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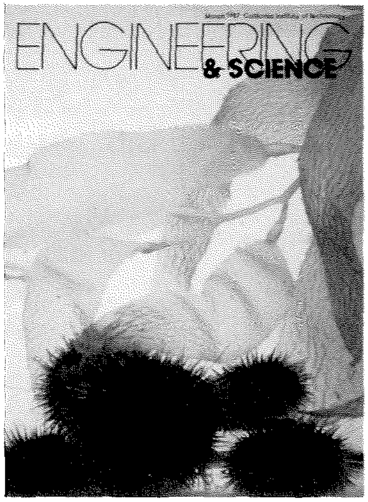
In This Issue



Developmental Diversity

On the cover — sea urchins (*Strongylocentrotus purpuratus*) dine on kelp in an aquarium at Caltech's Kerckhoff Marine Laboratory, where they are part of a larger population providing a steady supply of eggs for research in developmental biology. Sea urchins produce thousands of eggs at a time, which develop synchronously into mature larvae in three days — features that make them extremely well suited for such studies.

Developmental biologists investigate the processes by which complex organisms with many kinds of cells develop out of a single cell — how the genes in a cell are expressed differentially to determine the fates of the cell's progeny. The new techniques of genetic engineering are bringing scientists closer and closer to the answer to this fundamental question.

One of the great strengths of developmental biology at Caltech is the coexistence of multiple approaches to this fundamental question, including the use of experimental subjects ranging from fruit flies to birds to a common weed. "From Cell to Organism: Discovering the Mechanisms of Development," beginning on page 2, discusses some of these approaches. A recent $12.5 million grant from the Lucille P. Markey Charitable Trust is supporting much of the work.

Mars Missionary

Bruce Murray and Mars go back a long way. As a member of the imaging team of the Jet Propulsion Laboratory's Mariner missions in the 1960s and 70s, he participated in obtaining the first close-up pictures of the Martian surface. He was also head of the imaging team for the Mariner 10 flyby of Venus and Mercury and from 1976 to 1982 was director of JPL, during the triumphant Voyager missions to Jupiter and Saturn.

When Murray returned to his position of professor of planetary science, which he has held since 1968, he also returned to Mars. In his article, "The Poles of Mars: A Key to Understanding Earth's Ice Age," he discusses some of his current research and the reasons he believes the U.S. should continue to be a spacefaring nation — first stop, of course, Mars. The article, which begins on page 10, was adapted from his Seminar Day talk last spring.

Murray's degrees are all from MIT (SB 1953, SM 1954, PhD 1955) in geology. He has been at Caltech since 1960.

Computer Course

Four years ago Steve Koonin originated a course — Advanced Computational Physics Laboratory — that teaches Caltech students to use computers to solve highly complex physics problems. Now, about a third of Caltech's physics majors elect the popular course, and it has also been adopted at several other universities (including Yale and MIT) in the U.S. and West Germany. Koonin has written a textbook on the subject — with a floppy disk containing the necessary software.

Koonin discusses his course in "Teaching Computational Physics," beginning on page 17. The article was first published last fall in IBM's magazine *Perspectives in Computing (Vol. 6, No. 2)*, and Koonin also spoke on the subject at the February 1987 meeting of the American Association for the Advancement of Science. A graduate of Caltech (1972), he received his PhD from MIT in 1975, the same year he returned to join the Caltech faculty. He is currently professor of theoretical physics.

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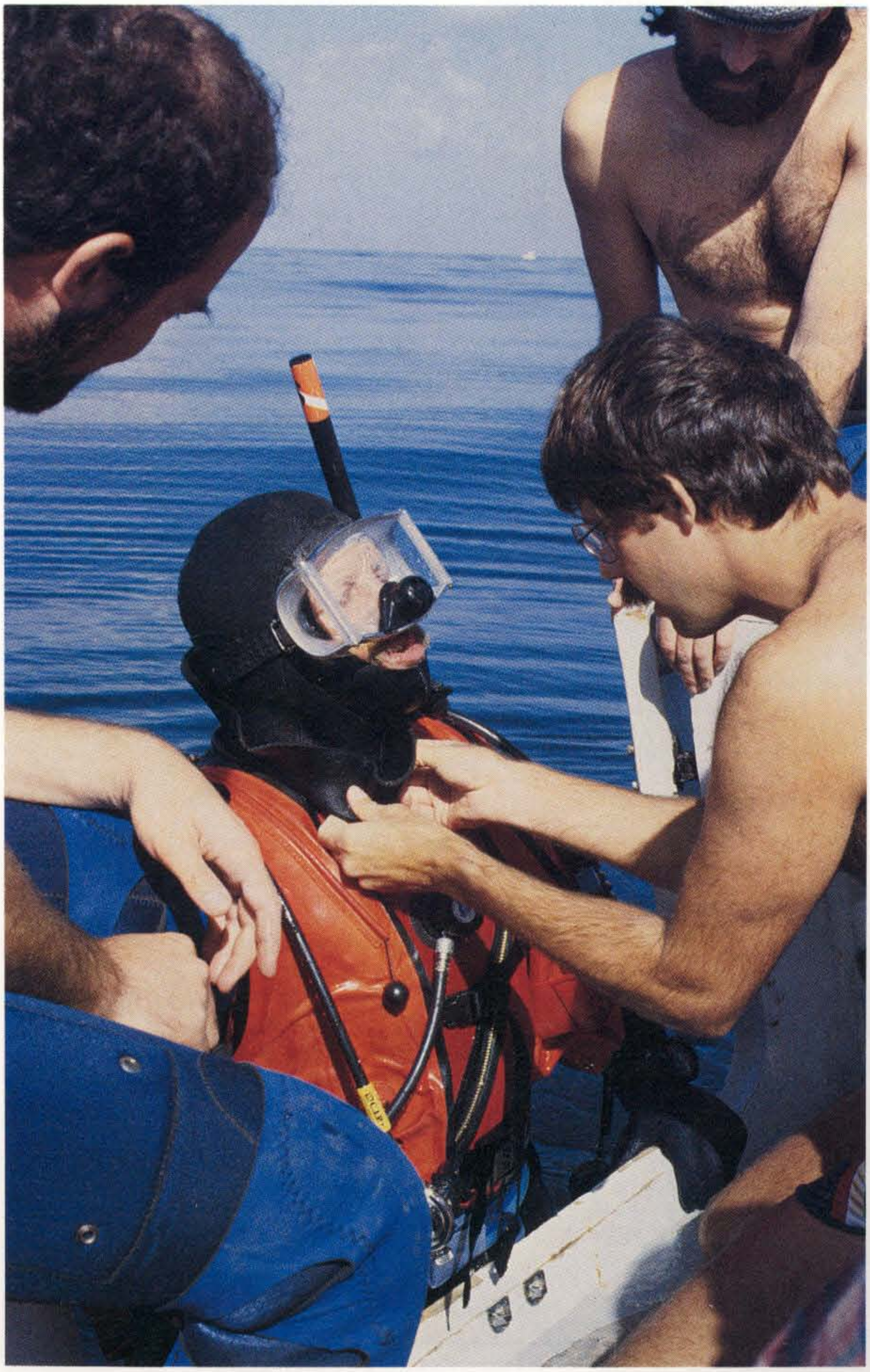
Departments



Above: Eric Davidson (in diving gear) prepares to dive off Point Loma for sea urchins that live under rocks 60 ft. down. Only these deep-dwelling, non-seasonal sea urchins spawn year round, providing a steady supply of eggs for Davidson's laboratory. Other divers on this expedition last fall included grad student Henry Sucov (left), postdoc Steve Fain (top right), and Pat Leahy (right), technician at Kerckhoff Marine Laboratory.

Top*: A fluorescent dye injected into one cell of the embryo at its eight-cell stage lights up all the daughter cells derived from that cell in this mature sea urchin larva containing 1,500 cells. The face of the larva is toward the top, and the stomach is obscured by the fluorescent cells. (Photo by R. Andrew Cameron)*

Bottom*: A sea urchin releases thousands of eggs into a beaker.*

From Cell to Organism:

Discovering the Mechanisms of Development

THE COMMON CALIFORNIA purple sea urchin, *Strongylocentrotus purpuratus*, although a pest to kelp harvesters, is a valuable commodity to developmental biologists. In just 72 hours a single fertilized sea urchin egg turns into a relatively complex organism of 1,500 cells — a larva that can swim, feed, and maintain itself. Sea urchins are plentiful, and they produce thousands of eggs at a time, which proceed to develop synchronously. What's more, the embryo is transparent and permeable, that is, you can introduce tracer molecules and watch what happens as development unfolds.

Over the past hundred years this favorite experimental subject has provided great insight into the processes of embryogenesis. Now, with the new techniques of recombinant DNA the lowly sea urchin is helping to elucidate the answer on a molecular level to the fundamental question of developmental biology: How does a complex organism with many kinds of cells develop out of a single cell?

"We want to know the nature of the process encoded in DNA that transforms genetic information into three-dimensional structure," says Eric Davidson, the Norman Chandler Professor of Cell Biology. Cells with different functions are determined by the differential expression of particular genes. But since each cell contains in its nucleus the entire genome, that is, all the genes possessed by that organism, the fate of any one cell is directed by a particular set of genes turning on at a particular time and place. How do the genes know when and where they are supposed to turn on?

Davidson and his group, including his long-time collaborator, Roy Britten, Distinguished Carnegie Senior Research Associate, study on a molecular level the very earliest of these processes in the sea urchin embryo. The unfertilized egg itself is not symmetrical. It consists of two distinct hemispheres that will give rise to distinct types of cells. So there are potential spatial cues already present in the original cytoplasm. As the egg begins to divide after fertilization, a crucial series of spatial reorganizations sets the stage for the differential expression of genes that will create the different cell lineages.

