deflections must be limited to about a thousandfold less than the thickness of a human hair, says Nelson. Such a large mirror would require a massive telescope structure and a dome of enormous proportions, leading, again, to unacceptable costs.

To avoid these difficulties, the telescope's designers have developed a primary mirror design composed of a mosaic of 36 hexagonal mirror segments only 1.8 meters in diameter. Many of the problems are thus reduced to those of a 1.8-meter telescope. This allows a much lighter mirror, and modern computer-aided structural design tools have also made an extremely lightweight telescope structure possible. In fact, at 158 tons, the Keck Telescope will weigh less than one-third as much as the Hale Telescope.

But construction of the ten-meter telescope is not without problems of its own. Polishing the mirror is complicated by the fact that each segment is neither flat nor symmetrical, but rather is one of six off-axis sections of a shallow paraboloid. The design team developed a method called "stressed mirror polishing" to arrive at each of the six shapes. This technique takes advantage of the ease with which opticians can polish a spherical surface. It involves first applying precisely calculated forces to a circular mirror blank, intentionally warping it. The mirror blank is then polished to a concave, spherical surface. Once the applied force is released, the mirror blank springs into the desired final shape. Its edges are then cut off to form the hexagonal outline.

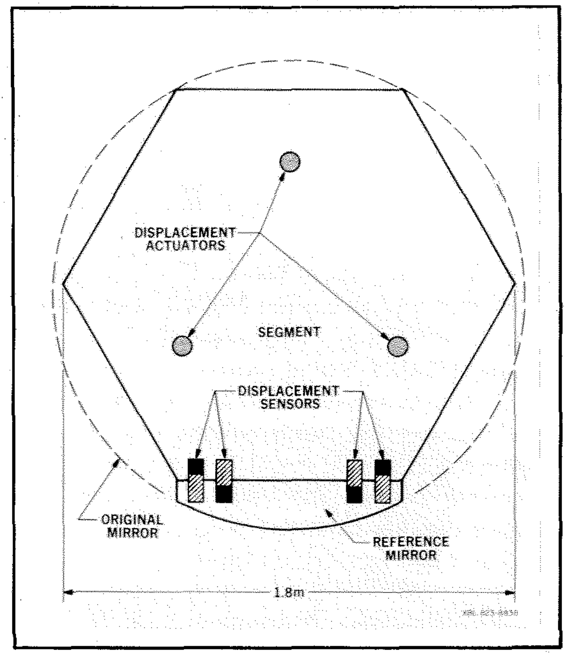
During the cutting of an initial test blank, larger than desired warping occurred. This led to the idea of putting a "stressing" jig on each segment to remove the warp. This dewarping method, whose feasibility has been demonstrated, may also lead to a faster mirror production by allowing more relaxed tolerances during the polishing phase.

These difficulties in polishing the hexagonal segments are minor compared to the problem of polishing a single large mirror. But the multi-segment approach introduces other problems. A single mirror could be held steady in a rigid but passive support. But a system of multiple mirrors must be continually realigned, since the forces that tend to disrupt the aim (gravity, wind, and heat are the most important of these) act differently at each mirror location and change over time. Each segment, therefore, has edge displacement sensors on its back surface that bridge the gaps between one segment and its neighbors. If one segment should move relative to another, these sensors will send a signal to the computer control system. The computer will then make the necessary corrections by adjusting the three actuator pistons that support each segment. In order to maintain a sufficiently stable image, the computer will make such corrections 300 times a second to a tolerance of 3.75 nanometers. In this way the 36 segments, each individually controlled, will constitute, for all intents and purposes, a single mirror.

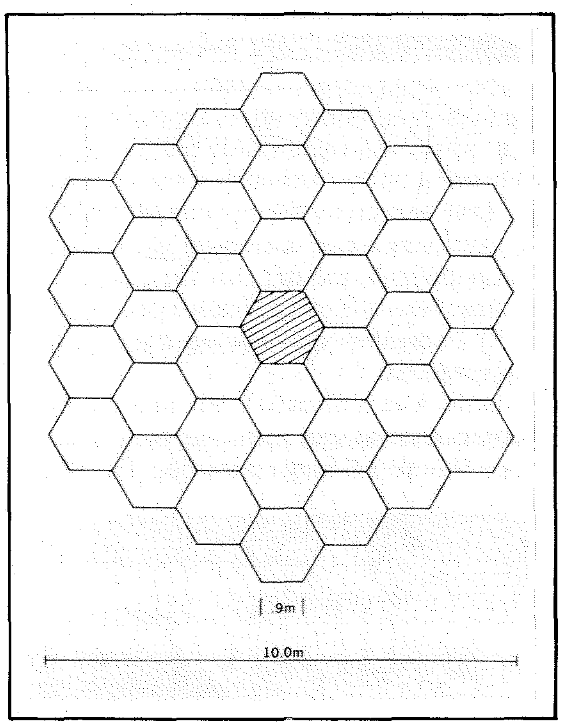
Light falling on this mirror will be directed to the telescope's six focal points, where various instruments such as cameras, spectrographs, photometers, and polarimeters will be housed. The designers have deferred decisions on the exact specifications of many of these instruments because of the rapid pace of technological advance. Light detectors in particular are currently undergoing dramatic improvements in sensitivity coupled with decreases in size, and these characteristics are fundamental starting points in some instrument designs. This flexibility to take advantage of the latest advances in instrument and detector technology is a further advantage ground-based telescopes have over space platforms.

But even a telescope in the best location in the world can have its seeing degraded by thermal inhomogeneities causing local atmospheric turbulence. Experience has shown astronomers that, ironically, the most damaging source of such turbulence is often the observatory itself. Ideally, all parts of the telescope would maintain the same temperature as the surroundings, but in practice this is not possible. To minimize damaging temperature gradients the designers will take a number of steps. These include painting the dome with a special, heat-reflective paint; actively controlling the temperature of the dome floor so that this massive structure will be neither a source nor a sink of heat; and locating much of the heat-producing electronic equipment in the heavily insulated observatory building.

This one-story building will contain the control room, offices, a library, and mechanical and electrical shops, including an aluminizing facility where the mirrors will be



Each hexagonal mirror will be cut from a circular mirror blank. Displacement sensors will bridge the gap between adjacent mirrors, will detect any motion of one mirror relative to its neighbors, and will compensate for this motion by adjusting displacement actuators 300 times a second to a tolerance of one one-thousandth the diameter of a human hair.



The segmented primary mirror as it would appear to a star. Up close one would see that the segments are neither flat nor regular hexagons, but rather are off-axis sections of a shallow paraboloid. The central hexagon contains no mirror.

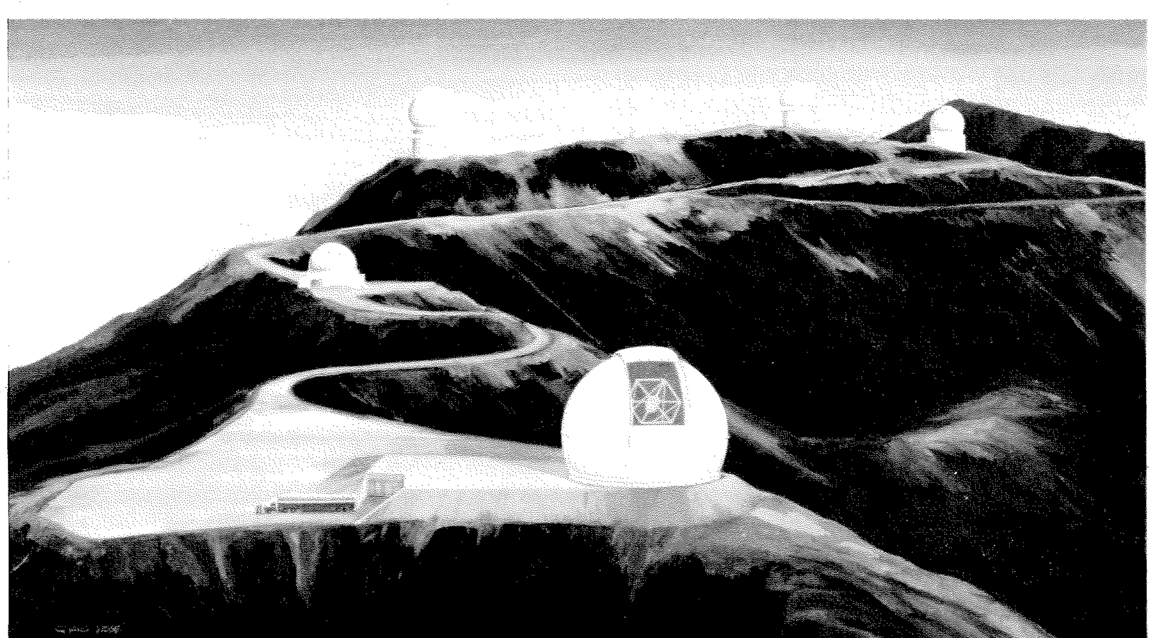
cleaned and resurfaced. Some of these rooms will be supplemented with oxygen, since the atmosphere at 13,600 feet contains only 60 percent of the oxygen present at sea level. This low oxygen level significantly degrades a person's mental and physical performance, but often people don't notice this reduction in performance soon enough. Several of the other observatories on Mauna Kea provide masks and bottled oxygen to their personnel, but although this is a much less costly option than oxygenating whole rooms, studies show that these aids are underused. The supplemental oxygen will not provide a sea-level environment, which would be prohibitively expensive. Instead, the oxygen levels will simulate conditions at the Hale Pohaku base camp at 9,200 feet, where the astronomers and support staff will study, eat, and sleep.

Although there's a strong tradition of astronomers making their observations while in residence at a telescope, full remote control of the Keck Telescope will be possible. This will allow astronomers to make their observations from their home offices around the world, which will significantly reduce travel and housing costs. Although some astronomers may be secretly disappointed by this, since justifying a trip to tropical Hawaii will be more difficult, the fact that the temperature atop Mauna Kea is usually between 30° and 50° Fahrenheit may assuage their disappointment.

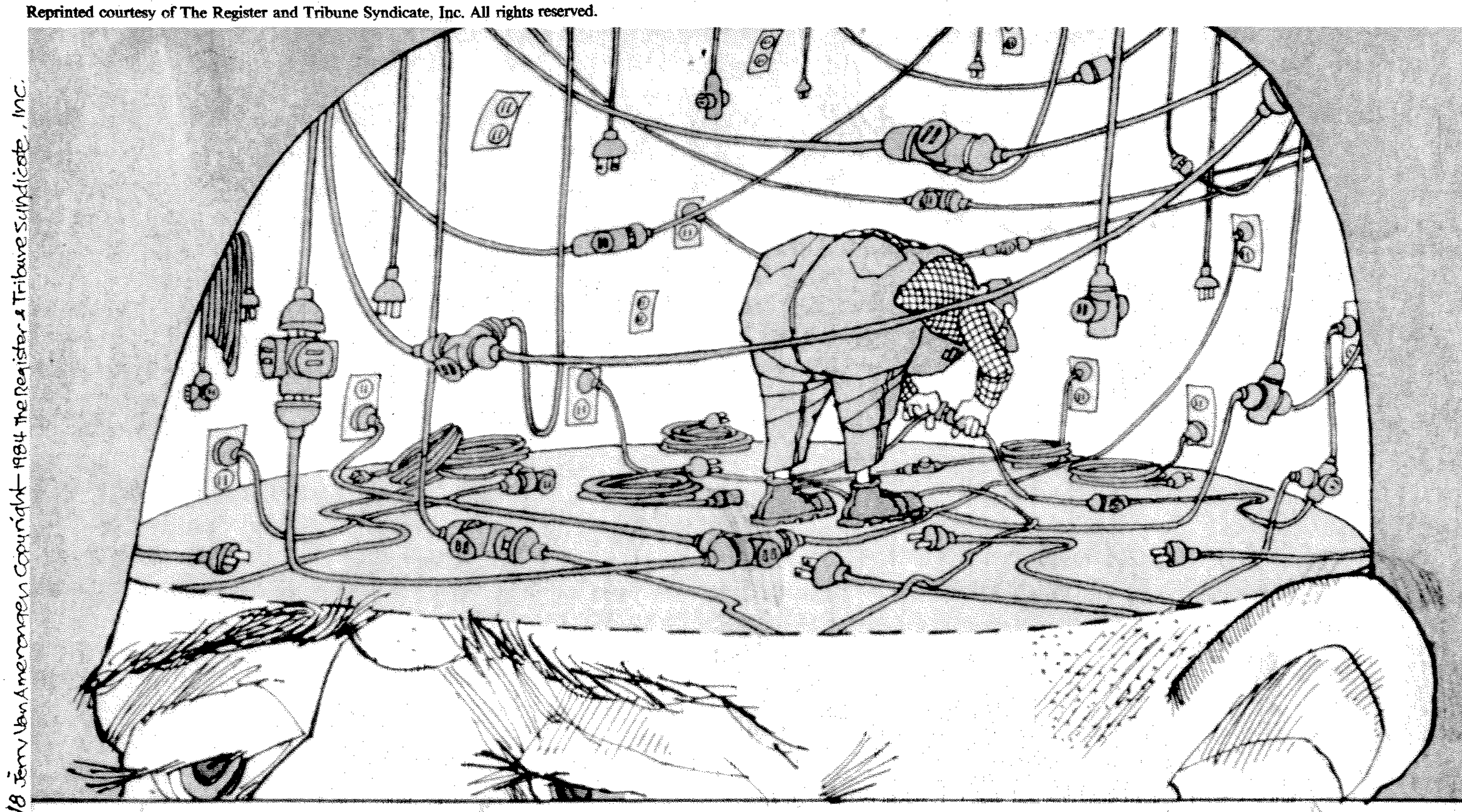
Mauna Kea is already home to a number of major observatories including the Canada-France-Hawaii 3.6-meter telescope, the NASA 3.0-meter Infrared Telescope Facility, the United Kingdom 3.8-meter Infrared Telescope and the University of Hawaii 2.2-meter telescope. In addition, the Caltech 10.4-meter telescope for submillimeter wavelengths and a United Kingdom-Netherlands 15-meter telescope for millimeter-wave observations are under construction. Caltech scientists anticipate that the Keck Telescope will be linked to the 10.4-meter telescope to form a 400-meter-baseline interferometer at submillimeter wavelengths. This will allow them to examine sites of star formation, for example, in unprecedented spatial detail.

Future hopes for the site call for the construction of a second, identical ten-meter telescope that may be used in conjunction with the first to perform optical interferometry. The effective resolving power of such tandem observations, with both telescopes trained on the same area of the sky, would be equivalent to that of a telescope having a single mirror with a diameter equal to the distance between the two scopes. No funds have yet been raised for the second telescope, which could cost an additional $60 million.

Even without its twin, the Keck ten-meter telescope will be the source of significant advances in astronomical knowledge for decades to come. Considered together with the Hubble Space Telescope and a number of other observatories that may come on line within the next decade, the Keck Observatory will set the stage for possibly the fastest increase in our understanding of the cosmos since the time of Galileo. □ — *RF*



The Keck Telescope (foreground) will share Mauna Kea's fine "seeing" with several other observatories. Someday a second, identical ten-meter telescope may be built in the cleared space at left. Astronomers could then perform optical interferometry, an extremely powerful technique that requires tandem observations of a single point in space.



How the brain works.

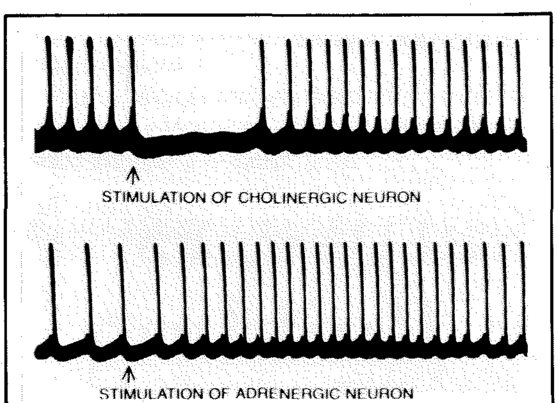
Nature vs. Nurture in Building the Nervous System

by Paul Patterson

GENERATION OF CELL DIVERSITY is one of the central problems of developmental biology. Every embryo starts as a single cell, the egg, and by maturity countless numbers of cells have been generated of many different types, from muscle cells to sperm cells. In the brain alone there are an estimated 10 billion nerve cells of thousands of different types. Added to this diversity is the fact that these nerve cells, or neurons, are interconnected in a highly complex way. For instance, a single motor neuron in the human spinal cord carries out the mundane task of controlling the contraction of a handful of muscle fibers in the arm or leg. To accomplish this simple task, this single neuron receives some hundred thousand connections from other nerve cells.

The shape and size of neurons is also diverse. For example, the Purkinje cell, found in the cerebellum at the base of the brain and involved in controlling balance, contains an extremely elaborate dendritic tree, where it receives connections from other kinds of nerve cells. These connections, or synapses, are made on the numerous branches and tiny spines of the dendrites. At the other extreme are the neurons that control the contraction of the iris. These have no dendritic tree at all; all the inputs to these neurons are on the cell body.

In addition to their size and shape, number of branches, and other morphological features, neurons can also be distinguished from one another by their chemical composition. Most neurons make chemical synaptic connections with each other, and a variety of different transmitters are used at these connections. For example, adrenergic neurons use catecholamines as transmitters in their synapses on the heart, whereas cholinergic neurons release acetylcholine at their connections with the heart. We distinguish these two transmitters chemically because their effects on target cells are quite different. Acetylcholine inhibits the heartbeat, while catecholamines excite it. In the autonomic nervous system the balance of these two transmitters controls the rate of the heartbeat. Therefore, it is very important for a neuron to know what kind of transmitter to produce. Certain neurons should produce excitatory transmitters, and others should produce inhibitory transmitters. Mistakes in this chemistry would lead to a speedup of the heartbeat when it should rest and vice versa.



Stimulating a cholinergic neuron causes the spontaneous contractions of the heart muscle to stop temporarily (top), while stimulating an adrenergic neuron speeds up the contraction frequency (bottom).

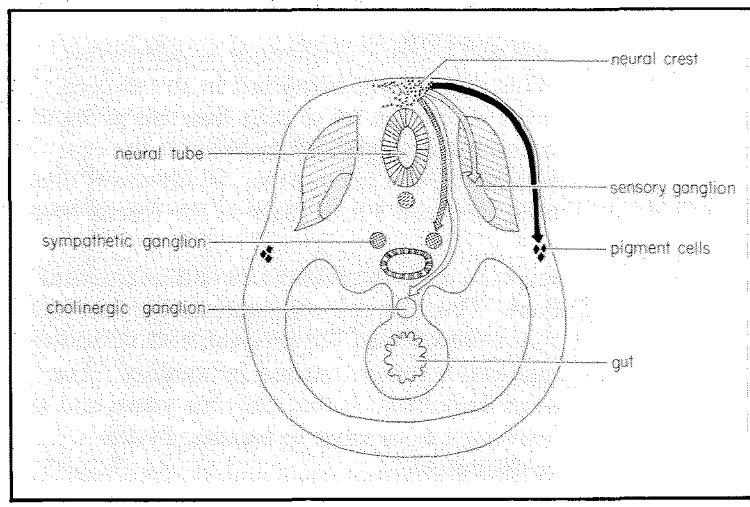
How do neurons decide which kind of transmitter to produce? Two explanations have been offered as to how this might come about. Sidney Brenner (of the Medical Research Council, Cambridge, England) has characterized these two extremes as the European plan versus the American plan. In the European plan the developing neuron would behave according to its ancestry or lineage; it would do what its family had always done. Neurons on the American plan, on the other hand, would do what their neighbors tell them to do. By this we mean that the local environment surrounding each cell would play a role in influencing its development. Recent work has shown that the chemical identity, or phenotype, of each neuron is surprisingly plastic, even in adult animals. Furthermore, neurons are influenced by local cues or signals in their environment, such as other cells, hormones, and so on.

How does the nervous system develop during embryogenesis? After fertilization, folds rise up on the surface of the embryo and meet to form a tube. This simple neural tube will give rise to all the cells of the brain and spinal cord, which make up the central nervous system with its 10 billion neurons and supporting cells. In addition, there is a peripheral nervous system. These neurons come from a group of cells at the top of the neural tube, called the neural crest. The neural crest cells migrate to many different locations in the embryo and take up many different identities. Some migrate to the skin to become pigment cells; some migrate out and cluster to form ganglia or groups of neurons. Some of these are sensory neurons, which send one process out to the periphery in the skin, where they mediate sensations such as touch, heat, cold, or pain. Other neural crest cells migrate to still different locations and become the autonomic nervous system. These are the neurons that innervate the heart, the iris, various glands and smooth muscles, and thereby control blood pressure, pupillary dilation, and so on. The autonomic system is, in turn, composed of the sympathetic and parasympathetic systems, which use the transmitters mentioned previously — catecholamines and acetylcholine, respectively.

These various derivatives of the neural crest do not all come from the same axial level of the embryo. The adrenergic neurons of the sympathetic system come from the lumbar, or middle, region of the crest. The cholinergic neurons of the parasympathetic system innervating the intestine come from the rostral and caudal regions of the crest. This arrangement suggests, in terms of how these cells decide what kind of phenotype they will take up, that perhaps the neural crest is made up of at least two populations of cells. Cells in the lumbar region may be predestined to be adrenergic sympathetic neurons. Cells from the rostral and caudal regions may be predestined to be cholinergic neurons innervating the gut. This possibility corresponds to the European plan. The other possibility would be that the neural crest cell population is homogeneous and naive. The cells migrate out passively and are led to locations appropriate for that axial level of the embryo. Cues in these locations then instruct the neuron as to its fate. This possibility corresponds to the American plan.

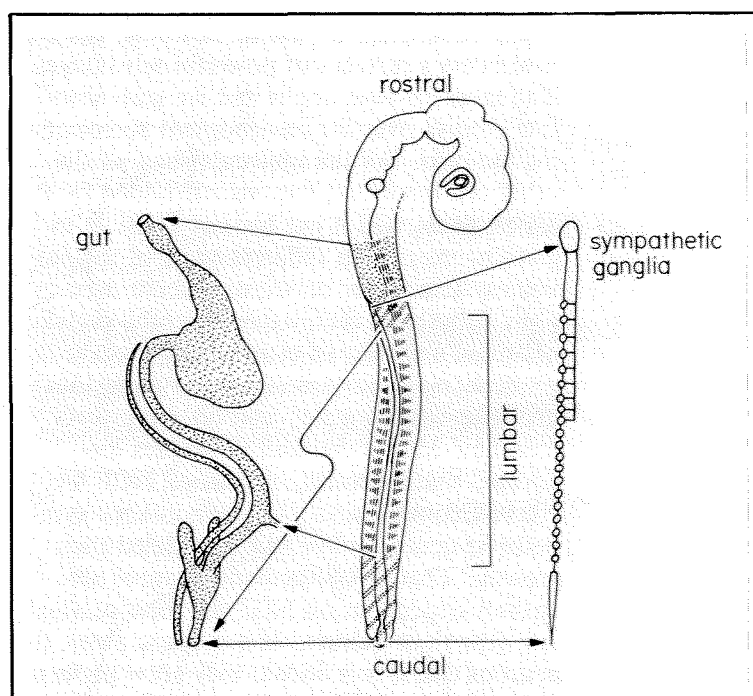
How do we go about investigating which of these plans is the correct description? One way — a very dramatic way of doing experiments on this system — is to take neural crest cells from the rostral region of one embryo and transplant them in a different embryo at the lumbar region, so that cells that would normally have become cholinergic are now put in a location where cells normally become adrenergic and vice versa. In order to do this experiment, of course, it is not enough just to transplant cells, but we have to keep track of where the cells go. We have to know the difference between donor cells and host cells, so that the fate of the donor cells can be determined. Nicole LeDouarin and colleagues in Paris have solved this problem by transplanting crest cells between two species, quail and chick.

Cells from each of these species can easily be distinguished from one another by simply looking at their nuclear staining patterns under the microscope. They transplanted the neural crest from a quail donor embryo into a chick host, effectively transplanting cells that would have become cholinergic neurons in the gut into a lumbar location in a different embryo. Do the quail cells now find their way to their original destination or do they migrate to the new location determined by the local environment? The result is that at least some of the cells do migrate to the new location appropriate for that axial level and become sympathetic neurons. Furthermore, some of these quail cells stain for catecholamines. Thus some of the cells in this population of crest cells that would, if they had been left in place, have become cholinergic neurons in the gut, when put into a new location migrate to an entirely new place and take up a new identity.



This cross section of a developing chick embryo shows the migration pathways of various derivatives of the neural crest.

This series of experiments shows that the neural crest cell population can be influenced as to the kind of phenotype, or chemical identity, they develop by the environment in which they find themselves. These important experiments raise several further questions. One question is: What happens at the level of individual cells? This experiment dealt with populations of cells — how do individual cells make their transmitter decision? Two very different hypotheses can be used to explain these results. It is possible that no individual crest cell is actually changing its identity after the transplantation; the crest population could be heterogeneous, contain-



Sympathetic neurons arise from different axial levels of the neural crest than do the cholinergic neurons of the gut. (Adapted from LeDouarin, 1977.)

ing two populations of predetermined cells that will become cholinergic or adrenergic. What might have happened in this experiment is that the set of cells that was going to become adrenergic did so because the environment was permissive. If, however, these cells had been left in place at the rostral level, they would have migrated out, found themselves in a nonpermissive environment, and died. Thus the cells appropriate for that location were selected for survival, and no individual cell actually changed its identity. The other hypothesis is that cells are naive and are instructed as to what to become by the environment.

The second question raised by the transplantation experiments is: What is the nature of the molecular cues that are instructing or controlling the survival of these cells? To answer these questions we turn to the technique of cell culture — growing cells *in vitro* in dishes. The problem with cell culture is that once we take cells out of the body and put them in a dish, we assume responsibility for their life and death. We have to provide all the functions that the body normally provides; we have to take over the role of the circulatory system by providing all essential nutrients, the role of the kidney by removing toxic wastes, the role of the lungs by providing an appropriate mixture of gases, and so on. If this is not done very precisely, cells become sick and die. Those of us working in the field of cell culture are very familiar with the phenomenon of cell death. If the appropriate conditions are found, however, cell culture offers a number of powerful advantages. The most obvious one is that we gain absolute control over the environment surrounding the cells. All the molecules and all the other cell types that they see are added by the experiments, and it has become possible to grow neurons from different parts of the nervous system under conditions where they grow entirely by themselves or in the presence of any of a variety of other kinds of cells.