With radioactive probes as molecular markers Davidson and his lab have tracked differential gene expression in the cell lineages of the sea urchin embryo's gut, skeleton, and ectoderm (the layer of cells that will ultimately give rise to the larva's single-cell-thick body wall), trying to trace the mechanisms back to their beginnings, long before any visible change in embryonic structure. Differentiation in each of these lineages, they have found, begins at a different time and follows its own regulatory signals. The earliest evidence of gene differentiation they have discovered occurs in the ectodermal cells. At 10 to 12 hours after fertilization, a gene called CyIIIa first turns on. This gene codes for the protein actin, an essential ingredient of ectodermal cellular structure. What is interesting is that CyIIIa, although it exists in all the early cleaved cells of the embryo, turns on only in those cells whose offspring will give rise to the ectoderm.

To track this mechanism further, the researchers had to follow the actual functioning of the gene. "If you can put genes into an embryo and they work, you can find out what makes them work," says Davidson. He and his group fused the CyIIIa gene to a bacterial gene with an easily recognizable product, CAT (chloramphenicol acetyltransferase). This fused gene is injected into the unfertilized egg — anywhere in the egg. By observing when and where the CAT gene is activated, they have located the gene's regulatory sequences, which lie along the DNA strand immediately next to the gene they are regulating. These regulatory sequences apparently spring into action when they are recognized and bound by other molecules — proteins called trans-regulators, which have been looking around the cell nucleus for precisely those sequences. Since the researchers knew that the CyIIIa-CAT gene was not localized to a particular neighborhood, they can conclude that the trans-regulators must somehow be trapped in certain areas, producing a heretofore invisible asymmetry.

There still remains the question of the identity of these trans-regulators and how such proteins are distributed to produce this spatial organization in the early embryo. They might derive from maternal spatial assignments already present in the unfertilized egg. Or the trans-regulators might be localized by movements in the egg cytoplasm after fertilization. A third possibility is that contiguous cells could affect each other in ways that could cause synthesis or release of these molecules.

Although there will undoubtedly be some basic similarities, these mechanisms may turn out to be different for each stage of development in each organism — what's true for the sea urchin will not be true for the frog or the fruit fly or the human being. Since these very differences and similarities between systems can be so illuminating, it is important to study development in a wide variety of organisms. Multiple approaches can provide comparative insights from different angles into the basic question of how genes function.

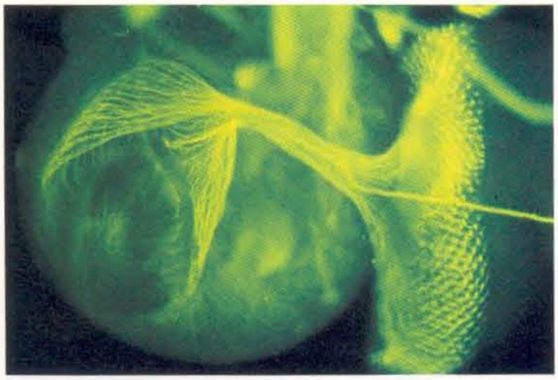
Flies' Eyes

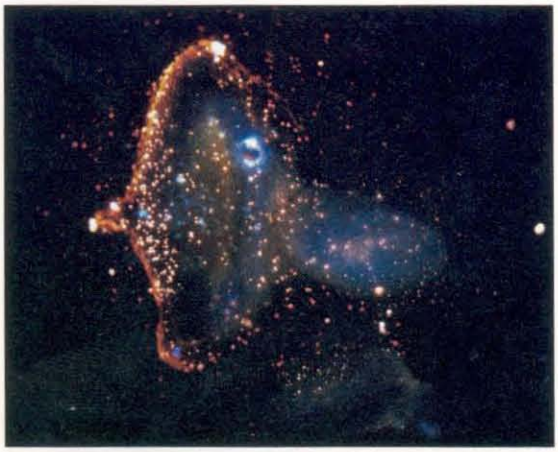
Seymour Benzer, the James Boswell Professor of Neuroscience, compares the different approaches of developmental biology to the old joke about the blind men feeling an elephant: "One is feeling the gene, one's feeling the cell, and another the embryo. But it's really the same huge problem we're all working on. We know a set of monkey genes makes a monkey; all we have to do is fill in the gap." Benzer is actually filling in the gap between fruit fly genes and fruit flies. Caltech possesses one of the world's most important repositories of mutants of *Drosophila melanogaster* — 1,500 different strains. The Institute has been a major center of *Drosophila* research ever since Thomas Hunt Morgan, the founder in 1928 and first chairman of the Division of Biology, began using *Drosophila* to explore some basic theories of genetics. The tiny fly with a convenient 10-day life cycle went on to become a favorite of geneticists everywhere. And as new techniques such as recombinant DNA shed new light on molecular processes, Caltech has become a place where classical genetics and molecular biology are closely intertwined.

Benzer and his associates approach a later stage of development than Davidson does, concentrating on the late larval stage when the adult eye is forming and its neurons making the appropriate connections. *Drosophila's* compound eye provides a highly regular repeated pattern — 800 identical modules, each containing eight photoreceptor neurons arranged in a pattern of six cells surrounding two others. These neurons make three different types of connections — the six surrounding cells form a particular synaptic hookup to the optic ganglia while the other two form different synapses at another level. Benzer's group has determined that these different cells do not descend in neat cell lineages from different parent cells. Rather, they all start off equivalent, and who's who among the eight is determined by interactions between cells based on positional information.

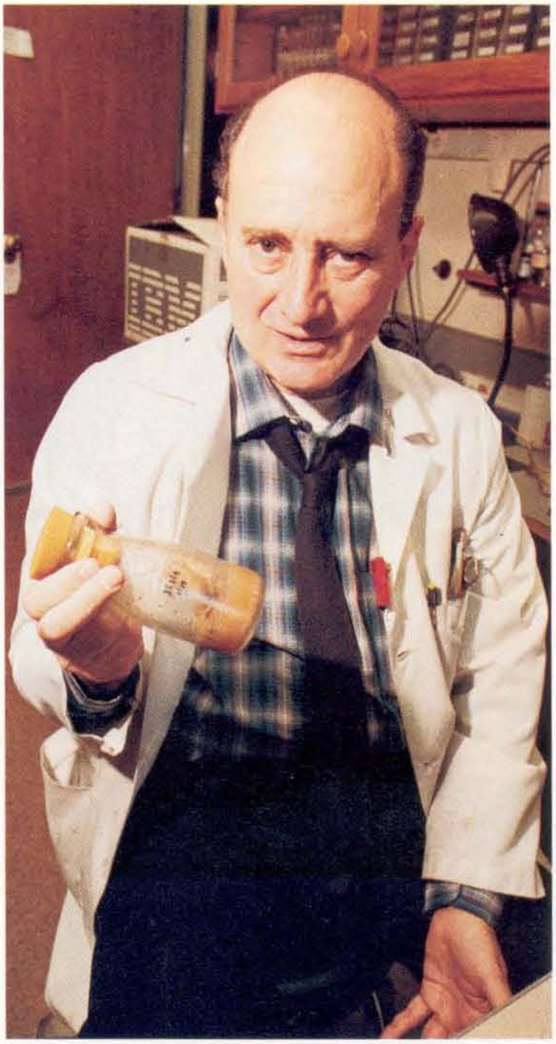
As the adult eye is forming in the mature larva, a wave called the morphogenetic furrow moves across the disk of the developing eye. In front of the wave the cells destined to become the photoreceptor neurons are all alike and are randomly arranged. After the wave has passed, they're grouped together in the six-surrounding-two clusters, with each of the three types sending its characteristic axons to the proper place on the optic ganglia.

Benzer wants to find the molecules associated with this wave that cause this cell differentiation. One of the new techniques of



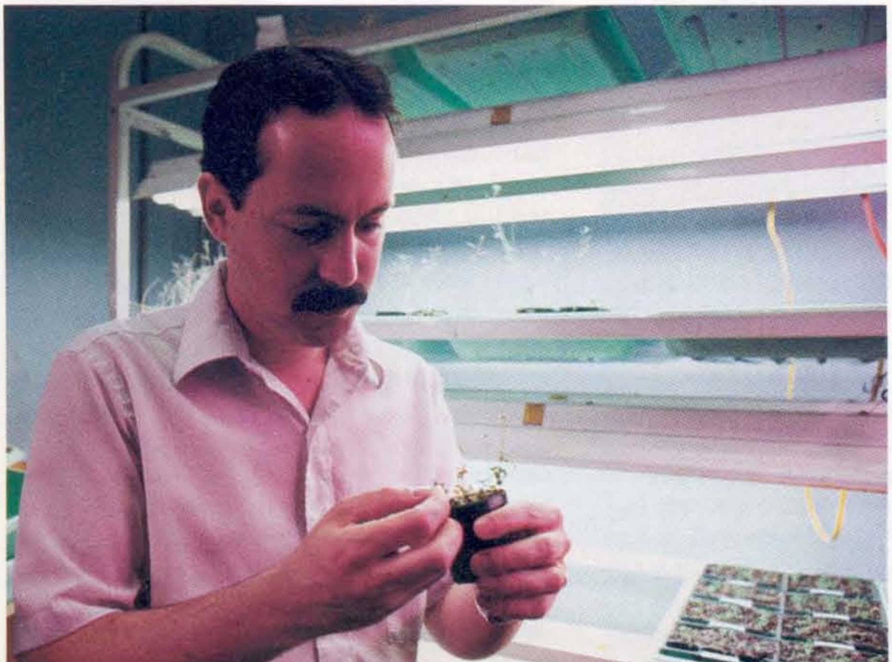


Above: *In this developing* Drosophila *eye disk, the bright white dots at left signify the presence of the messenger RNA to an activated photoreceptor-specific gene. This photoreceptor gene turns on early in the eye's development and stays on until the larva emerges as an adult fly. (Photo by John Pollock)*



Top left: The developing Drosophila *adult eye (right) was stained with a monoclonal antibody (and fluorescent dye) specific to axons. The photoreceptor axon bundles can be seen entering the optic stalk (center) and fanning out inside the brain (left) toward the developing visual formation center. (Photo by Pat Renfranz)*

Left: Seymour Benzer displays a bottle of Drosophila *from Caltech's extensive collection of mutant flies. The flies live in old-fashioned milk bottles; the layer on the bottom is their food.*



Left: Elliot Meyerowitz inspects an Arabidopsis *plant (visible in its full glory below) in his basement-closet garden.*

***Right:** Roy Britten injects potassium chloride into a sea urchin recently hauled from the depths. This will make it release its eggs if it's gravid. The divers seek non-seasonal colonies of sea urchins that are not all gravid at the same time.*

***Below:** Back on board, the divers (Davidson at center) relax while the sea urchins are packed in ice chests for the trip to their new home at Kerckhoff Marine Lab. This expedition netted about 600 animals to replenish the lab's population.*

revealing such molecules is that of monoclonal antibodies, which recognize and bind certain antigens. When these are tagged with fluorescent labels, they light up on meeting their targets. Benzer's lab has developed a panel of 150 such monoclonal antibodies targeted at the *Drosophila's* nervous system. Although a number of them lit up at different stages of the development of the eye, one in particular, named MAb24B10, proved to be highly specific for the photoreceptors in a crucial stage.

The researchers could now take the antigen, or protein, recognized by MAb24B10, purify it, and determine its sequence of amino acids. This sequence was then compared to a similar sequence in the *Drosophila* DNA "library" to discover the gene that produced the protein. When genes are located on a particular chromosome, they can then be altered to produce mutations. Mutations of a defective gene will indicate the function of the original sought-after molecule.

"That's the great thing about *Drosophila*," says Benzer. "The process is a closed circle. You can enter at any point on the circle — at the gene, the antibody, or the behavior, wherever it's convenient — and determine the rest of the information."

Flower Genes

For this sort of circular process *Drosophila*, with its advantages of a long history of cataloged mutations and its adaptability to modern molecular techniques, makes a perfect experimental subject. But Elliot Meyerowitz, taking his cue from *Drosophila*, is on the trail of what may be an even better one. Only it's a plant.

Meyerowitz, associate professor of biology, still works with fruit flies, deciphering the regulatory sequences of genes that code for proteins produced in the larval salivary glands and secreted to form a glue that attaches the pupal stage of the insect to a surface. But his discovery of the beauty of *Arabidopsis thaliana* is leading him in other directions.

Beautiful in the ordinary sense it's not. "It will never replace the rose or the carnation in horticulture," says Meyerowitz. *Arabidopsis* is a member of the mustard family, a harmless weed with a tiny white flower and absolutely no commercial value. It's been used in classical genetic experiments for more than 40 years; its generation time of only five weeks and its production of 10,000 seeds per plant make it attractive for cross-breeding. And its small size and modest requirements for growth make it possible to grow tens of thousands of them in a small space. In fact, they're so small, says Meyerowitz, that "you can even grow them at Caltech" (which is not known for its spacious farmlands). Meyerowitz grows his plants in a basement closet. "My wife taught me how to grow plants," he says. "I now pay a lot more attention to what she does in the yard." (He would try growing *Arabidopsis* in the yard, but it's too hot.)

Like *Drosophila*, *Arabidopsis* is well suited to experiments in classical genetics. The flower has a simple, regular, geometric form of four petals, four sepals (the green leaves that enclose the bud), six stamens, and two carpels. Mutations can turn petals into stamens or sepals, stamens into carpels, and produce all manner of easily recognizable interconverted organs. (This is also common in horticulture, Meyerowitz explains; a many-petaled rose is really a mutation or set of mutations that turns stamens into more petals than the flower's original five.) Meyerowitz is especially interested in this sort of pattern formation.

But the little mustard plant is also, it turns out, ideally suited to the techniques of molecular biology. Meyerowitz's laboratory discovered that *Arabidopsis* has a tiny genome; its total complement of DNA consists of only 70 million base pairs — far smaller than that of any other flowering plant. It also has very little repetitive DNA; most of its DNA is organized as extremely long blocks of unique sequences of nucleotides. This makes it much easier to map the location of a small DNA segment. Meyerowitz and his group have already localized 25 random pieces of *Arabidopsis* DNA and expect to have 50 by the end of this year. Before long Meyerowitz expects to find one of these random locations turning up close to a flower gene (flower mutations have been plotted on the same map). Then the researchers will have a flower gene that they can clone with recombinant DNA techniques. The cloned gene can then be modified and introduced back into the mutant plant to determine its function.

Meyerowitz's lab has already cloned several genes not involved in the flowering structure, including a gene that encodes the large seed-storage protein, one that encodes the plant's light-induced chlorophyll-binding protein, and another that codes for alcohol dehydrogenase (which may keep the plant from drowning by overwatering). Because *Arabidopsis* genes will cross-hybridize with the genes of other plants, this work has significance for plants of more economic value, whose vastly more complex systems are difficult to study.

But the fundamental question is still the same, in Meyerowitz's mustard plants as in Benzer's fruit flies and Davidson's sea urchins: What are the intrinsic rules that say to one *Arabidopsis* cell, "You're going to turn into a petal," or to a sea urchin cell, "You're going to become part of the gut"?

Bird Brains

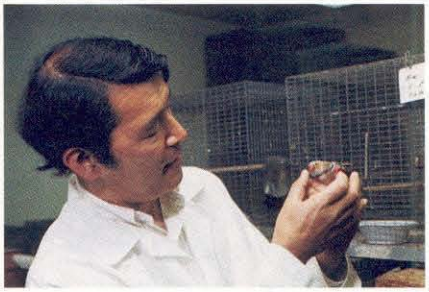
Mark Konishi comes at the problem of cell differentiation from a different direction. Konishi, the Bing Professor of Behavioral Biology, is interested in the development of behavior — specifically birdsong.

Male zebra finches sing; females do not. Finch sons have to learn how to sing from finch fathers. But the capability for singing lies in an area of the brain that is developed in males and not in females. The search for the origins of this sexual dimorphism has led Konishi closer and closer to molecular biology for an answer.

The mature male zebra finch possesses more neurons of larger diameter in the song-control area of its brain than does the female. The sexes do not, however, start off that way. Up until 12 days after hatching, their brains look identical. Then, between 12 and 35 days of age, dramatic changes take place: In the male the nerve cells in the song-control area grow, while in the female they atrophy and die. Actually, all known cases of brain sexual dimorphism — in mice, rats, gerbils, and probably in humans, as well as finches — involve cell death in the female.

In experiments Konishi has found that the divergence between the sexes in the zebra finch can be modified by implanting estrogen under the skin of newly hatched female chicks. The song-control cells of those chicks do not die but grow some of the male characteristics. (It's not so strange that the female hormone, estrogen, should promote masculinization, says Konishi. Although testosterone, the male sex hormone, masculinizes a rodent brain, it works by being converted to estrogen by a brain enzyme.) The discovery that these nerve cells in the zebra finch die because they lack a particular chemical has wide-ranging implications far beyond sex differences. Certain human diseases, such as Alzheimer's and Parkinson's, result from nerve cell death. "So it's interesting to know what chemicals might maintain nerve cells," says Konishi.

The researchers don't yet know how the process works. Since females implanted with estrogen on the first day after hatching continue to develop masculine song characteristics long after the hormone's effect has expired, it may be that estrogen is only a trigger. It's also not yet known whether the natural neuronal growth of the *male* is actually due to the hormone. Other investigators have demonstrated an upsurge of estrogen in



Right: Mark Konishi holds two zebra finches seen in closer view below. The male, on the right, is distinguished by the golden patch on its face and the red beneath its wing. But more interesting to Konishi are the differences in the finches' brains.

The song-control areas, stained dark and indicated by arrows, are larger in the brain of the male zebra finch (right) than in that of the female (left).

the male chick's blood (and not in the female's) between two and five days after hatching. But this doesn't prove that the hormone is responsible for masculinization of the brain.

To try to observe these opposite processes of normal differentiation and cell death, Konishi and his group are growing finch brain cells in tissue culture. The first problem is to be able to determine which are the cells of the song-control area. They have recently developed a monoclonal antibody that labels almost exclusively the nerve cells of two of these areas, and they are encouraged that this antibody can be used to identify the song-control cells in tissue culture. Then the next step will be to see first *if* and then *how* and *where* estrogen works to make these cells thrive. "At least, if estrogen masculinizes tissue culture brain cells," says Konishi, "we have a strong hint that we can analyze the problem further." So far this has been a classical cell biology approach, but "we're now getting a bit molecular," he says. "It may lead to the level of how genes are expressed."

Konishi's lab contains large breeding colonies of zebra finches. Since it's important to know when they hatch, the eggs are collected and kept in an incubator. Zebra finches, an Australian species domesticated only recently, are "lousy parents," according to Konishi, who gives the chicks to Bengalese finches to raise. Since the more laid-back foster parents will adopt babies of any age at any time, the researchers don't have to be overly solicitous about their birds.

Developmental biology at Caltech, which crosses the interdisciplinary lines of neurobiology, cell biology, and molecular biology, includes many other researchers employing a wide variety of approaches and techniques to solving the question of how genetic information is translated into the patterns of life. Among them is Edward Lewis, the Thomas Hunt Morgan Professor of Biology, who has been working with mutant *Drosophila* strains since the 1940s, before anyone knew what DNA looked like (*E&S* September 1981). In creating an array of mutant flies with their body segments oddly hooked up and tracing the genes that caused these abnormalities, Lewis discovered a set of genes, called homeotic genes, that seemed to play the role of a "master control," switching other genes on and off. Assistant Professor Mark Tanouye also works with *Drosophila,* investigating the regulation of potassium permeability, which determines membrane excitability in nerve cells.

The classic laboratory mouse is also still alive and well at Caltech. James Bower, assistant professor of biology, uses mice to study how patterns of neuronal connections are established during the development of the central nervous system. Professor Elias Lazarides investigates how differential gene expression determines the structure of red blood cells (*E&S* March 1984). And Ellen Rothenberg, assistant professor of biology, studies the development of T-lymphocytes, which play a crucial role in the immune system (*E&S* March 1983, May 1984). Division chairman Leroy Hood, the Ethel Wilson Bowles and Robert Bowles Professor of Biology, has used embryo gene transfer techniques to cure "shiverer" mice of their genetic disease (see page 24).