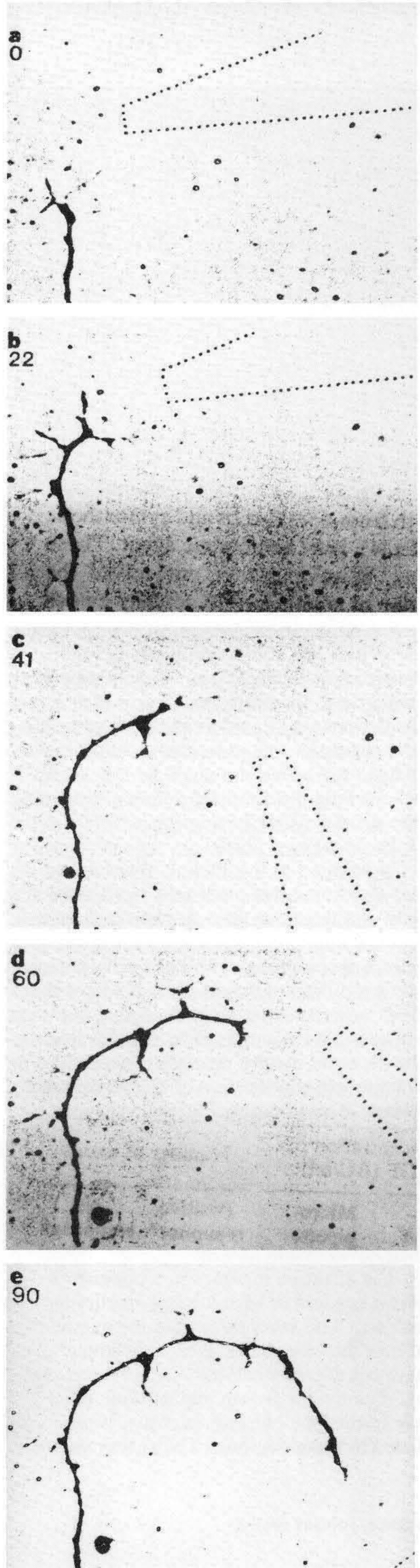
Early on in the search for the molecules necessary for neuronal survival and growth, Rita Levi-Montalcini and colleagues discovered that a protein, christened NGF for Nerve Growth Factor, was able to keep sympathetic neurons alive and stimulated their growth. That is, sympathetic neurons are entirely dependent on NGF for their survival and growth in culture. If it is taken away, the neurons die; if it is added, they grow perfectly well. If an antibody against NGF is injected into an embryo to bind and inactivate the protein, the animal will grow up without a sympathetic nervous system. Furthermore, if extra amounts of NGF are injected into the embryo, it grows up with more sympathetic neurons than a normal embryo. This latter result was a profound finding. It has been subsequently found that many neurons die throughout the nervous system as a part of normal development. About one-half to two-thirds of all the neurons that are born in the embryo die before the animal reaches maturity. We now see this naturally occurring neuronal cell death as a kind of Darwinian struggle for survival; that is, the neurons appear to compete with one another for trophic or growth factors such as NGF. If extra amounts of this factor are added, then neurons that normally would have died can survive; take away the NGF, and all of the neurons die.

These observations raise the question of which cells produce NGF or trophic factors like it. It is now clear that target tissues toward which the neurons' axons are growing (heart cells, iris muscle, various glands, and so on) actually produce NGF. Wherever sympathetic neurons are found, it seems that the target cells synthesize and release this neural growth factor. What happens when a neuron actually gets to the source of the nerve growth factor? It binds it on its surface, internalizes it, and transports it from its growing tips back to its nucleus. In fact, neurons such as sympathetic neurons that are sensitive to NGF can actually change the direction of their growth in culture toward the source of NGF. The growing axon tips, or growth cones, can orient towards this soluble trophic molecule. It is also clear that the direction that nerves grow can be controlled by the surface on which they are moving. A good example of this comes from the work of Paul Letourneau at the University of Minnesota. He coated dishes with various pathways made of different kinds of artificial polymers and found that the growth cones move best on the surfaces to which they adhere well. Artificial substrates can support and guide growth; biologically relevant cells, such as muscle cells and glial cells, secrete a large protein complex into the culture medium, which will also stick to a dish and coat it. This biological substrate can also control the direction of axon growth just as the artificial polymer did.

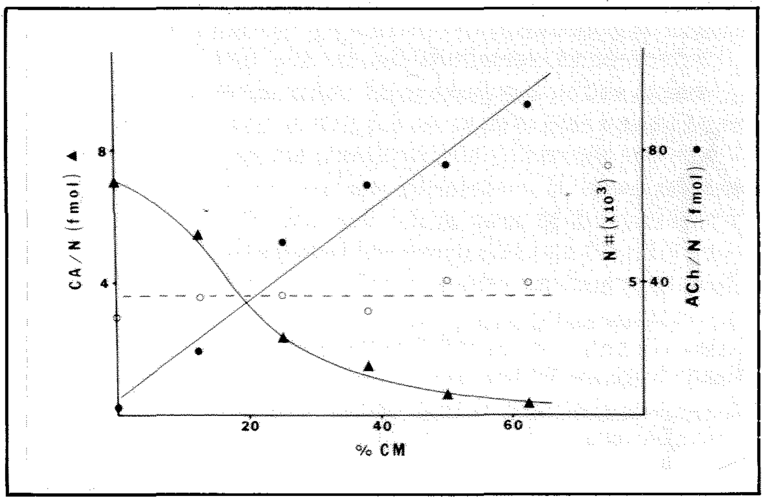
Our group at Caltech and others are characterizing the molecular nature of this protein complex to try to see what molecules are involved in this guidance and growth stimulation. Using a novel method, we made an antibody that binds to this complex somewhere near its active site, so that it blocks the activity of the molecule. This antibody should be able to tell us something about the chemistry of the complex. Research fellow Arlene Chiu and graduate student Josette Carnahan are using the antibody to localize the molecule and have discovered it in places in the animal that are known to support regrowth of damaged axons. It was well known that when peripheral axons in the limbs and body cavity are damaged, they can regenerate back to their target sites, whereas once central nervous system axons (in the brain and spinal cord) are damaged, there is very little ability to grow back properly. Finding the molecule in places that are known to support regeneration suggests the possibility that this molecule itself could be one of the key factors in axon regeneration. Another way of stimulating regeneration, of course, would be through soluble molecules such as NGF.

A third way of looking at regeneration, or lack of it, has to do with the formation of scar tissue. Central nervous system neurons, damaged, for example, in an auto accident, may not be able to cross the simple physical barrier created by the scar where damage occurred. The same type of barriers do not appear to form in the peripheral system where regeneration can occur. We now know, however, that the growing tips of axons release enzymes, called proteases, that may help them get through such barriers. Proteases break down large proteins into small pieces. Research fellow Randy Pittman has used biochemical techniques to characterize the proteases released by growing neurons. He puts neurons in the central chamber of a culture dish and lets them grow their axons out into the surrounding chambers in a radial fashion so that the fine, distal processes and growth cones end up in the outermost chamber. He then collects the culture medium off the three different chambers — the cell bodies from the center, the axons from the middle, and the growing distal processes from the outer chamber — and analyzes it biochemically by electrophoresis to see what kinds of proteases are present.

In electrophoresis, proteins migrate in an electric field through a gel and separate according to their molecular sizes. Once



In an experiment by Gunderson and Barrett of the University of Miami, an axon with a growth cone on its tip turns toward a pipette (dotted line) with protein NGF. The numbers indicate elapsed minutes.



As the concentration of heart-cell factor in the conditioned medium is increased, the neurons' ability to produce acetylcholine rises with a corresponding decrease in their ability to produce catecholamines.

separated, the proteases eat little holes in the protein of the gel, so when the gel is stained for protein, there are bare spots where the proteases are located. In this way it is possible to analyze very small amounts of mixtures of proteases from, for instance, the growth cone. In other experiments Pittman found that one of these proteases has the properties of a collagenase. This enzyme breaks down the protein collagen which is the fibrillar material found in all of our extracellular spaces, as well as in hair and fingernails and so on. Collagenase might be very useful to a growing neuron tip to help the axon get through the extracellular space, which is a jungle of collagen fibrils.

In addition to this finding, Pittman has also discovered that other cells (such as heart cells — a target for these neurons) release a protease inhibitor. Thus, when the growing neuron is confronted with heart cells, it runs into a significant amount of an inhibitor that binds irreversibly to the protease and inactivates it. We're intrigued by the idea that growth could involve protease release and stopping growth could involve inhibiting that release. This discovery illustrates the idea that axon growth is not a one-way street; that is, axons don't just go wherever they are told. Rather, there seem to be many interactions. Growing axons react to soluble and surface-bound protein cues, and they can also modify their environment as well.

The direction in which neurons grow may play a key role in what kind of identity they take on. This takes us back to the question of how the cells choose their transmitter. We have considered whether NGF, a critical signal required for growth and survival, plays a role in the type of transmitter that is produced by these neurons. The answer seems to be no. Linda Chun and I did a series of experiments a few years ago showing that there is a different protein that can control the phenotype of these neurons. In particular, we found that a protein secreted by heart cells can control whether sympathetic neurons become cholinergic or adrenergic — whether they have an excitatory or inhibitory transmitter. It's a very simple experiment of growing heart cells in a dish, collecting the medium containing a variety of proteins of the heart cells, and putting it on the neurons in a separate dish. Neurons are then grown in various concentrations of this so-called conditioned medium, that is, a medium that has been incubated in heart cells.

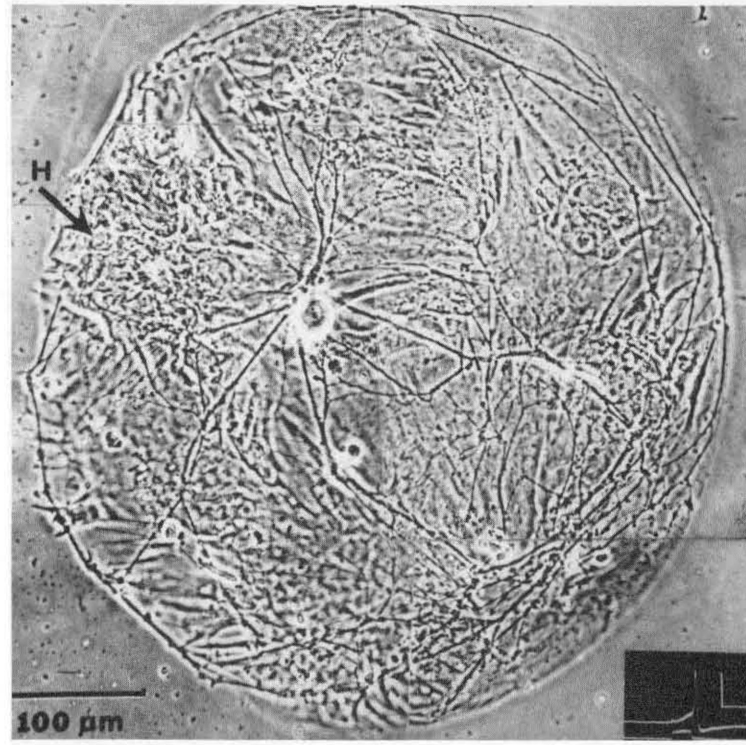
When we assay the ability of the neurons to synthesize and store catecholamines versus acetylcholine, our two transmitters of interest, we see that adding more and more of the heart-cell factor increases the neurons' ability to produce acetylcholine, and there is a corresponding decrease in their ability to produce catecholamines. So there is a reciprocal change in the transmitter identity of these cells caused by a protein, which research fellow Keiko Fukada has been purifying. This heart cell protein, unlike NGF, does not affect the survival of the neurons. It does not affect their growth either; rather it instructs them as to what kind of neuron they're going to become — what kind of chemical identity they will adopt.

This heart cell conditioned medium experiment was also done with populations of neurons and, again, we wanted to know what happens at the level of single cells. To do that we needed to follow individual cells during development. To this end we have cultured single nerve cells on islands — called microcultures — of heart cells. We can impale the heart cell and the neuron with microelectrodes, stimulate the neuron, and see what effect this has on the heartbeat. By seeing whether the heart cells are speeded up or slowed down, we can determine if the transmitter released by the neuron is a catecholamine or acetylcholine, respectively.

Edwin Furshpan and David Potter and their colleagues at Harvard have done this experiment on individual neurons. Recording from the heart cells showed that stimulating the neuron causes a substantial increase in the contraction rate of the heart cells. This is a classical effect of catecholamines, and the effect can be blocked completely by the drug propranolol, which is used in some cases to control blood pressure. Thus this neuron started out the experiment as an adrenergic neuron using catecholamines as a transmitter. When the cholinergic factor from heart cells was added, stimulating the same neuron some days later speeded up the heartbeat again as it had done before, but there was also a slight inhibition. (This effect can be seen better if the excitatory effect is blocked by adding the drug that blocks adrenergic speedup.) The neuron had become dual- functional, seeming to release both acetylcholine and catecholamines. Some weeks later, stimulating the same neuron revealed no speedup of the heartbeat at all — just the inhibition. The neuron had begun the experiment with an adrenergic identity, midway through it produced both transmitters at the same time, and by the end it was completely cholinergic.