Some of this work and that of still others at Caltech is being supported by a recent $12.5 million grant from the Lucille P. Markey Charitable Trust. Mrs. Markey, who died in 1982, owned Calumet Farm, a thoroughbred horse breeding and racing stable in Lexington, Kentucky. She had created the trust to support "the interdisciplinary efforts by small groups of able investigators who are addressing fundamental questions in biomedical science judged to be of potentially great importance." A symposium this month on "Cell Lineage and Specification in Development" (March 11-13) is marking the inception of the Lucille P. Markey Charitable Trust Program in Developmental Biology at Caltech. A number of internationally known scientists (several of them from Caltech) will present some of the latest advances in this field.

These advances have been made in a number of different organisms, each system providing another piece of the puzzle. All of the pieces will be necessary to see the whole picture of the diversity of life forms and how they arise. As Davidson says, "I believe that the means by which the correct spatial presentation of the necessary regulatory factors is arranged, the levels of hierarchy required, and the functions of the genes that are being regulated, will all turn out to be characteristic and distinct for each system of embryogenesis. It is in unraveling these very distinctions that we will meet, and solve, the real biological problem of explaining embryonic development in its many forms."
□ — *JD*

The Poles of Mars:
A Key to Understanding Earth's

by Bruce C. Murray

ANYTHING HAVING TO DO with the United States and space these days is still colored by the Challenger tragedy — not just by the loss of life but by the total disruption of the American space program. It's going to be a long, painful way back — probably three to five years before we can again begin to resume world leadership in civilian space activities. In fact, return to world leadership at all is by no means assured. We might, through mediocre policies, become a second-class spacefaring nation permanently.

The key to our recovery is going to be selection of national goals. We have not had goals for accomplishments in space since John Kennedy announced the Apollo mission 25 years ago, in May 1961. It was completed in 1972. Since that time we have substituted a focus on the *means* (such as the shuttle and the space station) as the *ends*. We talk about what we'd like to build or do but not what it's for or why it's worth the cost either in dollars or, as we now know, in human lives.

If we are going to be a major spacefaring nation in the future, it will be because we have a collective purpose important enough to bring various elements of the space program together. I think that this purpose will likely be human travel to Mars in the next century. This logical destiny for humans in space would give sense to a lot of precursor steps — and eventually even to the risks to human life demonstrated by Challenger.

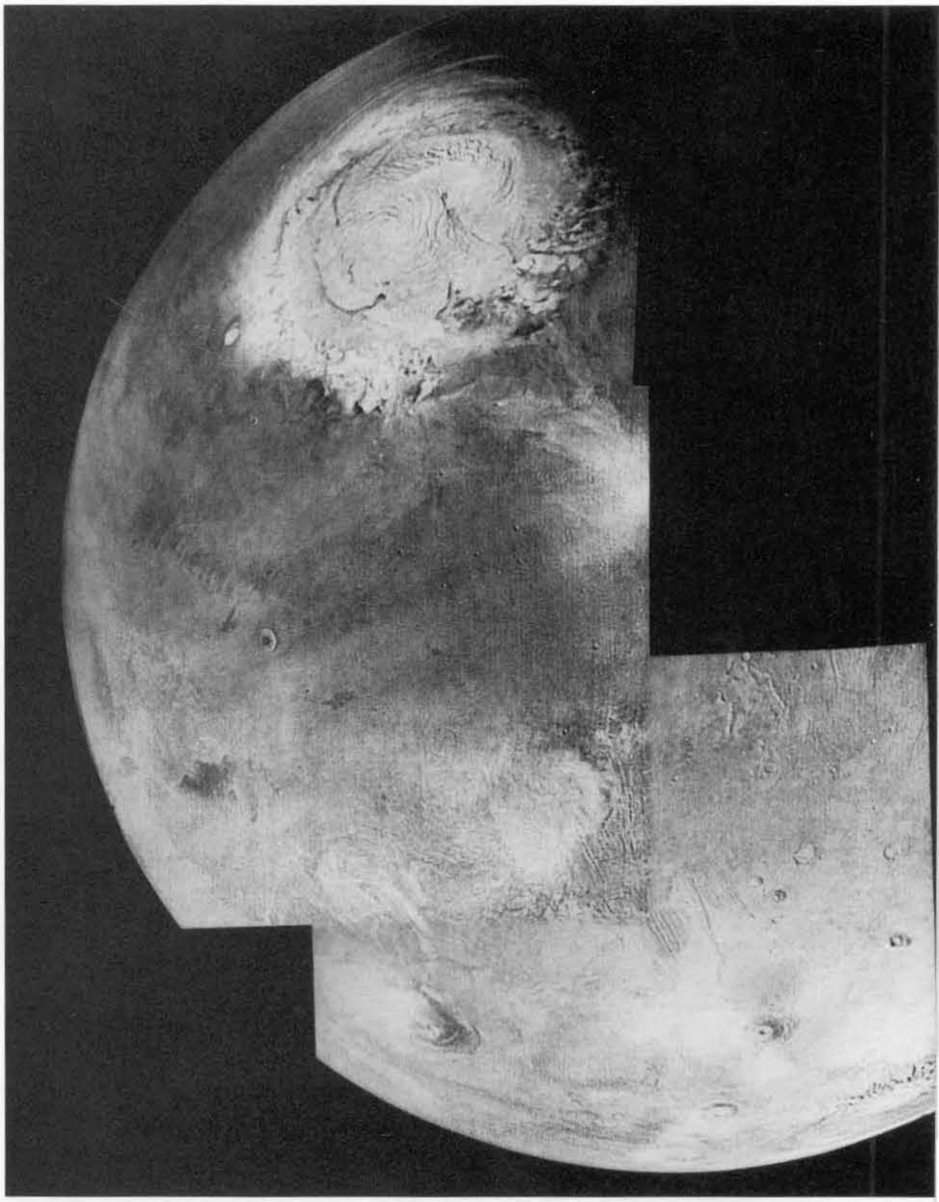
My own research concern is the poles of Mars; they're scientifically interesting and may have some relevance to Earth. But my discussion of the poles here is nested within a larger subject — the exploration of Mars — a subject that really is relevant to all of us and in which we are all, as taxpayers and voters, participants.

Mars, like Earth, has north and south polar caps. It also has seasons, since the spin axis of Mars has the same obliquity (tilt) as that of Earth. Each polar cap is very large at the beginning of spring, reaching equatorward to around 55 degrees latitude at the height of the winter. But in the summer they retreat to tiny caps barely visible from Earth. This seasonal frost that comes and goes at both poles is made of solid carbon dioxide. Underneath this frost, which except for its composition is somewhat analogous to winter snow cover on Earth, lies a permanent, residual polar cap

Ice Age

made mainly of water ice. The residual cap at the south pole is smaller than that of the north pole, and its carbon dioxide seasonal frost is relatively thin — a few feet in thickness. When the seasonal frost recedes and exposes the residual caps, we see smooth, finely layered terrains with scarps that exhibit dark and light banded deposits. We believe these layers can give us clues to the way in which the residual caps formed — and are still forming.

This layered terrain looks a bit like a French omelet — layer after layer, perfectly made. Since these layers are almost flat, our pictures look like contour maps of that surface. These layers are 50 to 100 feet thick. There may be 30 of them in one stack, making the whole thing about a kilometer in thickness. They're abundantly present at both poles and must have been laid down by global winds. They're very smooth and are made of either dirty ice or icy dirt. Slight differences in the proportions of ice and dirt in each layer end up making them weather a bit differently and possess different albedos, or brightnesses. The layered terrains may include 500 million years of geologic history, and they are interesting to us because they record global climatic fluctuations on Mars.

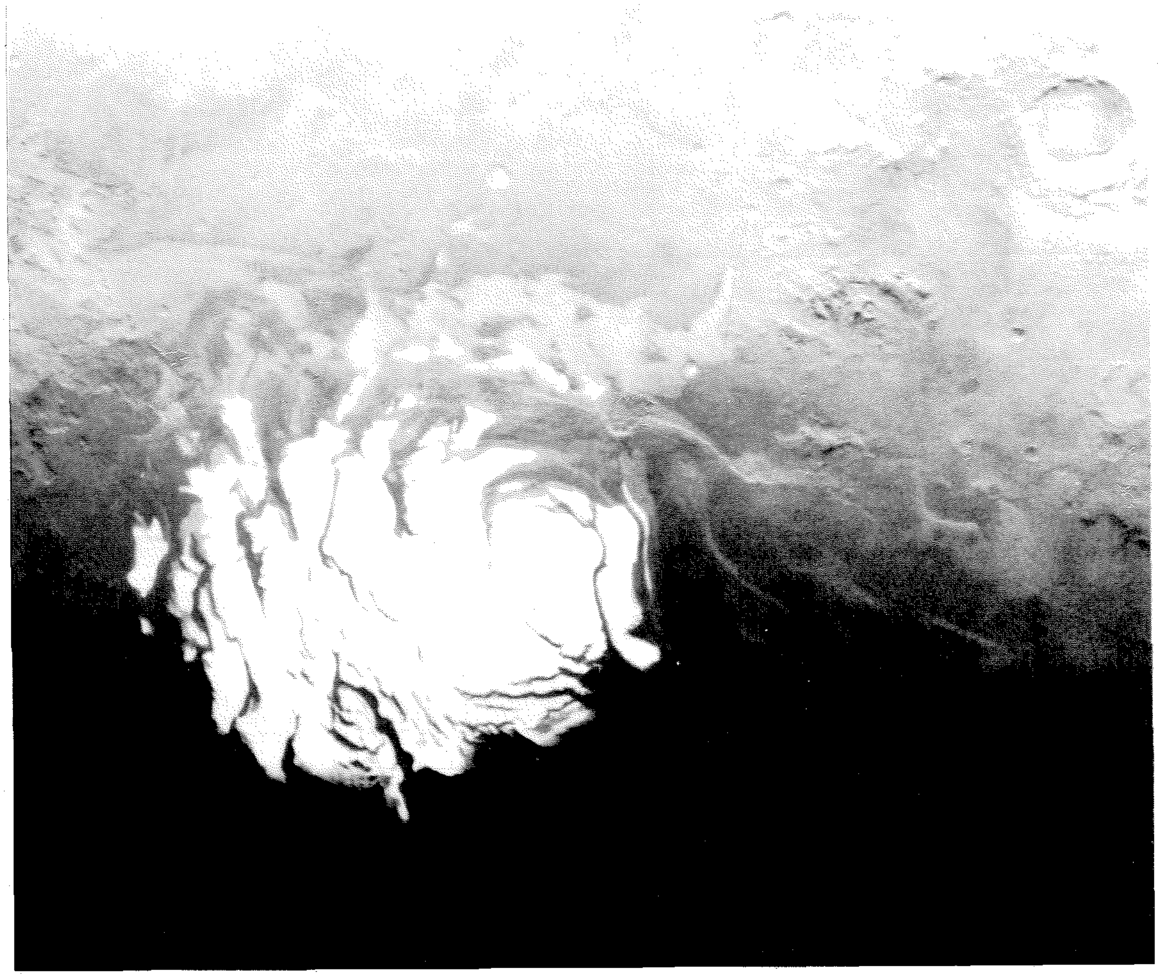


The northern polar cap of Mars, shrinking during the late Martian spring, can be seen in this mosaic (three pictures) taken by Mariner 9 August 7, 1972. The picture shows the northern hemisphere almost to the equator.

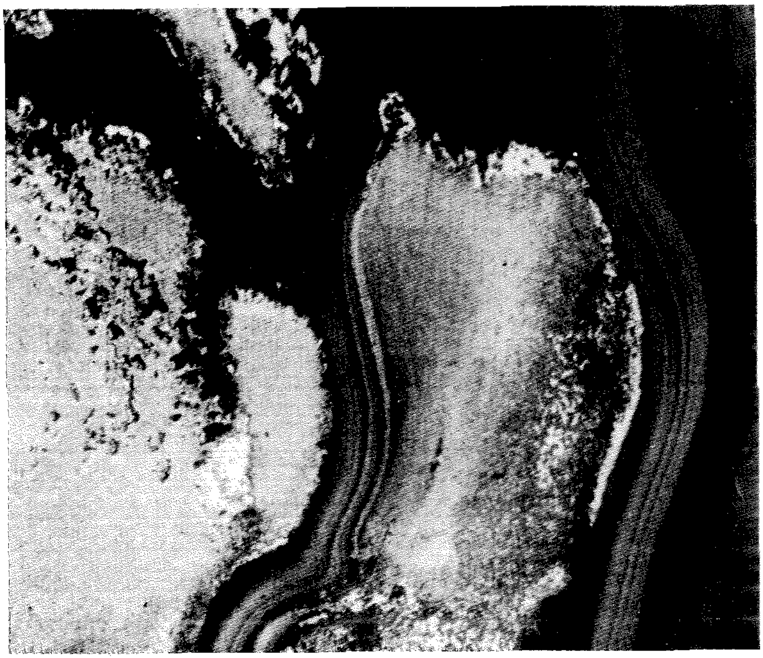
Water ice is remarkably stable on Mars because the planet is so cold. Mars is half again as far away from the sun as Earth, and because it doesn't have any oceans to hold in the heat, it experiences extreme temperature fluctuations. In the polar regions a block of ice will evaporate very slowly. It's like putting water ice in an ice cream factory with temperatures low enough to freeze carbon dioxide; it becomes a stable substance that doesn't go anywhere very fast. So even though there might be only 10 to 20 feet of water ice now exposed in the residual caps, it may remain stable for hundreds of thousands of years on Mars.

How do we know that the seasonal "snow" on Mars is carbon dioxide? We know

Right: This view of the south polar cap of Mars was imaged by Viking Orbiter 2 on September 29, 1977, when the residual cap had retreated to its nearly minimal size of about 200 km across. Four overlapping wide-field scenes were combined by the Astrogeology Branch of the United States Geological Survey in Flagstaff, Arizona, to produce this computer mosaic.



Below: A high-resolution image acquired by Mariner 9 on March 8, 1972 shows in greater detail the largely defrosted "forklike" feature that can also be seen on the right side of the whole south residual cap image at right. The delicate banding of the layered terrain underlying the residual cap is apparent in this frame, which is about 40 km wide.



from measurements of Mars's atmosphere that, although it's very thin compared to Earth's (about one half of one percent that of Earth's), it's almost all carbon dioxide. Mars has about 30 times more carbon dioxide that does Earth. Since Mars is so cold, the carbon dioxide will freeze out of the atmosphere slowly at night as the surface radiates heat during the long polar winters when the sun disappears for six months. This forms the huge seasonal cap of carbon dioxide frost. When the sun hits the cold carbon dioxide frost in the spring, the carbon dioxide begins to sublimate into the atmosphere again. The gaseous atmosphere and the surface deposits of solid carbon dioxide are in balance. This was first predicted in 1966 by Robert Leighton, the William L. Valentine Professor of Physics, Emeritus, and confirmed by Mariner 7 in 1969 (partly with a instrument developed by Gerry Neugebauer, the Howard Hughes Professor and professor of physics and director of Palomar Observatory).

We think there is also excess solid carbon dioxide in the Martian south polar region, because Mars's carbon dioxide atmospheric pressure seems to be regulated by the temperature at the poles. Imagine a laboratory experiment to illustrate this: If we have a bell jar in which we can regulate and measure the temperature and pressure from outside, we can stick a block of carbon dioxide in, evacuate the bell jar, and set the temperature at 143 degrees Kelvin — the average temperature at the Martian pole. That is the temperature of a bright substance at Mars's poles that reflects most of the light, averaged over the year. When we let the carbon dioxide gas sublimated from the block of carbon dioxide come into equilibrium with that temperature and then measure the pressure in the bell jar, it turns out to be one half of one percent of the Earth's atmospheric pressure. This is exactly the pressure of the carbon dioxide atmosphere on Mars!

So the atmospheric pressure on Mars is governed by this solid carbon dioxide at the poles. The Earth's atmosphere, mostly nitrogen, behaves differently. Since there's no solid nitrogen on the surface, our atmospheric pressure is not governed by the surface temperature. But on Mars it is, and that's a key to the global variations recorded in the layered terrains. The Martian atmosphere has changed drastically and periodically as a consequence of the change in the polar temperature.

But there's also dust in the layered terrains. Where does it come from? We know that there's lots of dust in the Martian atmosphere because Mariner 9 arrived there in 1971 during a dust storm; we practically couldn't see the planet. Decades of telescopic studies from Earth had shown that a global dust storm usually occurs when the planet gets closest to the sun. (Mars has a moderately eccentric orbit). We think that near the equator, the hottest place on the planet, temperatures get so high that vertical dust devils start to swirl up from convection — just as in Earth's dry deserts in the summer. There's no moisture, so this very dry dust gets sucked up, creating much dust in the atmosphere where it absorbs the sun's heat. The dust in the atmosphere gets hotter and hotter, heats the atmosphere, and the process takes off, ending up as a global dust storm. It's an unstable process for a while but is turned off when the dust finally spreads globally and gets carried up to the poles. So the source of the dust in the polar layered terrains is the equatorial areas, driven annually by the year's hottest conditions. The sink of the dust is in the polar regions, where the average annual conditions are much colder and residual water ice caps provide a permanent trap.

If there is a solid seasonal cap on the poles, and the atmospheric carbon dioxide is regulated by the solid deposit on the surface, the pressure on Mars ought to change significantly over the year. Viking landers on Mars in 1976 and 1978 conducted measurements showing that indeed the Martian atmosphere has a 20- to 30-percent annual variation in pressure simply because of the seasonal freezing out and sublimating of carbon dioxide in the two caps. But to explain these smooth layers that formed over thousands of years, we're looking for a longer term variation that could cause the conditions on Mars to vary over long periods of time.

For example, the amount of eccentricity of Mars's orbit varies. It has 100,000-year fluctuations and million-year fluctuations from the combined effect of Jupiter and Saturn tugging on Mars's orbit. When Mars's orbit is very eccentric, the planet gets much closer to the sun at perihelion, and the heating increases. When the eccentricity is small, the differential seasonal heating will be minimal.

Another effect, which we also have on Earth, is the precession of the spin axis. This will cause the hemisphere that happens to lean toward the sun at perihelion to alternate

Smoothly eroded layered terrain at 75° south latitude is displayed in this Mariner 9 high-resolution image. The nearly horizontal layers are estimated to be 20 to 50 meters thick. The overall dimension of the frame is about 30 km across.

back and forth over a period of 50,000 years. This periodicity, called the equinoctal period, will also cause a global climatic fluctuation in dust production.

But there's something else going on on Mars that affects the poles themselves, and which is even more important. As I mentioned earlier, Mars's axis is tilted about the same amount as Earth's is — about 24 degrees — so the planet has the same kind of seasons we have. But Jupiter and Saturn wreak enormous havoc on this obliquity, as well as on its orbit, over time. About 700,000 years ago it was tilted only 16 degrees — more straight up and down. Since the poles were not tilted as much toward the sun in summer, they remained much colder. That means that the average temperature and pressure of the atmosphere went down too. At that time the pressure was about 40 percent of what it is now.

On the other hand, about 800,000 years ago the opposite happened: The axis was pulled more over on its side, leaning at an angle of 33 degrees. At this tilt the poles got *more* heat than normal. The pressure of the atmosphere must have been six to eight times what it is now. This has been going back and forth periodically over 100,000-year and million-year cycles — not exactly the same periods as the eccentricity, but similar. This obliquity variation will strongly affect the dust storms, but even more important it will affect the capacity of the polar ice "sink" to capture the dust and create layers. So, in the variation in obliquity we have the mechanisms to explain to some extent how these layers may have formed. But we still have to understand much more of the details.

Mars is a planet that's very sensitive to sunlight; its climate fluctuates very easily. This isn't true on Earth because much of the heat absorbed from sunlight stays in the oceans and is mediated over thousands of years by a very complex, long-term exchange of heat with the atmosphere. So even though some climatic processes on Earth are similar to those on Mars, there is no such direct relationship on Earth to the short-term changes that exist on Mars.

We do have ice ages on Earth. We're in one right now — the Pleistocene — which began about 3 million years ago. Actually, we're in a brief warm period, but it's still an ice age, a phenomenon that has happened only rarely over geologic time. There was another about 250 million years ago, which was the end of the Permian and another at the end of the Precambrian about 700 million years ago. There have been other smaller scale ice ages, but these three were the worldwide ones that stand out in the geologic record.