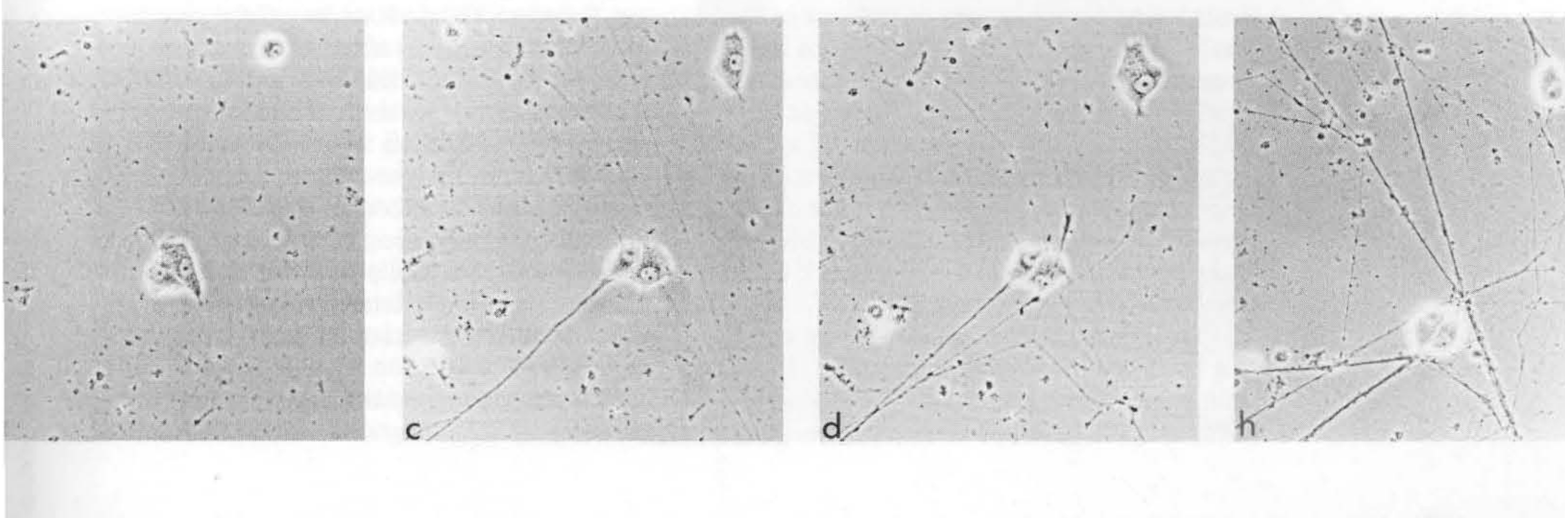
Studies like these demonstrate that individual postmitotic neurons can be made to change their identity by external signals. This is true also of neurons taken from adult rats. This kind of plasticity may be important in thinking about whether the results of the previously described experiments on transplanting neural crest cells were due to selection or instruction. It's possible in those experiments also, as in the culture one, that environmental cues instructed the cells as to which developmental pathway to follow.

Cells also have another kind of phenotypic decision to make — whether to become a neuron or a non-neuronal cell. Klaus Unsicker and colleagues at the University of Marburg, Germany, have studied this phenomenon, as have Allison Doupe and myself — specifically the decision whether to become an adrenal chromaffin cell or a sympathetic neuron. These are two quite different cells — different in their morphologies, chemistry, and the antigens on their surfaces. Adrenal chromaffin cells have to be grown in the presence of the hormone hydrocortisone, which is very important in development. If the corticosteroids are removed from the culture medium and protein NGF is added, these chromaffin cells will grow processes. In a couple of weeks they become neurons; they get round and much larger; they grow long axons, and they lose all the characteristics of a chromaffin cell. Furthermore, we have shown that these neurons derived from chromaffin cells can be converted into cholinergic neurons by using the cholinergic protein from heart cells. Thus they can go the complete route of being changed from an adrenergic chromaffin cell to a cholinergic neuron.

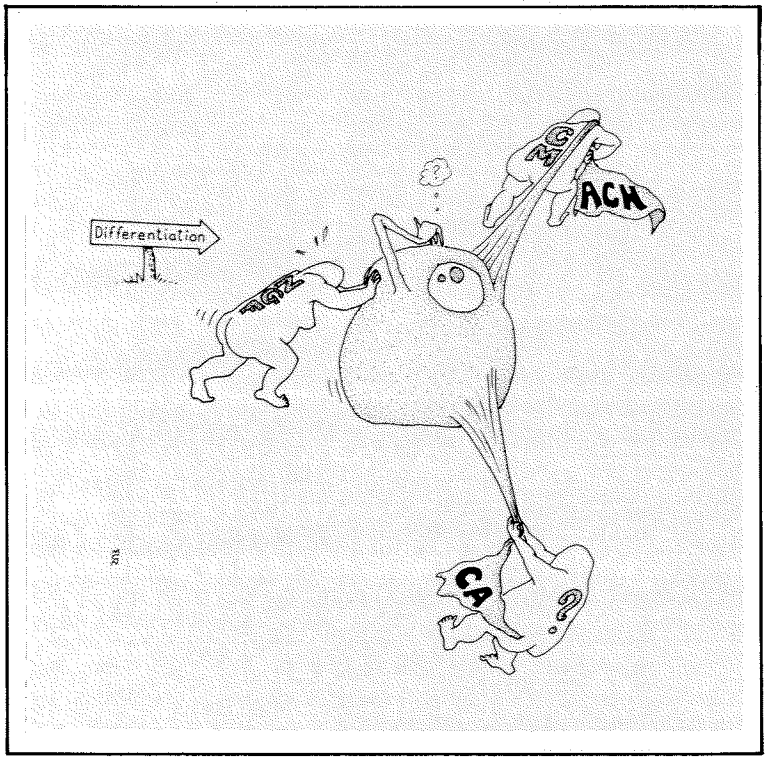


A single neuron extends its branches over a conditioned medium that has been incubated in heart cells.

People often ask what the practical sig-



An adrenal chromaffin cell (a), when corticosteroids are removed and protein NGF added, begins to grow processes (c, d), finally turning into a neuron (h).



When pushed by NGF, a neuron tries to decide which direction it should take. A conditioned medium of heart cells pulls it toward producing acetylcholine, while an as-yet-unknown factor is pulling it in the direction of catecholamines.

nificance of all this is. In the case of neuron survival, I've described very briefly some of the work in terms of characterizing signals that have absolute control over the survival of a given population of neurons. Why might this be important? There are pathological states that involve premature death of subpopulations of neurons. Alzheimer's disease is a classic case, in which neurons in certain parts of the brain die prematurely, leading to senility. In amyotrophic lateral sclerosis, motor neurons die prematurely, leading progressively to paralysis of the limbs and eventually to death. It would be interesting to know whether trophic factors that can keep those neurons alive in culture could be used to keep them alive in such disease states.

Second, a number of pathologic conditions are thought to be caused by chemical imbalances among groups of neurons in the brain. For example, the symptoms of Parkinsonism and schizophrenia can be characterized by imbalances between adrenergic and cholinergic functions of the brain. If we could get more information on the molecules that control that balance (such as the cholinergic protein signal from heart cells), it would be interesting to see if we could reform the balance in those diseases.

Third, work is now being done on rectifying brain lesions via transplantation. In certain cases it is possible to correct the behavioral deficit caused by lesions in the rat brain by transplanting fetal brain tissue from a rat embryo. In Sweden several transplants have been done with terminal Parkinson's disease patients, moving a piece of their adrenal medulla (containing the adrenal chromaffin cells) into the brain at the site of the lesion. This is of interest to us, because we're looking at the ability of cultured chromaffin cells to become neurons and what factors control the type of neurons they become.

Finally, we can now at least imagine solving the problem of axon regeneration in the damaged central nervous system. For example, the protein complex mentioned earlier, which promotes regeneration, is found only on the surface of peripheral cells, which are known to promote regeneration. Is its absence the problem in the lack of regeneration in central neurons? Or is it perhaps a problem of soluble trophic factors, such as NGF? Is there a problem that prevents central neurons from growing through particular parts of extracellular space, such as the lack of a particular protease? These are just idle speculations at this point, but at least there are now testable ideas available, and the appropriate experiments are currently under way.

Another point of interest is that we see that putting the brain together during development involves a massive struggle for survival — cells competing for essential survival factors. We've also seen that interactions between cells in the developing nervous system can lead to changes in the character of both participants in these interactions. It strikes me that all of this sounds a bit like what goes on at the level of the whole organism, both in the behavior of animals and in their evolution as well.

Perhaps we are beginning to make at least some modest progress toward answering a few of the questions posed at the turn of the century by the great Spanish embryologist, Santiago Ramón y Cajal. Ramón y Cajal posed most of the questions about neuroembryology that are discussed in this article, and he stated the problem of axon growth and synapse formation in his characteristically romantic fashion: "What mysterious forces precede the appearance of the processes, promote their growth and ramification, and finally establish those protoplasmic kisses, the intercellar articulations which seem to constitute the final ecstasy of an epic love story?"

We have at least made some progress on the foreplay. □

A Special Relationship

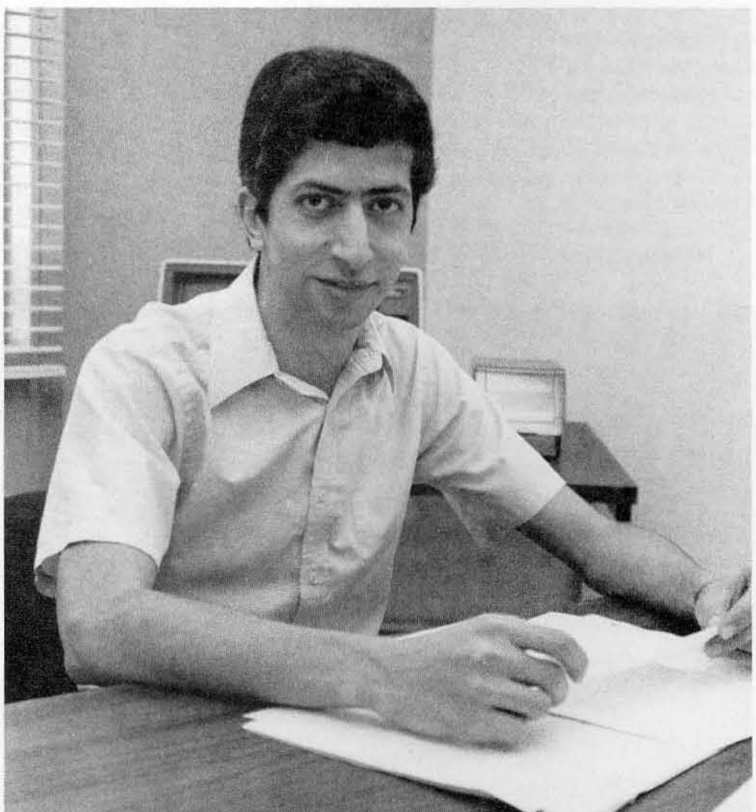
YASER ABU-MOSTAFA, assistant professor of electrical engineering and computer science, does theoretical work on pattern recognition — how a computer might go about recognizing a visual object, a task quite natural and simple for the human brain but a formidable job for a machine. In fact, a computer fails miserably at recognizing something as obvious to us as a tree, for example, because computers are systematic and structural. Recognizing the visual image of a tree is a vague and unstructured problem, a type of problem called in mathematics random in the Kolmogorov sense.

Abu-Mostafa is trying to develop a theory of computation for such random problems, to figure out how a computer might actually undertake solving them. His previous work (he earned his PhD from Caltech in 1983) has also been mathematical and theoretical — describing the general complexity of such natural problems and estimating what the "cost" would be, in terms of computer time or memory, to solve them. But he also wants to be able to apply his theoretical framework of pattern recognition and, working with his Caltech colleagues, design digital systems that can actually recognize images.

Although he is a theorist motivated by the intriguing questions involved, Abu-Mostafa is pleased that his research does have applications — from military radar to computerized vision for the blind. His work is typical of the sort of basic research that underlies future technological progress and that establishes the primary motivation for universities and industry to work together in planning for the future. And in fact, Abu-Mostafa's work in pattern recognition is one of seven projects being supported by the Program in Advanced Technologies, a joint undertaking by Caltech and four industrial sponsors announced in the fall.

The structure of the Program in Advanced Technologies, more familiarly known as PAT, was carefully hammered out over the last three years by Caltech and the companies involved and may serve as a model for future industry/academia arrangements. It is viewed

Yaser Abu-Mostafa



by the participants not as an outright grant but as, according to Ruben Mettler, chairman of the board and chief executive officer of TRW Inc., "a special relationship for addressing a number of advanced technologies that will be critical to society in the 80s and 90s." Mettler is also Caltech's new chairman of the Board of Trustees (as of January 1).

"It offers a tremendous opportunity to share ideas and concepts and to critique ideas of the future in technology, which we often see from different perspectives."

Caltech President Marvin Goldberger, former Provost John D. Roberts, former Vice President for Institute Relations Dwain Fullerton, and former division chairman Roy Gould participated in the initial conception of the program. The Institute's current Provost, Rochus Vogt, has been instrumental in the program's implementation.

The four companies will each contribute $200,000 annually for five years to support research in fluid dynamics, electronics, and solid state materials. Half of that will go directly to research, the other half to Institute and division discretionary funds, which will include equipment grants and graduate fellowships. Control of the program remains within the traditional academic structure, but the process of deciding which research to support depends on the input of a committee of Caltech faculty and industry representatives. In fact, the collegiality of the program is one of its unique aspects. "It offers a tremendous opportunity to share ideas and concepts and to critique ideas of the future in technology, which we often see from different perspectives," says Arden Bement, vice president for technical resources of TRW.

TRW was the first company to conceive, with Caltech, the idea of a consortium of companies playing a positive role in supporting a broad spectrum of research at the Institute. GTE Laboratories and Aerojet General subsequently enlisted in the program, and General Motors joined up this month. One of the strengths of the program, as William Nelson, director of collaborative research for GTE Laboratories, sees it, is the relatively small number of sponsors. "So there's a degree of compatibility and some technical overlap, but at the same time we're not competitors fundamentally. And all the sponsors are sophisticated in their own right; we carry on sizable research efforts of our own," says Nelson. Although the main benefit to the sponsors is working with Caltech faculty, there are also potential tangential benefits from working with other companies, he believes.