What causes ice ages to occur? Most of the Earth's geologic history has not had ice ages. But we probably wouldn't even be here except for this climatic anomaly. The whole development of *Homo sapiens*, and *Homo erectus* who preceded him, was tied to climatic change and effects of the ice age. But we don't know what causes ice ages to occur. Two categories of possibilities have been debated for a long time. One category suggests that something peculiar happened on the Earth itself. For example, an excessive amount of vulcanism may have thrown a lot of particulates high into the atmosphere and cooled the planet. Or perhaps two plates of the Earth's crust came together in some strange way that disturbed the oceans sufficiently to change the climate. Somehow, a chance activity of the Earth's surface or interior must have triggered ice ages.

The other theory postulates instead that something peculiar happened to the sunlight. Perhaps the sun occasionally gets a little cooler and doesn't radiate so much heat, and this triggers an ice age. Because the climatic record on Earth is mixed up, it will probably never be possible to confidently determine from a terrestrial record alone whether the cause of ice ages is internal or external.

But Mars is clearly a much more sensitive indicator of solar activity. Suppose the sun for some reason did cool down 3 million years ago. Because its effect on Mars would be far stronger that its effect on Earth, there should be a record of it in those layered polar terrains. On the other hand, if there is no record there of reduced solar heating starting 3 million years ago, then our ice ages must have resulted from an internal process of Earth. Mars may well provide the solution to the puzzle of ice ages. But how do we find out? We will have to go to Mars.

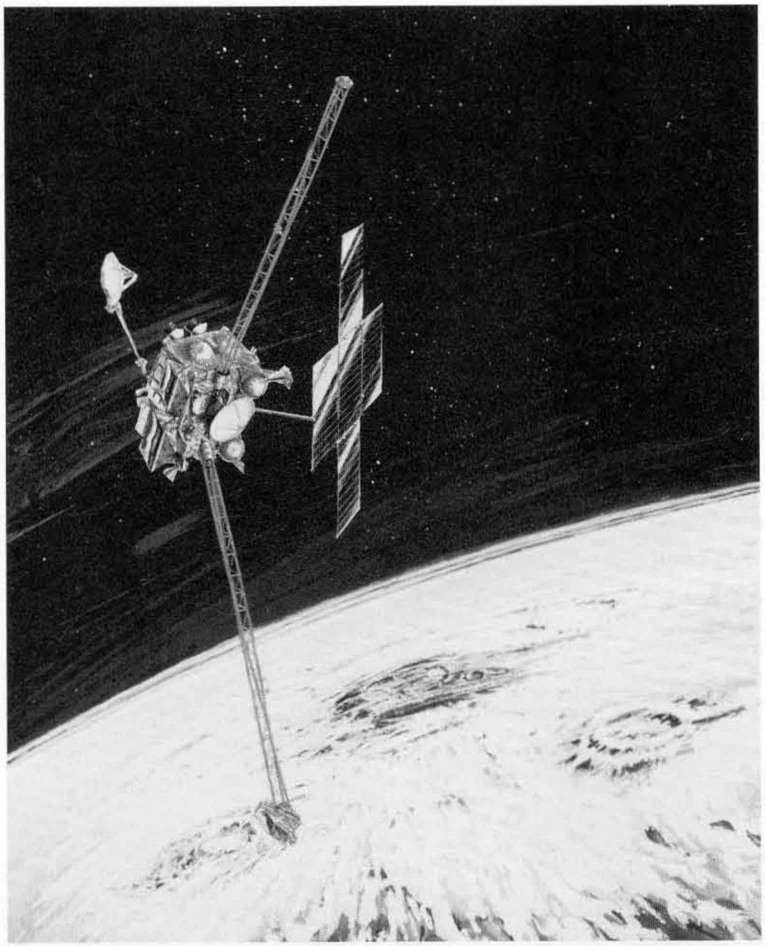
Mars and Earth get together on the same side of the sun once every 25 months. The next three times this happens — in 1988, 1990, and 1992, there will be some new launches of spacecraft for exploration there by Earth's robots. First, in early 1989 two Soviet spacecraft will rendezvous with Mars's moonlet Phobos. These spacecraft will come within a few hundred feet of the surface of

Phobos and try to measure its composition with lasers and a number of other instruments. Then, two landers will be projected onto the surface to measure directly what Phobos is made of. We're very interested in this moon because it's one of the darkest objects in the solar system. In some ways it's like the nucleus of Halley's Comet, and it may well contain organic materials with a record going far back in time. Then the two spacecraft will go into orbit around Mars itself. It's an ambitious mission, which requires big launch vehicles, so it's fortunate that the Soviets are trying to do it instead of us right now. They're using two large rockets of the same class that launched our Viking and Voyager spacecraft.

After that the next visit to Mars is supposed to be an American one — a single spacecraft called Mars Observer. It will orbit 500 km from the surface and include radar measurement of the altitudes of Martian features. It will also measure how light is emitted and reflected from the polar deposits to try to determine their chemical composition. Also planned is an experimental camera to return extremely high-resolution pictures. G. Edward Danielson, member of the professional staff of the Division of Geological and Planetary Sciences, is developing this camera along with Andrew Ingersoll, professor of planetary science, and Michael Malin, PhD 1976 (now professor of planetary science at Arizona State University). This remote-sensing mission was supposed to be launched by the space shuttle in 1990. NASA now feels, however, that the shuttle will still not be adequate for the task. They might use a Titan 3 rocket, or the mission may slip until 1992. But there will be an American presence at Mars in the next decade.

The Soviet Union is on a roll and is doing some very good things in interplanetary space — ambitious missions with great big rockets and sophisticated spacecraft. They have announced the objectives of the Phobos mission in advance, as they did with their previous successful mission to Halley's Comet, which had originally dropped balloons and landers into Venus's atmosphere. The Soviets encouraged international participation in that mission, and this will continue, with the Phobos undertaking including several American investigators.

The Soviets were planning to go back to Venus in 1992 but have changed their minds and have decided to focus on Mars instead.



Mars Observer, a remote-sensing mission to study the planet's geology and climate, under way at Caltech's Jet Propulsion Laboratory, will b launched early in the 1990s.

What they're going to do on Mars are things we *thought* about doing, but didn't do, 10 years ago. Now the Soviets, instead of us, plan to send a mission specifically to land on Mars in 1992. An orbiting spacecraft will probably rocket-propel several six-feet-long, bullet-shaped probes backward from the spacecraft's direction of motion, a maneuver that will slow them down sufficiently for them to fall onto the surface of Mars. They will still crash at high speed, but they will be designed to do that. In the backs of these probes would be scientific instruments, such as cameras, chemical analysis instruments, seismometers, and so on, that can survive that kind of impact. In the layered terrains that I have just discussed these instruments could gather information both chemically and with imaging.

In addition the Soviets plan to float balloon-mounted electronic cameras in Mars's atmosphere to obtain high-resolution traverses across the surface. This is really difficult to do, because the atmosphere of Mars at the zone they're planning to observe is 50 times less dense than the atmosphere of Venus, where they flew balloons with their

On the dry lake bed at Edwards Air Force Base a team from JPL and Caltech conducts a flight test of a Montgolfiere balloon with a segmented payload and drag rope, which might be used to keep a balloon's height constant above the Martian terrain.

Vega mission. It will be a very ambitious surface exploration mission preparing for more precise ideas of where to send future missions — both automated and manned. I have been working with Caltech students and with a group at JPL to develop such special balloons and miniature cameras. I hope there may be an opportunity for some American participation in this Soviet mission — or perhaps eventually we will be ready to fly such devices ourselves.

What we really need on Mars is to be able to move around. We could do this with rovers containing artificial intelligence run remotely from Earth. These could, for example, make an autonomous decision not to drive over a cliff and fall down a crevasse and would have arms to collect samples. They could take these samples to another location, to a different rocket vehicle, which could fire itself back out and eventually return to Earth. This sort of robotic sample-return mission has been studied for years by the U.S. and by the Soviets.

The Soviets have indicated an interest in flying such a mission as early as 1996, and there have been discussions about the U.S. taking the rover portion and the Soviets doing the sample-return part. Perhaps we could collaborate on the surface of Mars, which might be a first step toward collaborating on the surface of Earth. A rendezvous of robots on Mars's surface seems to be a lesser problem for the technology transfer people, because the robots talking to each other on Mars will probably not reveal any state secrets. Of course, such an ambitious joint mission has not yet been accepted and it may never be, but at least the Soviets have the momentum to do it. The question is whether *we* have the will to get back in the act and do it. Fortunately, the proposed rover can be launched by the new, large, automated seven-segment rocket that the Air Force has on order. By 1996 we could probably spring one or two of them loose for Mars. So we could probably still manage to do this despite the delay following the shuttle disaster.

In the longer range, of course, humans will go to Mars. History has shown that humans will explore anyplace they can get to. One reason they'll go to Mars is that the other planets are not suitable for human habitation. Venus is much too hot; Jupiter is surrounded by lethal radiation; Mercury's vacuum surface experiences 10 times the searing sunlight of the Moon; and Saturn and beyond is just too far. Mars is the right place to go. It even contains ice, which might provide oxygen and water for later expeditions. I'm sure the Soviets have been thinking about this for some time, and fortunately now our own government is finally doing some studies. A manned mission to Mars is something that could actually happen soon after the turn of the century — even a joint mission between the U.S. and the Soviet Union. It's something either country *could* do by itself, but that would take longer and cost more. What better way could there be for the two superpowers to demonstrate their commitment to long-term coexistence — and collaboration?

I believe that Mars is the place where the action is going to be for a long time. Humans very likely *will* go to Mars in the first quarter of the next century, and among the areas they will investigate are the poles, where they will elucidate geological records, pertinent not just to Mars but to the Earth itself. □

Teaching Computational Physics

by Steven E. Koonin

MODERN PHYSICS RESEARCH is concerned increasingly with complex systems composed of many interacting components — the many atoms making up a solid, the many stars in a galaxy, or the many values of a field in space-time describing an elementary particle. In most of these cases, although we might know the simple general laws governing the interactions between the components, it is difficult to predict or understand qualitatively new phenomena that can arise solely from the complexity of the problem. General insights in this regard are difficult, and the analytical pencil-and-paper approach that has served physics so well in the past quickly reaches its limits. Numerical simulations are therefore essential to further understanding, and computers and computing play a central role in much of modern research.