Another of PAT's strengths is the flexibility provided by its scope. This came about in the very early stages of negotiation, when a team of TRW's technical people visited the campus to explore what sort of research might be meaningful to them. After meeting with about 20 faculty members, the visitors decided they liked everything they had seen. Except for making the program difficult to name, this diversity has proved to be a definite plus for all the participants. "It's not dependent on a single individual or a single technical link," says Nelson of GTE, "and yet it's not so broad that there's no focus either."

The interdisciplinary nature of Caltech's research groups is particularly well suited to this sort of program. "Many of the advances that could enhance the progress of a wide range of industries over the next decades require bridging the gaps between traditional disciplines, which Caltech faculty are eminently able to do," says Goldberger.

Research proposals are solicited from faculty in the three broad areas — fluid dynamics, solid state materials, and electronics — covering, from the sponsors' point of view, something for everyone. Under fluid dynamics, the topics of interest are reacting fluids (chemical lasers, combustion, metastable two-phase flows, mixing, turbulence, and vortex control) and computational fluid mechanics (boundary and shear layers, downstream conditions, and new computational techniques).

The area of solid state materials includes metals (amorphous materials, dynamic compaction, sputtering, ion implantation, and failure of materials) and semiconductors (surfaces, interfaces, lattices, ion implantation, epitaxial growth, device applications). Under electronics three areas are under consideration: power electronics (models, analysis methodology, devices); electronic systems (error-correction coding, control and robotics, digital signal processing, image processing, electro-optic systems); and electronic devices and technology (integrated opto-electronics, millimeter and submillimeter wave devices and components).

One of PAT's principal objectives is support of new research efforts undertaken particularly by new or junior faculty — "for promising young faculty members with bright ideas, who might not otherwise get a chance to try them out," according to Vogt. But proposals from senior faculty are also considered, especially in those areas where there are currently no junior faculty. Proposals for research projects are submitted to PAT's advisory committee, which will evaluate them, rank them, and make recommendations. In a way, it will act as a mini granting agency. The first chairman of that committee, as well as the designated principal investigator who will administer the program, is William Bridges, the Carl F Braun Professor of Engineering. Bridges, who spent 17 years in industry at the Hughes Research Laboratories before joining Caltech in 1977, says, "I agreed to serve as manager for this program because of my strong belief that the interests of both the Caltech faculty and their industrial counterparts will be greatly enhanced by the technical dialog that PAT will create."

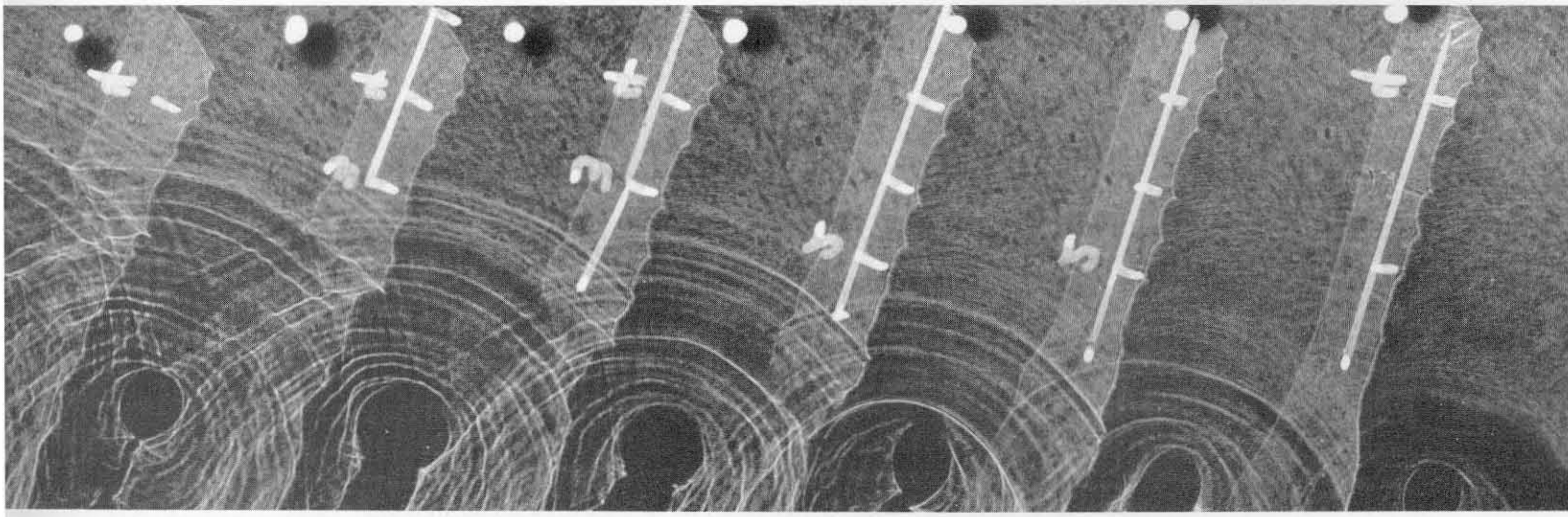
The advisory committee consists of a representative from each industrial sponsor and an equal number of Caltech faculty members, appointed by the chairman of the Division of Engineering and Applied Sciences. Paul Jennings, professor of civil engineering and applied mechanics, has recently assumed this post. The division chairman will also determine the final distribution of funds. Overall responsibility for the program lies with Vogt.

Current members of the committee are Nelson of GTE; George Gleghorn, vice president and chief engineer, Space and Technology Group, TRW; James Myers, vice president, operations, Aerojet General Corporation; and John Caplan, executive director, Research Laboratories, General Motors Technical Center. Caltech's representatives, besides Bridges, include Frank Marble, the Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and professor of jet propulsion; Robert McEliece, professor of electrical engineering; and Thomas McGill, the Fletcher Jones Professor of Applied Physics. In addition, Terry Cole, Chief Technologist at the Jet Propulsion Laboratory, is the insider/outsider on the committee; he's also senior research associate in chemistry and chemical engineering at Caltech.

This collegiality of decisionmaking is an aspect of the program that all parties find particularly satisfactory. Robert Carroll, director of engineering and research at Aerojet Tactical Systems Company, one of Aerojet's five divisions, finds that "it gives Caltech almost the benefit of an outright gift, but it's a lot better than an outright gift for us." Carroll, who serves on an Aerojet internal steering committee that also got a chance to rank the proposals, says that "even if we're not in direct control, we can help select what direction the research goes in." The top five proposals ranked by the Aerojet committee ended up getting funded.

PAT's first awards were announced at the end of November. Grants totaling $300,000 went to seven faculty members. Associate Professor of Electrical Engineering Slobodan

These high-speed photographs show dynamic caustic patterns formed around the tip of a fast-moving crack. The time between frames is five microseconds. A PAT equipment grant provided an argon ion laser for the high-speed camera system.



Cuk will be working on power electronics inverter topologies, and David Rutledge's proposal is to design a square array of field-effect transistors as amplifiers in a millimeter-wave power generation system. Rutledge is also an associate professor of electrical engineering. P.P. Vaidyanathan, assistant professor of electrical engineering, received a grant to develop efficient design methods for digital filters requiring few or no multiplications and to apply these filters in digital communications, including speech transmission.

Fred Culick, professor of applied physics and jet propulsion, will develop programs on an advanced, interactive computer graphics system with animation to analyze the unsteady internal flows in combustion chambers. And two grants were in the field of materials science. Professor Thad Vreeland is investigating production of metal glasses in bulk samples larger than currently possible by consolidating amorphous and crystalline powders with strong shock waves followed by solid state reactions. Professor William Johnson is interested in preparing a variety of thin films and coatings of refractory metal glasses and studying their properties of unusual hardness, high strength, adhesion, and stability at high temperatures.

Jennings and Bridges also announced three equipment grants totaling $75,000. One of these is a high-rate sputtering system for William Johnson's work preparing thin films and coatings of metal glasses under controlled conditions. Ares Rosakis, assistant professor of aeronautics and applied mechanics, received a grant for an argon laser for a high-speed camera system. The camera, capable of half a million frames per second, will be part of an experimental setup for the study of the dynamic fracture of structural metals. The optical patterns (caustics) recorded by the camera allow measurement of the stresses at the tip of cracks propagating with velocities of the order of a kilometer per second. Bradford Sturtevant, professor of aeronautics, will use his grant for digital transient recorders, a data acquisition system to be used in a number of experiments simulating vapor explosions such as might occur in nuclear reactors and volcanoes.

Three graduate fellowships were also announced: Michael Atzmon, in applied physics, is the Aerojet Advanced Technologies Fellow; Ed Schlesinger, also in applied physics, is the GTE Advanced Technologies Fellow; and Alan Zehnder, in mechanical engineering, is the TRW Advanced Technologies Fellow.

PAT guidelines, which were developed in concert, also follow academic tradition with regard to "intellectual property" and publication rights, which have historically been sticky points in negotiating industry/university collaboration. Under PAT, there are no restrictions on publication, although researchers are asked to send papers to the industrial sponsors at the same time that they submit them for publication. All intellectual property will belong to Caltech, which will grant nonexclusive licenses to the participating companies.

This is largely due to an "open stance" on these issues on the industrial side, according to TRW's Bement. "We don't see it as a quid pro quo, but rather a long-term relationship that we agree to help nurture along. We didn't want to pose a threat to the normal prerogatives of university members." But, he adds, "we also had interests that Caltech honored; we had respect for each other's positions."

The participating companies seem to agree that the major benefit is the collegiality of the program, the interaction with people. A key feature of the program is that Caltech will host two meetings a year for presentations and discussion of research by faculty and industrial participants. The first of these meetings will take place this spring. According to Bridges, "These meetings will serve as a forum for the Caltech people to report their program and for industrial researchers to present their problems and results to us; we want it to be a two-way street. I've seen research activities from both viewpoints in my career, and I feel strongly that both academic and industrial researchers can benefit greatly from hearing each other's tales." By mutual agreement companies may also send their scientists to work with Caltech faculty.

For Bement, when you get the technological know-how of industry together with the deep scientific insights of academia in a relationship of this quality, new concepts and new pathways for applications are bound to emerge. "It's a sharing of vision of where technology is going," he says. "Anticipating where the real opportunities are going to be a few years in advance is a tremendous advantage to any company. It contributes to our ability to manage technological change in a fast-changing world." □ — *JD*

Pump Lab Reminiscences

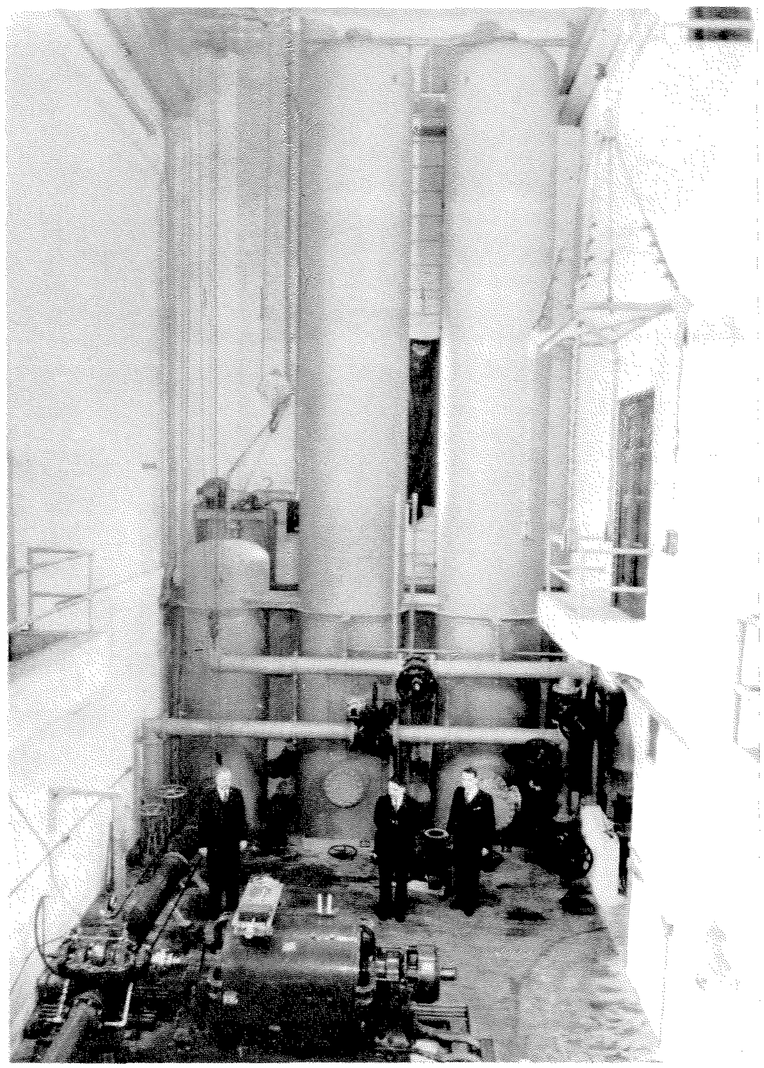
Many who have been around Caltech since the 1930s remember the old Hydraulic Machinery Laboratory, better known as the pump lab. Last year George Housner, now the Carl F Braun Professor of Engineering, Emeritus, who has been here since 1934, and others (including pump lab veterans Rolf Sabersky and Allan Acosta, both professors of mechanical engineering, and Vito Vanoni, professor of hydraulics, emeritus) were reminiscing about the pump lab and realized that no one had a clear picture of how it had come into existence.

Housner set about clarifying that picture, soliciting the recollections of some of the "old timers" who were still around. The picture still isn't clear, though, since these old timers were too young at the time to have been in on the arrangements that were originally struck between Caltech, the Metropolitan Water District of Southern California (which was about to embark on a mammoth pumping project), and the city of Pasadena, which had more than a passing interest in independence from the water supply of Los Angeles.

The Caltech Archives contributed some background, including a letter from F. E. Weymouth, general manager and chief engineer of the MWD, outlining what the MWD stood to gain from the proposed research at Caltech: The power and pumping system of the aqueduct would call for a long-term involvement of more than $33 million; each percent gained in pumping efficiency would mean savings of about $49,000 a year (in 1930 dollars) in power cost.

A letter from Theodore von Kármán to the Executive Council made the case for Caltech's involvement. It said in part: "If the research work would be chiefly directed to the improvement of hydraulic machinery on the empirical basis, then objections against the permanent value for the Institute might be raised. But if the research program is founded on a broader conception, I believe that a laboratory of this kind will have a unique position in this country and almost in the whole world.

"Considering the recent development of aeronautics as a science and as a technical art, the great achievements are due to the fact that the technical development was connected simultaneously with the development of the scientific fluid mechanics, and that the aeronautical engineers departed from the method of purely empirical computation and adopted the methods used in natural science



The pump lab tanks, which were built to withstand a pressure of 600 psi and were used to control the pressure for cavitation tests, tower over von Kármán (right), Knapp (center), and an unidentified man, probably from the MWD.

and applied mathematics. The same development is starting now in hydraulic engineering. I believe that the substitution of the results of systematic theoretical and experimental research for empirical methods will bring great benefits in the near future to several very different branches of engineering dealing with problems of fluid motion."

Clearly there was good reason to get together.

Perhaps the most knowledgable of the old hands is Jim Daily, who came to the pump lab as a graduate student in 1935 and became the lab's "curator" for several years before finishing his PhD in 1945. (Sally Atwood Daily, Jim's wife, helped publish the first issues of the Caltech Alumni Review *in 1937-38 with her brother Bill Atwood, its first editor. Atwood was a Caltech alumnus and part of the MWD staff; the* Alumni Review *was renamed* Engineering & Science *in 1943.) Daily left in 1946 to join the faculty of MIT for 18 years and is now professor of fluid mechanics and hydraulic engineering, emeritus, from the University of Michigan. He recently returned to Pasadena to live and contributed the following reminiscences to Housner's history project.*

by James W. Daily

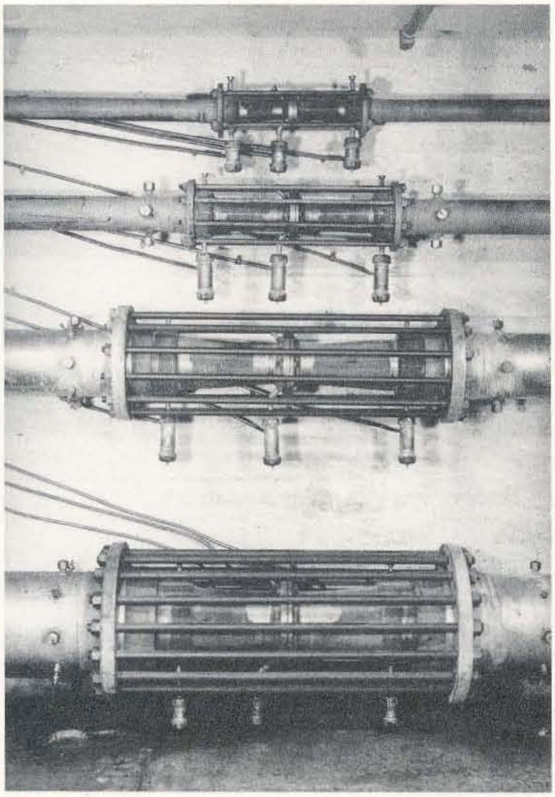
THE HYDRAULIC MACHINERY Laboratory at Caltech had its genesis with some graduate student thesis projects in the early 1930s under Robert T. Knapp, assistant professor of mechanical engineering. Bob Knapp had spent 1929-30 as a Freeman Fellow in Europe, visiting hydraulic laboratories and other hydraulic facilities and factories with a special interest in hydraulic machinery. He came back with much enthusiasm and many ideas. The sharpest was his conviction that there was a need in this country for more definitive research into the hydraulics of centrifugal pumps, that it should be done in a laboratory independent of all manufacturers, and it should be located at Caltech.

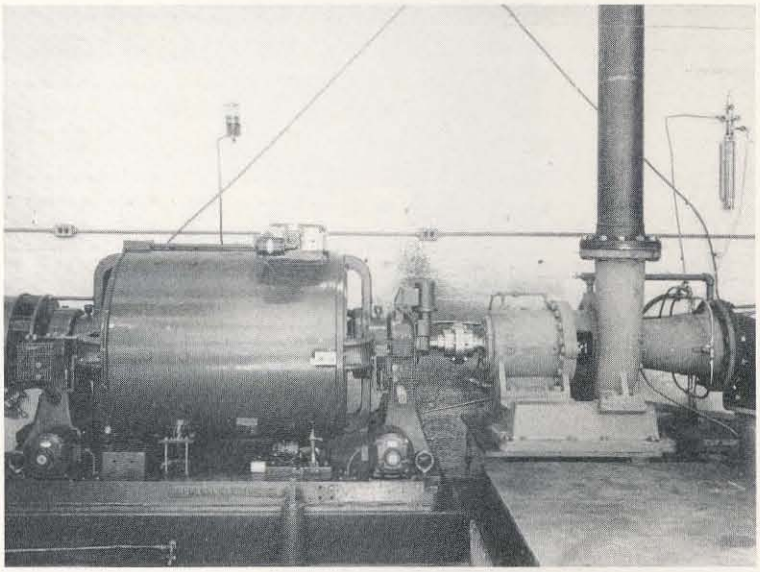
The time was ripe for many reasons. First, the Europeans, and especially the Germans, had a lead in pump research and technology. Second, southern California needed water, and there was a project underway to build a great aqueduct from the Colorado River to Los Angeles and adjacent cities and districts. It was to be 300 miles long, and a series of five pumping plants were necessary to lift the water some 1600 feet over the mountains. The pumps were to be among the largest and most powerful installed anywhere in the world. There was a fledgling organization, the Metropolitan Water District of Southern California (MWD), which had designed the project and was busy initiating the construction.

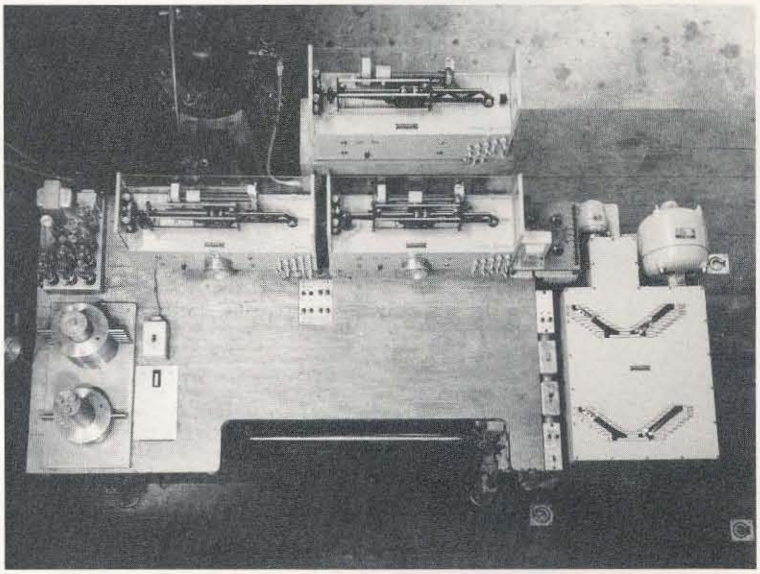
The pump research program began in an "initial" pump lab, as George Wislicenus, one of Knapp's early students, has called it. This was in the north end of the Caltech boiler building (or at the west end of what is now Spaulding Laboratory) where there was some space for experiments. "Wis" was a young pump designer from Worthington Pump Company in Harrison, New Jersey, who had come to Caltech for graduate study. In 1931 or 1932 he carried out various pump tests which figured importantly in the efforts under way to induce the MWD to support a more sophisticated laboratory effort aimed, of course, at the problems that might arise with the exceptional pumps that were required for the new aqueduct. This eventually became the "final" pump lab.

The exact steps leading to the contract with the MWD are not clear, but the agreement seems to have been the result of an orchestrated effort that began in 1930. In addition to Knapp, Professors Robert L. Daugherty (mechanical and hydraulic engineering), Franklin Thomas (civil engineering and chairman of the division), and Theodore von Kármán (aeronautics and director of GALCIT) were involved, as well as Robert A. Millikan. Daugherty and Thomas were active in Pasadena affairs; they were or had been city directors. At some time in that era Daugherty was mayor. Thomas was also Pasadena's representative on the MWD Board of Directors. Von Kármán, who was a new and widely respected professor from Aachen, Germany, became interested in seeing the development of a program in hydraulics. Moreover, Millikan was showing interest.

As early as December 1930, a conference with MWD officials that was attended by Knapp, von Kármán, Daugherty, and Millikan disclosed MWD's interest in a pump testing facility because MWD foresaw many







Pump lab fixtures (1936) included venturi meters (far left) to measure the rate of flow, a dynamometer and one of the test pumps (top), and the test bank (below) with its beam balance-type gauges to measure pressure.

hydraulic problems of scientific importance. It was concluded that Caltech should make a careful study of the possibilities. In brief, the studies were made, there was some iteration, and, following the inevitable delays, the contract was finally signed on November 14, 1933.

The laboratory was planned to occupy the tall three-story bay and subbasement at the west end of Guggenheim Laboratory and part of an east-west channel along the northern face of the Guggenheim basement and subbasement. The three-story bay was intended originally to house a large universal testing machine. The channel was to have been a towing tank.

Design of both the instruments and the equipment began immediately after the contract was signed. Wislicenus designed much of the main system and instrumentation under Knapp's supervision. The lab and its instrumentation were designed to provide accuracy (0.1 percent to an individual test point), to eliminate the personal equation in taking data, to use primary standard type of instruments and to have the utmost flexibility. Special features included weighing-type pressure gauges and venturi manometers, a quartz crystal time standard, a feedback device for comparing the dynamometer speed with a standard speed and automatically providing corrections to overcome instantaneous differences, and a system for "freezing" the instrument readings when conditions were stable. This last was accomplished by both of two operators simultaneously exercising their individual controls to interrupt the current flow to the instrument readout bank.

The laboratory was calibrated and in full operation by September 1934. Today Wis assumes a modest attitude about his role. Actually, his instruments used in this laboratory and in the later Caltech water tunnels constructed during and after World War II were excellent and exceptional and later were copied extensively.

Knapp's vision in the whole project, including the laboratory plan and most of its details, led to an accurate and efficient data collection system, which was the forerunner of the systems now used worldwide in modern laboratories. The latter make use of solid state devices and computers, neither of which existed in the 1930s. The pump lab instrumentation was a combination of mechanical and electrical devices and vacuum tube electronics; it made up an advanced and sophisticated system for its day. The laboratory instruments (as well as many later precision machined devices for the lab) were made by Fred C. Henson's shop on East Colorado.

Among those who took a deep interest in the pump lab development was Aladar Hollander, known affectionately as A. H. He had been a student at the Technische Hochschule in Budapest during von Kármán's time and after World War II became professor of mechanical engineering at Caltech. In the early 1930s, however, he was chief engineer for the Byron Jackson Co. Pump Division and in one sense a bystander. But he was well known for his expertise and his sage advice, and his support of the project was invaluable.

In the beginning of the MWD program the pump lab experiments looked into a variety of phenomena as well as the basic behavior of centrifugal pumps. The effects of cavitation on the performance of pumps were examined in a detail not done before. The suitability of single-stage, single-suction, volute pumps for the MWD application was investigated. In addition, radial thrust measurements were made with the results leading to specifications for heavier shafting than normally used by the manufacturers. The basic impeller flows and volute effects were studied by measuring the impeller outflow velocities and directions versus vane tip position. Ray Binder conducted these impeller studies as his PhD dissertation under Knapp. A. L. (Maj) Klein, assistant professor of aeronautics, suggested a special sampling valve, which was constructed for these measurements.

This first phase of the MWD program also included determination of *Complete Characteristics,* that is, a four- quadrant performance plot of lines of constant head and power on a chart of discharge-versus-speed giving alternate modes of pumping and turbining. Such data were used in calculations of pressure surges (water hammer) during startups and shutdowns.

The result of this preliminary work was to "tighten up" the final specifications for the pump purchases in various ways from what MWD might have used if the prevailing "wisdom" of many pump engineers' recommendations had been followed.

When I arrived at Caltech, Ralph M. Watson was in charge of the Hydraulic Machinery Laboratory under the triumvirate of von Kármán, Daugherty, and Knapp. Wislicenus, who had finished his PhD program in 1934, had gone back to his firm in the summer of 1935. On arrival I learned that a man named Frank Wattendorf had preceded Watson. Frank was from Aeronautics, and von Kármán had arranged that he go to Peking to build a wind tunnel at Tsing Hua University. This, I was told (by the boys), created a vacancy, at the lowest level, of course, which I filled. This job allowed me to continue graduate studies on a part-time basis. Later such positions came to be called research assistantships.

By December 1935 four pump manufacturers had submitted bidders' models for testing to decide which ones, if any, were to be awarded contracts. The awards were to Byron Jackson (Intake and Gene plants), Worthington (Eagle Mountain and Hayfield), and Allis Chalmers (Iron Mountain). These contracts covered three pumps of the total of nine planned for the ultimate installation in each of the five pumping plants.