Using a computer to model physical systems is, at its best, more art than science. The successful computational physicist is not a blind number-cruncher, but rather exploits the numerical power of the computer through a mix of numerical analysis, analytical models, and programing to solve otherwise intractable problems. It is a skill that can be acquired and refined — knowing how to set up the simulation, what numerical methods to employ, how to implement them efficiently, when to trust the accuracy of the results.

Despite its importance, computational physics has largely been neglected in the standard university physics curriculum. In part, this is because it requires balanced integration of three commonly disjoint disciplines: physics, numerical analysis, and computer programing. The lack of computing hardware suitable for a teaching situation has also been a factor. Students usually acquire what skills they do have by working on specific thesis problems, and as a result their exposure is often far from complete.

This situation and my professional background in large-scale numerical simulations motivated me to begin teaching an advanced computational physics laboratory course at Caltech in the winter of 1983. My goal was to provide students with direct experience in modeling non-trivial physical systems and to impart to them the minimal set of techniques for dealing with the most common problems encountered in such work. The computer was to be viewed neither as a "black box" nor as an end in itself but rather as a tool for getting at the physics.

Another factor in my decision to develop a computational physics curriculum was the ready availability of hardware that could pro-

Unit	*Numerical Methods*	*Example*	*Project*
1	Differentiation, quadrature, finding roots	Semiclassical quantization of molecular vibrations	Scattering by a central potential
2	Ordinary differential equations	Order and chaos in two-dimensional motion	Structure of white dwarf stars
3	Boundary value and eigenvalue problems	Stationary solutions of the one-dimensional Schrödinger equation	Atomic structure in the Hartree-Fock approximation
4	Special functions and Gaussian quadrature	Born and eikonal approximations to quantum scattering	Partial wave solution of quantum scattering
5	Matrix inversion and diagonalization	Determining nuclear charge densities	A schematic shell model
6	Elliptic partial differential equations	Laplace's equation in two dimensions	Steady-state hydrodynamics in two dimensions
7	Parabolic partial differential equations	The time-dependent Schrödinger equation	Self-organization in chemical reactions
8	Monte Carlo methods	The Ising model in two dimensions	Quantum Monte Carlo simulation of the hydrogen molecule

Computational Physics curriculum

vide each student with an individual computing environment. Personal computers can be used easily and interactively through a variety of high-level languages, and they offer a numerical power sufficient for illustrating many research-level calculations. Moreover, the graphics facilities commonly found on such systems allow an easy but often startling insight into many problems. In short, I (and the students) could concentrate on the strategy of a calculation and the analysis of its results, rather than on the mechanics of using a computer.

How, then, was I to teach the art of computational physics? I quickly decided that the traditional lecture-cum-assignment approach was not optimal, as there is no teacher better than direct experience and computing is a very personal activity for most physicists. I therefore planned a situation where students would work through material on the computer that would teach by example and exercise. This format had the added benefit that students could work largely on their own, at their own pace, and at times of their choosing.

In defining the course, it was relatively easy to identify the broadly applicable numerical methods I wanted to cover, but choosing the physical situations in which to demonstrate these methods was more difficult. I attempted to satisfy simultaneously the criteria that the physics discussed be an "interesting" extension or enrichment of the usual quantum, statistical, or classical mechanics material, that the scale of the computation be appropriate to the numerical power of the hardware, and that the problem not be soluble analytically. In the end, I was able to find 16 such case studies. In more than half of them the student can compare calculated results with experiment or observations.

The curriculum I developed during the 1983 and 1984 academic years consists of eight units. The student begins each by reading a text section that gives a heuristic discussion of several related techniques for accomplishing a particular numerical task. Intuitive derivations of simple, general methods are emphasized, with appropriate references cited for rigorous proofs or more specialized techniques. Short, mathematically oriented exercises involving only a small amount of programing reinforce this material.

After reading the text section, the student works through the remaining two sections of the unit — the example and the project. Each of these is a brief exposition of a particular physical situation and how it is to be modeled, using the numerical techniques taught in that unit together with a set of exercises for exploiting and understanding the associated program. The example and project differ only in that I expected the students to use the canned program for the former, while perhaps writing their own program from scratch for the latter.

Each of the programs I developed functions in several capacities — as an easy-to-use demonstration of the physics, as a laboratory for exploring changes in the numerical algorithms or parameters, and, in the case of the projects, as a model for the student's own program. Thus, more than simply working correctly, the programs had to be easily read and understood. Simple organization, full documentation, and a structured programing style were essential. As much of each program tends to be input/output (I/O) and "bookkeeping," the few important numerical sections had to be called out clearly and I often had to sacrifice elegance in coding and speed of execution for the sake of intelligibility. More significantly, my ambitions were restrained frequently by a desire to keep the calculation and graphics displays simple. Despite these constraints, with some thought and care I was able to work to my satisfaction within the format described.

The choice of language invariably invokes strong feelings among scientists who use computers. Any language is, after all, only a means of expressing the concepts underlying a program, and the important ideas in the curriculum are relevant no matter what language I decided to use. However, some language had to be chosen to implement the programs, and I finally settled on BASIC. The BASIC language has many well-known deficiencies, foremost among them being a lack of local subroutine variables and an awkwardness in expressing structured code. Nevertheless, these are more than balanced by the simplicity of the language and the widespread fluency in it; BASIC's ready availability on the microcomputers I was using; the existence of both BASIC interpreters convenient for writing and debugging programs as well as of compilers for producing rapidly executing finished programs; and the powerful graphics and I/O statements in this language. Virtually all of the students were familiar with some other high-level language and so could learn BASIC "on the fly" while taking the course. Several students elected to write their projects in other languages.

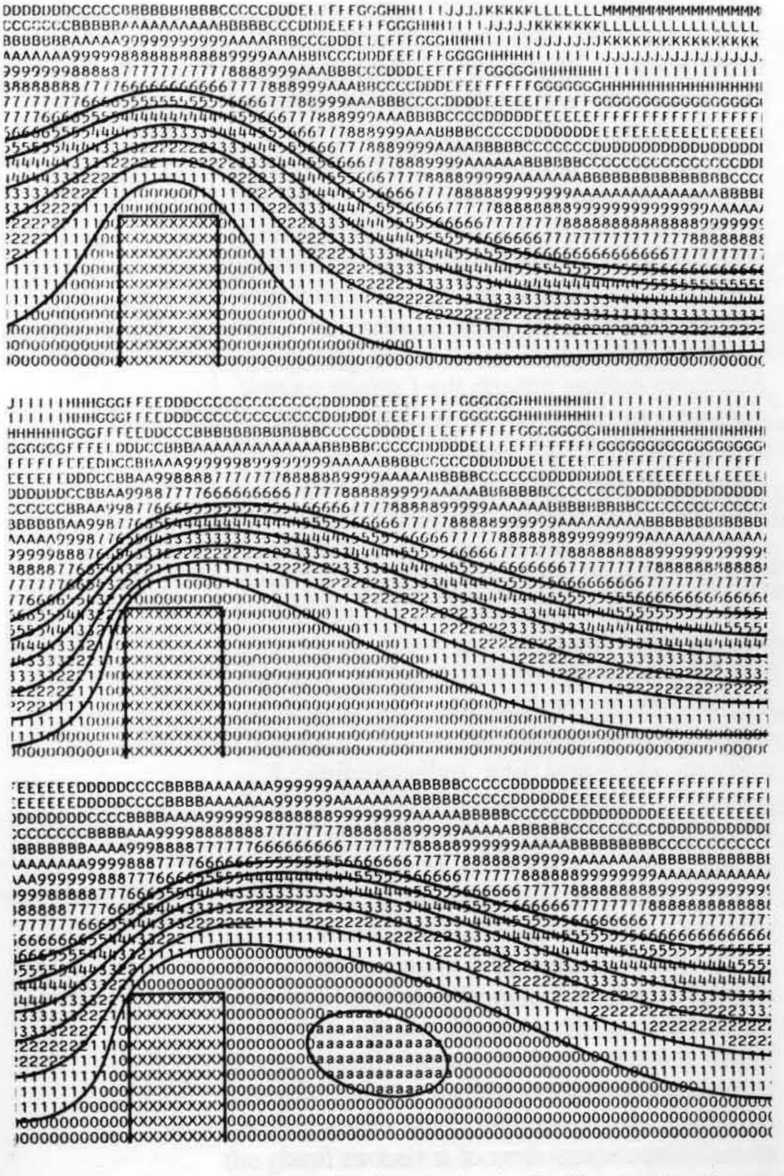
I taught the course in a laboratory format to junior and senior physics majors. All of the students had taken (or were taking) the conventional courses in classical, statistical, and quantum mechanics, and so were familiar with many of the physics concepts involved. Moreover, there is enough of a computer culture among the Caltech undergraduates so that most of them were quite familiar with the hardware before beginning the course; those who were not became proficient after several hours of individual instruction. As mentioned above, students worked through the material largely on their own, although a teaching assistant and I held weekly office hours during which we were available for help and consultation. Individual half-hour interviews upon the completion of each unit served to monitor the students' progress and assess their understanding. I found that typical students, working six or seven hours per week, could complete three or four units in a ten-week term, perhaps writing their own codes for two of the projects and using my codes for the others.