At this stage the active lab staff was small and included some on temporary duty from MWD as well as the Caltech employees. The people from the MWD office were A. W. (Bill) Atwood, an electrical engineering graduate of Caltech doing hydraulics temporarily (who in due course became my brother-in-law), Paul Winn, and Harold Levinton. The Caltech group included, as I remember, Ralph (Pop) Baker (older, of course — maybe 35!), an aeronautics graduate student; John Knecnik, an M.E. undergraduate; Ray Binder, an M.E. graduate student; Ed Simmons, an E.E. and of strain gauge fame; and Rudi von Huene, an M.E. and specialist in making thin sections. Mechanic Ray Kingan was a mainstay of the lab. Ray is now deceased, but his son Jack is employed at Caltech.

Soon after my arrival at Caltech, I met Bert Fenner who was both purchasing agent for the Institute and in charge of the "wiring shop," which handled all the electrical maintenance for the Institute and all its labs. I had many pleasant dealings with him throughout my stay at Caltech. Later I had similarly satisfying contacts with Wesley (Herky) Hertenstein, who was in charge of buildings and grounds.

The crew of the pump lab included (back row, from left) Harold Levinton (MWD), Ralph Baker, Bill Atwood (MWD), John Knecnik, Jim Daily, Art Ippen; (front row) Ralph Watson, Ray Kingan, Rudi von Huene, and Ed Simmons.

All of the bidders' models submitted for the MWD tests of December 1935 were designed to operate at speeds which would give the full prototype head. This gave water velocities inside the pump equal to those in the prototype machine. There was some disagreement among engineers at the time, as this differed from the practice with turbines of using straight Froude number modeling and hence very low speeds and internal velocities. The Caltech method, however, gave a high model Reynolds number, a compromise with the even higher and unattainable Reynolds number inherent in the prototype.

One fact that helped both the initial bidders and the awardees was that the requirements for Intake and Gene plants were nearly the same. Consequently, one model was required for the pair. The same held for Eagle Mountain and Hayfield.

As the next step each successful bidder submitted a contractor's model, which was to a larger scale than the bidder's model but also designed to operate at a speed giving the prototype head. These were thoroughly tested to verify that any changes from the bidders' models did indeed satisfy the specifications.

Simultaneously with the testing of the contractors' models, some other investigations were made for MWD. One of particular interest at that date was measurement of valve pressure drop versus opening. Such data were especially useful for combining with the previously mentioned *Complete Characteristics* of pumps when calculating hydraulic transients. To make a comparison of gate valve and plug valve behavior, Arthur T. Ippen (PhD 1936) joined the project in the spring and early summer of 1936. This resulted in plug valves being specified for the discharge cutoff valves which followed each pump in each plant.

The project ended in the summer of 1936. The MWD personnel returned to their Los Angeles office, and the Caltech students either graduated or went back to school full time. Art Ippen, who was from Germany, went to Lehigh as a faculty member in 1938. Following World War II he went to MIT, where he became head of the Hydrodynamics Laboratory. After a very successful career he died suddenly in 1974. Watson went to New Jersey to employment with Worthington until the mid-1950s, when he went to Syracuse University as professor and associate dean of engineering until his retirement.

Wattendorf remained close to von Kármán after returning from China and was his right-hand man until von Kármán's death in 1963. Wislicenus did defense work with Packard Motor Car Company during World War II. After teaching at Johns Hopkins until the early 1950s, Wis went to Pennsylvania State University, where he headed the Naval Ordinance Research Laboratory and the Garfield Thomas water tunnel and was head of the Aeronautics Department until his retirement. Kingan became the mechanic in the old M.E. shop and laboratory. I became the "curator" of the suddenly quiet pump lab as it awaited its next challenge. I believe it was at this time that MWD passed title to its interest in the laboratory to Caltech.

As curator my duties were to look after the equipment and the instruments. This included operating it every now and then, oiling all parts and instruments and so on. One day when entering the laboratory, there was a strong odor of gases such as rocket exhausts. There were also the remains of a pendulum supported from the ceiling two floors above. It seems that Frank Malina's crew had used the dormant lab for their rocket experiments. Objections were raised, and they were banished to an outside site at the east end of Guggenheim (where Firestone now stands). I didn't know (nor did they, for that matter) that this early experiment was one of the first steps leading to today's giant Aerojet General Corporation and the Jet Propulsion Laboratory.

The MWD tests did result in large overall savings and avoidance of future problems, such as deflections due to radial thrust as well as avoiding excess vibration and materials damage that cavitation would have caused. Moreover, many of the questions investigated affected the first cost of the pumping plants as a whole, in addition to affecting the costs of the pumps themselves. The field tests of the completed initial three prototype units, which took place in 1939, proceeded smoothly, and the results followed the predictions based on the laboratory tests.

There was one perturbation to interrupt the smoothness of the field test procedures. These tests used the salt velocity method to measure the water flow rates in the 10-foot diameter penstock following each pair of pumps. In this method a salt solution is injected to be entrained by the flow, and the water velocity is then measured by timing the salt's passage between two downstream sets of electrodes. The method depends on thorough mixing of the salt solution with the water flow. The first determinations gave too low a value, as everyone agreed. It was surmised that better radial mixing of the salt cloud was necessary. Baffle turbulators were added, and the measured flow rate increased! Agreement was reached on the acceptable amount of baffling to use, and the tests proceeded. These tests were supervised by Professor L. J. Hooper of Worcester Polytechnic Institute.

Bill Atwood tells the following anecdote about the field tests. "The tests on the model pumps proved that a single-stage centrifugal pump would meet the requirements and an efficiency of 88 percent or better could be achieved. Therefore the final specifications for the prototype units (MWD 116) required a guarantee of 88 percent efficiency and provided a bonus for each percent achieved above that. Failure to meet the guarantee required the manufacturer to modify or replace the pump.

"Paul Winn and I, having spent several years as MWD representatives at the Caltech pump lab, were both deeply involved in the final field tests. The tests at Intake and Gene were witnessed by A. H. Hollander. He would look over our shoulders at the readings as we recorded them and retire to a corner of the pump house and work his little slide rule. We would glance over, and if he was smiling all was going well, but if he was frowning we would check our instruments. After the run was over, Paul and I would retire to the conference room and with the calculator apply the various corrections and grind out the results. However, from Hollander's smiles we already knew they would be good. The final results showed an excellent 90.9 percent for the five pumps that were tested. That evening A. H. treated the entire test crew to a case of special German wine he had brought along in anticipation of such excellent results."

The machinery for the Colorado River Aqueduct started pumping in 1939, transporting (as efficiently as science had deemed possible) water to thirsty southern California. The knowledge gained from the extensive testing resulted in considerably higher efficiencies than would otherwise have been obtained, according to the MWD. The contractors got their bonuses, MWD got lower operating costs, and the Caltech pump lab got a rest before going on to one more major project — investigating hydraulic problems for the Grand Coulee Dam irrigation project for the U. S. Bureau of Reclamation from 1938 to 1940. □

Research in Progress

Inside Information

PROBING THE INTERIOR of the earth to figure out the processes that determine its surface configuration has been a daunting problem for modern technology. But a recently developed technique combining seismology and computer modeling techniques has enabled scientists to construct images of the earth's crust and mantle down to the core-mantle boundary and to begin to understand the convection mechanisms in the mantle that drive the moving plates of the crust.

Seismic tomography was adapted from medical technology — computerized axial tomography, better known as the CAT scan — that has allowed the three-dimensional imaging of the inside of the human body. Robert Clayton, assistant professor of exploration geophysics, pioneered the application of tomographic techniques to the earth. A CAT scan uses x-rays, which are variously absorbed by the different densities they pass through, to image, say, the brain. The computer is used to reconstruct a three- dimensional picture of the density by creating a composite of the information measured from many ray paths onto a grid of cells. High-resolution pictures can be achieved if the experiment contains many crisscrossing ray paths.

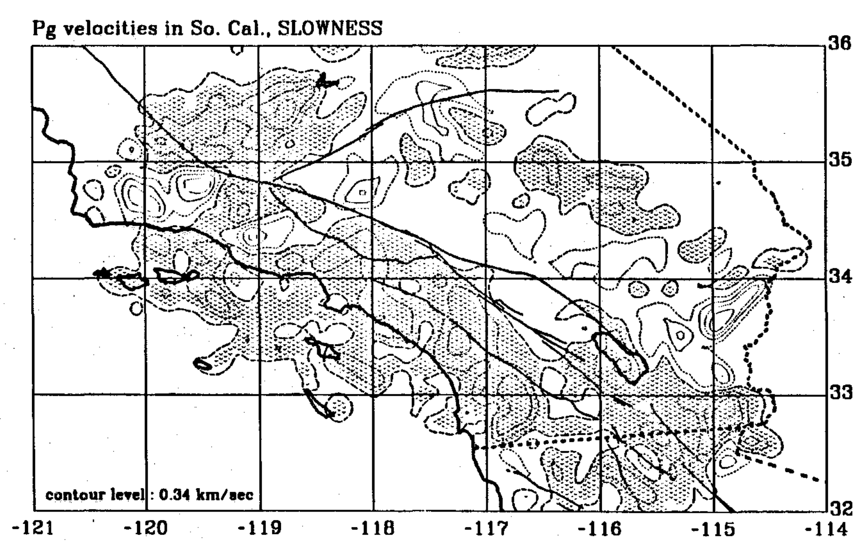
Instead of x-rays, seismic tomography measures the velocity of the waves generated by earthquakes that travel through the earth; the rate at which these waves propagate is affected by the rigidity and compressibility of the material they are traveling through. They travel faster through denser, or colder, rock. Signals recorded from various earthquake sources at arrays of seismographic stations, both local and worldwide, provide the crisscrossing network of rays necessary for a three-dimensional image of the intervening space.

Using seismic data from local earthquakes recorded on Caltech's southern California seismic array, Clayton and his colleagues have mapped the crust below southern California to 30 km; teleseismic, or more distant, events, recorded on the southern California array provide clues to the underlying mantle (to 500 km); and a worldwide network of seismic instruments is providing a picture of the earth's mantle down to the core boundary at 2900 km. The cells determining the resolution of the crustal study are 5 by 5 by 15 km; the upper mantle was imaged with a resolution of 50 by 50 by 50 km, and the global study at 500 by 500 by 100 km.

Clayton and Thomas Hearn (PhD 1984) delivered a paper on the first seismic tomography crustal maps of southern California at the December meeting of the American Geophysical Union. They used two types of waves to obtain images of the crust at two depths: Pg waves, which dive down into the mid-crust at 10-15 km and back up, and Pn waves, which dive 30 km to the edge of the mantle (the Moho discontinuity) and travel along it before returning to the surface. Travel times of approximately 300,000 waves were measured from earthquake sources within the southern California array (an area about 400 by 500 km) to their recording at the array's more than 200 seismographic stations.

The middle of the crust, according to Clayton and Hearn's findings, is intimately related to the surface tectonics, and, in fact, the tomographic maps show features recognizable to anyone reasonably familiar with southern California's surface geology. The San Andreas fault shows up as a sharp boundary with rocks on the eastern side characteristic of the less dense American plate, while that on the western side exhibits its origin in the Pacific plate. The Garlock and San Jacinto faults are also clear at this depth, but, surprisingly, the Transverse Ranges, including the San Gabriel and San Bernardino Mountains, are not visible as deep as 10 km below the surface and probably consist of rock that has migrated from elsewhere.

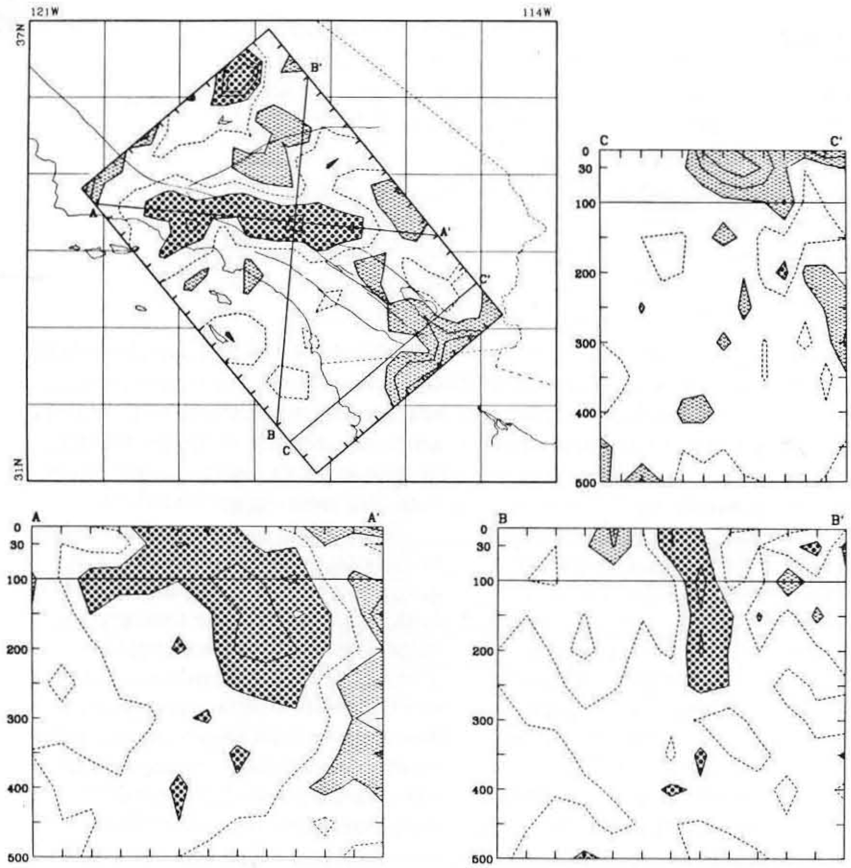
The lower part of the crust seems to have no immediately recognizable



Velocities of Pg waves under southern California show a clear relationship between the mid-crust (at 10-15 km) and the surface features. The San Andreas fault marks a sharp boundary at the denser (shaded) rock of the Pacific plate.

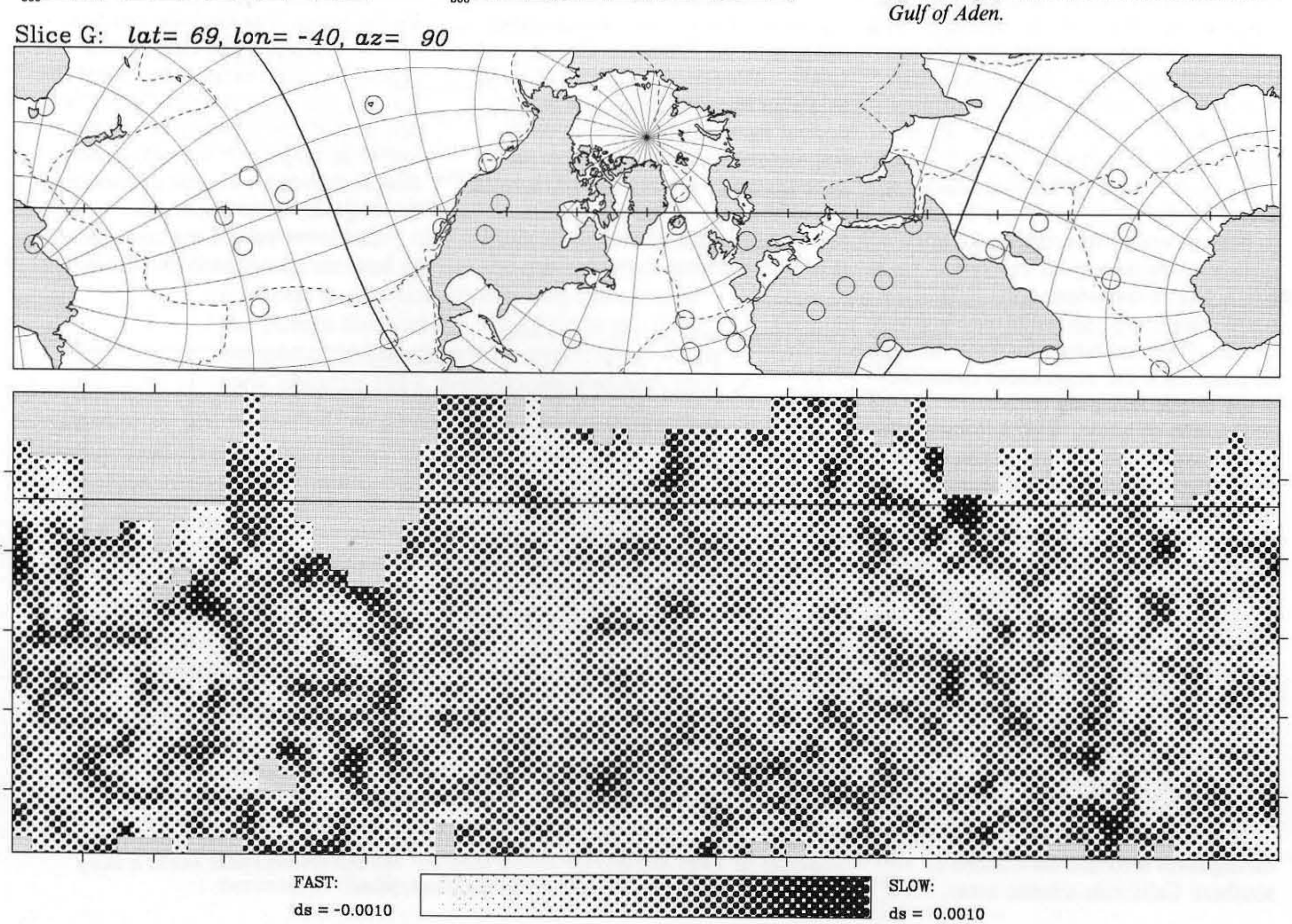
relationship to surface features. Clayton and Hearn determined from their data that the crust of southern California is of varying thickness, that under the Los Angeles and Ventura basins lies a 10-km-thick layer of sediment (a fact that may have been responsible for the unexpectedly great damage from the 1971 San Fernando Valley earthquake), and that the Moho boundary is deformed below the San Bernardino Mountains.

The Transverse Ranges were also involved in the most prominent feature found in a study (using teleseismic data) of the mantle underlying



(Left) In the top left panel the mantle structure at a depth of 100 km indicates the presence of a small convection cell with cold downward convection under the Transverse Ranges related to the warmer upwelling in the Salton Trough. Cross sections to a depth of 500 km are shown in the other panels.

(Below) A slice through the mantle to 2900 km shows evidence of known hot spots in the upper mantle under Iceland and the Afar triangle, where the Red Sea meets the Gulf of Aden.



the same region by Clayton, Bradford Hager, assistant professor of geophysics, and grad student Eugene Humphreys. This was a high-velocity anomaly beneath the mountains — a vertical slab extending downward to approximately 250 km on the deepest (eastern) side. The three scientists speculate that the Transverse Ranges are the site of a cold downward convection in the "viscous" mantle, related to the active geothermal "hot" area observed in the Imperial Valley, possible an upwelling in the mantle. This may be an example of a small convection cell under southern California, causing compression under the mountain ranges and locking the Big Bend of the San Andreas fault.

In their global seismic tomography mapping Clayton and Hager found significant variations in the mantle that appear to be related to a much broader scale of convection. Creating maps of the entire mantle down to the core boundary at 2900 km required data from 25,000 earthquakes recorded at a worldwide network of 1500 seismographic stations. More than 2 million rays were analyzed (this originally took many days' worth of computer time). Although there is evidence of such known hot spots as exist under Iceland, Hawaii, and the Afar triangle, the larger anomalies occur toward the bottom of the mantle. Few obvious patterns emerge immediately from the data, which should keep geophysicists busy for quite a while. Hager is currently using the densities to compute the earth's gravitational response, to corroborate the theory that variations in the earth's gravity are due to convection. And ultimately these first pictures of the dynamic processes going on inside the earth may be the key to understanding how our planet works. □ — *JD*

Books

On Food and Cooking
The Science and Lore of the Kitchen

by Harold McGee

Charles Scribner's Sons.......$29.95

THIS IS A splendidly encyclopedic treatment of a subject of direct interest to anyone who eats, drinks, or cooks. The migrations of the earth's crust and the formation of continents, as these relate to the distribution of plants; the anatomy and physiology of taste and smell; the biochemistry of metabolism; the organic chemistry of carbohydrates, fats, and proteins; the physical aspects of emulsions — these are examples of the fundamental aspects of the subject that are presented with a minimum of impenetrable scientific jargon. In general, McGee has got the basic facts and principles right, though the discussion on boiling water (page 584) was not one the author would have been taught during his time as a Caltech undergraduate (at least in chemistry). The book also includes marvelously detailed treatments of the historical origins of modern practices, the derivations of the terminology of the kitchen, and a great many amusing anecdotes. It's all here — including the physiological and biochemical basis of the morning-after hangover.

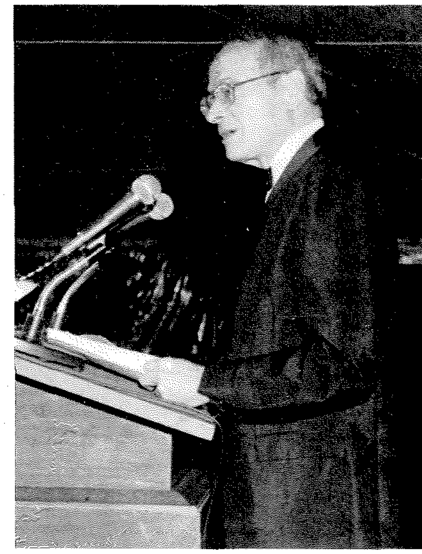
In a sense the book is like a pleasant dinner with good friends — fine food and drink together with unhurried, interesting, amiable conversation. The progress of the dinner provides some order to the evening, as the various aspects of food — milk, eggs, meats, vegetables, grains, breads, sauces, sugars, wine and spirits — provide order for the book. But during any particular course of the dinner, the conversation roams freely, as in any chapter of the book the treatment is discursive and even at times repetitive. The total information of the book could have been told in far fewer pages but then with far less charm.

This is not a book meant to be read at one time from cover to cover as a detective novel, but one in which the reader can spend an occasional relaxed hour learning, for example, the intricacies of why egg whites produce a particularly firm foam if beaten in a copper bowl. It is also not a book of recipes, nor is it a place to find instantly the remedy for a Bernaise sauce that separates minutes before it's due on the table. Rather, in the latter case, there's an eight-page treatise on the subject, including subheadings such as Double Layers and Vinegar; Vinegar Prevents Protein Coagulation; The Emulsifiers in Egg Yolk. How to keep vegetables green receives a three-page historical discussion, including the chemistry of inorganic cations bound to chlorophyll and a quotation from the Roman, Apicius, "omnes holus smaragdinum fit, si cum nitro coquatur" (all green vegetables will be made emerald green, if they are cooked with soda); this procedure has, however, many unfortunate side effects. Mrs. Lincoln of the Boston Cooking School in 1883 knew the correct remedy (put the vegetables into large amounts of rapidly boiling water and leave the top off the pan for the first few minutes of cooking), a solution that becomes apparent two pages into the discussion.

In short, a reader impatient for quick, terse answers might be frustrated, but one prepared to accept the leisurely, charming pace will be constantly rewarded by this wonderful book. □ — *John H. Richards, Professor of Organic Chemistry*

McGee received his BS from Caltech in 1973 (his wife, Sharon Long, was also class of 1973), and he also holds a PhD in English literature from Yale. A chapter, "Ripeness Is All," from this book appeared in the February 1981 E&S.

Opinion



by Frank Press
President, National Academy of Sciences

The following remarks were excerpted from a talk to The Caltech Associates October 30, 1984. Press was director of Caltech's Seismological Laboratory from 1957 to 1964.

If the United States is to assure itself of a primary place in the scientific and technological contests of the future, we will need sensitivity at the highest levels of government about what innovation means and how the government can be supportive. The tidal changes of scientific advances and introduction of new technologies are causing national stresses all over the world. The industrialized countries are being forced to create new strategies. Japan has done it consciously; West Germany, France, and other European nations are trying to do it. We are doing it too but, as is our national style, we're doing it messily.

The difficulties we now see in the weakness of many of our industries reflect a deep, global change born of the bonanza of new technologies. And the pace of technological change is quickening. Five years ago few had heard of expert systems. They are now on the verge of becoming a major industry, a technology of knowledge. Less than ten years ago monoclonal antibodies were only dreamed of. Ten years ago molecular beam epitaxy was basic science, and now it is entering manufacturing technology. The rapidity of these changes couples to the fact that purely domestic businesses are increasingly an anachronism. A multiplicity of forces has created world markets in a fluid, global economic system.

Investments of American corporations abroad totaled $227 billion in 1981. A U.S. company selling small computers gets its printers from Japan and its monitors from Taiwan. The Boeing 757 is a co-manufacturing effort of the United States, Japan, and Italy. So the notion of a world market is slowly infusing our national consciousness. Nevertheless, I think it will be a long time before it really seeps into national policies. Our policies have not kept up with these global changes, and they are largely rooted in the nation-state.

There are those who believe completely in laissez-faire — the government has to stay out of everything. Only the invisible hand of the market would prevail. That ideal in today's world is a mirage. Equally so is the converse of laissez-faire, a completely intrusive government policy where the government steps in and picks winners and makes investments or forces investments. We've tried that in the past, and it hasn't worked in most cases and has been disastrous in some. I think a middle course is emerging that is consistent with our traditions.

In that middle course the government should provide a nourishing climate for innovation, but it should not try to determine the outcomes. And that has some basic themes. First, the government *is* the patron of basic research. Basic research is relatively cheap, and it has enormous returns. The government should invest well in our research universities and also encourage the kind of linkages that are developing directly between our universities and industry. No other country has the strength of the American research university; tying our universities with our industrial prowess is absolutely the strongest force that we can bring to bear, and it's a force that's unique to our country.

Macro-economic policy, and that's determined by the government, is also of great importance. We have to insure the growth of capital; we have to have an economic environment that encourages investment. We have to be concerned with such things as the effect of the exchange ratios in controlling our innovation. For example, if a company increases its productivity by 10 percent (and that's a lot), and the yen/dollar ratio is changed by 10 percent to our disadvantage, it wipes out that productivity gain completely. So macro-economic policy is just as important as scientific creativity.

Some people think we don't have an industrial policy. We have 12 industrial policies. The Department of Justice has an industrial policy with its antitrust statutes. The Department of Commerce has one. The State Department has an industrial policy in the way that it negotiates international trade relationships. Our Defense Department through its procurement processes has an industrial policy. Our research agencies (the National Science Foundation and the National Institutes of Health), our regulatory agencies, our Treasury Department through its tax policies — all of these agencies affect the way we innovate. In the past 20 years they have never collectively added up their separate actions to see what the total effect was. I think we need coordination of all of these separate actions to enhance our ability to innovate. □

ENGINEERING & SCIENCE

California Institute of Technology
Pasadena, California 91125

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
PASADENA, CA
PERMIT NO. 583