A brief discussion of a couple of the examples and projects will give some feeling for the level of the material and the style in which it is presented. Project 6 illustrates techniques for solving elliptic partial differential equations by considering steady-state (time-independent) flow of a viscous fluid about an obstacle; for example, the flow of a stream around a rock. The mathematical description of the flow is based on continuity (fluid is neither created nor destroyed) and the response of each bit of fluid to the pressure and viscous forces acting on it. When the flow is two-dimensional (coordinates x and y), these two physical principles can be embodied in the coupled non-linear elliptic equations,

$$\left[\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right]\psi(x,y) = \zeta(x,y);$$

$$\nu\left[\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right]\zeta(x,y) = \left[\frac{\partial\psi}{\partial y}\frac{\partial\zeta}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial\zeta}{\partial y}\right]$$

Here, ψ is the stream function specifiying the direction of flow at each point, ζ is the



Printer output shows the flow of a viscous fluid around a rectangular plate at various velocities. Streamlines have been superimposed on the computer-generated pattern. The direction of flow is from the left, and each pattern is reflection-symmetric about the lower edge. Note particularly the hydraulic "jump" above the plate, the laminar flow at low velocity (top), the increasing separation of the flow from the rear of the plate at higher velocities (middle), and the vortex behind the plate at the highest velocity (bottom).

fluid's vorticity, and v is the kinematic viscosity. Boundary conditions on ψ and ζ (for example, the fluid cannot flow into the object's surfaces) complete the specification on the problem.

These equations cannot be solved analytically, but are amenable to a numerical treatment on the computer through discretization. The resulting large number of non-linear algebraic equations can be solved through a relaxation process, in which initial guesses for the stream function and vorticity are refined iteratively.

Following a brief derivation and discussion of the equations, students are guided through a series of steps culminating in a program to solve the flow about a rectangular plate at various speeds. Results can be displayed as character plots, as shown in the figure above, and the drag and pressure forces calculated can be compared with values measured in the laboratory. Here again, the computer is used to simulate situations for which analytical solutions are impossible and for which intuition is difficult to develop.

Example 5 illustrates the use of a computer in a different way — the analysis of experimental data by least-squares fitting. The physical situation here is the scattering of high-energy electrons (approximately 200 million electron volts or more) from atomic nuclei, a topic currently of high research interest in nuclear physics. Because the electrons interact with the nucleus through the Coulomb force, the cross sections for such scattering are sensitive to the distribution of electrical charge (that is, the structure) of the nucleus. Indeed, the measured cross sections can be "inverted" in a model-independent way to obtain the nuclear charge density.

My program for this problem analyzes actual experimental data to infer the charge densities for nuclei of calcium, nickel, and lead. An iterative, nonlinear least-squares fit procedure is used to adjust the charge density to the measured cross sections. The density and fit to the data are displayed as the iterations proceed. In running and understanding this program, the student is asked to check the accuracy of the fits obtained, to extract information about the nuclei from them and compare with simple nuclear models, and to explore alternative fitting strategies.

In the course of developing and teaching this curriculum, I have been impressed by several unexpected advantages in formalizing the instruction of advanced students in using the computer as a tool for doing physics. To write a program simulating a given physical situation, the student must understand the physics in a different (and complementary) way than is needed for an analytical approach. Programs also bring a flexibility and vividness of presentation that is difficult to obtain otherwise. Moreover, simulating systems brings a sense of exploration and surprise to the learning process, as understanding how results change as parameters or algorithms change often leads to greater insights. Finally, because complex situations can be presented, students are exposed in detail to research-level problems at an earlier stage of their career. In these ways, I expect that computer-based education in physics at this level will supplement, rather than supplant, the traditional mode of lecture instruction. □

Books

Gene Activity in Early Development
Third Edition

by Eric H. Davidson

Academic Press, Inc., 670 pages

IF MODERN DEVELOPMENTAL BIOLOGY can be said to have a central, unifying principle, it is the theory of differential gene activity: As development proceeds, the many cellular descendants of the zygote take on very different forms and functions by virtue of their differential utilization of the same genomic information. Thus, ectodermal cells and mesodermal cells contain the same complement of genes in their DNA but synthesize different (though overlapping) subsets of the total number of proteins encoded therein. If we ever arrive at a clear understanding of the wondrous process of development, it will consist in large part of a knowledge of both the causes and consequences of differential gene activity.

Gene Activity in Early Development is an attempt to provide a coherent description of the current state of our understanding of this problem and is consequently a very ambitious undertaking. This is all the more true because the interval between the second (1976) edition and the present one has been characterized by nothing less than an explosion of information (if not elucidation) relevant to the subject of this book. My copy of the second edition weighs 1,026 grams; the third, while larger, still weighs only 1,456 grams. It is safe to say that the sheer amount of data has increased by a vastly greater proportion, so to make sense of it in a book of manageable size clearly required a selective, critical, and synthetic approach. Given the added difficulty of the task, it is remarkable that this new volume is such a success.

The main concern of the book (as of developmental biology today) is the study of development at the molecular level. Yet the presentation and evaluation of the biochemical results is skillfully interwoven with the work of both early and modern embryologists, particularly regarding the mapping of cell lineage and cell fate. This serves to remind us that the developmental processes we seek to understand are ultimately cellular and organismal events, and thus provides the proper biological context in which to view the molecular analysis of development. The author's ability to organize and illuminate the very diverse embryology literature is especially apparent in the brilliant last chapter, which considers the evidence for localization in the egg cytoplasm of "morphogenetic determinants," substances with the capacity to direct the developmental fate of the cells that inherit them.

Two other important aspects of the book's approach are unique and must be described. There is an emphasis throughout on a *quantitative* understanding of early gene expression. The synthetic activities of the mother and the embryo are here considered in terms of numbers of RNA transcripts completed per second, or numbers of molecules per cell of a particular protein (with many of these values calculated, not just drawn, from the published data). This emphasis reflects the not yet widespread understanding that a successful description of embryogenesis must be able to account for its quantitative, as well as its (perhaps more obvious) qualitative aspects.

The main strength of the book, however, lies in the frequent comparison and synthesis of experimental results from diverse developmental systems — from snails to frogs to worms to flies to mice. We are provided with very satisfying insights into the different ways that a specific developmental problem has been solved during the evolution of various phylogenetic branches, each solution reflecting peculiar features of those animals' biology. And, of course, we are treated to the occasional generalization: In all systems for which there is evidence, the set of zygotic genes active in the midstage embryo consists largely of those used by the mother during oogenesis to provide the oocyte with its store of maternal transcripts. Such results are the molecular counterparts to the pictures found in nearly every embryology text defying the reader to tell the human embryo from the chicken embryo from the frog embryo.

The back of the book has a couple of features new to this edition. The mathematical treatment of three topics (nucleic acid reassociation kinetics, measurement of RNA transcript abundance, and RNA synthesis and turnover kinetics) has been gathered into three concise appendices. A pouch attached to the inside back cover contains an unusual treat — large-scale embryonic cell lineage diagrams from the sea urchin and the nematode *c. elegans.* (By the way, it pays to note how the nematode diagram is folded *before* examining it, unless you plan on tacking it on your wall.)

The book fills a critical need at an appropriate juncture. Developmental biology has been revolutionized of late by the application of molecular methods of analysis, particularly the techniques encompassed by the term recombinant DNA. The appearance of these powerful new experimental tools has led to the generation of large amounts of exciting new information; we are beginning to attack questions that were formerly unapproachable. But such a state of affairs makes even more acute the need for a critical synthesis of the results, to give as coherent a picture as our ignorance allows. It is essential that this synthesis maintain a broad perspective, drawing on all lines of evidence and not just the new, fashionable ones. Above all, we'd like to be introduced to new ideas and fresh ways of thinking about embryogenesis.

Gene Activity in Early Development represents an eminently successful attempt to accomplish the task. It is inevitably a somewhat personal perspective, for a work of this kind involves countless choices of interpretation and emphasis. But all who read the book, undergraduate and senior scientist alike, will find themselves well served by this unique and particularly insightful view of development. □

James W. Posakony
Assistant Professor of Biology
UC San Diego

To Utopia and Back
The Search for Life in the Solar System

by Norman H. Horowitz

W.H. Freeman and Company,
168 pages

PROFESSOR HOROWITZ'S short book, handsome, illustrated, with an index, bibliography, and glossary, is subtitled *The Search for Life in the Solar System.* This carries an emotional overtone mirroring the baffled scientific effort of the last century to find a nearby, inhabited world. Apparently, human beings do not want to be alone in a cold, empty cosmos. Horowitz, an eminent biologist, was central in the Viking Lander biology experiments, two small, elaborate, and successful laboratories that reached Mars in 1976. The second Lander arrived on a rock-covered plain called Utopia Planitia, but the environment proved far from utopian. There were no Edgar Rice Burroughs warrior queens and heroes, no remnants of a dying sophisticated civilization. It was cold, and there was no water. There were jagged rocks, windblown, coarse, reddish dust, sometimes morning frost — and no life.

The book is written for an intelligent reader; what one can absorb depends on one's background. There is much to feast on, although I find most articles on biology at the *Scientific American* level as difficult as those on particle physics. Horowitz describes the nature of life and the implications for its origin. If life is to develop spontaneously, and once, from complex, organic, but non-living molecules, its environment must have narrowly specified temperature, force of gravity, and chemical composition. Most important is a liquid solvent, water on the Earth, whose physical properties set the temperature and ambient gas pressure. He disposes of exotic solvents and of life based on compounds other than carbon, C.

Biology and astrophysics have progressed far this century; astronomers find a fortunate rightness in the fact that life is carbon-based. C was almost certainly the first chemical element synthesized in the nuclear furnaces of the stars, from hydrogen, H, and helium, He. The stars are roughly 98 percent H and He; C makes up much of the balance. The building blocks of life are nucleic acids (DNA or RNA), which carry the information, and proteins (which are made of 20 amino acids). Of the amino acids, which polymerize to form complex, three-dimensional compounds, 18 contain only H, C, nitrogen, N, and oxygen, O; two have sulfur. In contrast, the Earth (and probably Mars) has 62 percent iron, magnesium, and silicon, and only 0.05 percent H, C, N. The average protein is 49.6 percent H, 31.6 percent C, 9.7 percent O, 3.8 percent N (by numbers of atoms). Living things concentrate normally volatile gases on Earth enormously. Their cosmic composition encourages a theory that life can evolve from nonbiological compounds of H, C, N, O, given the right temperature, a gravity sufficient to retain some atmosphere, and liquid water, the most abundant universal solvent. Horowitz outlines the Oparin-Urey theory that life evolved spontaneously in a water solution of organic compounds exposed to a reducing (not oxidizing) atmosphere. Life developed just once — and not long after the Earth settled down.

Not all popularization of astronomy was in harmony, alas, with this picture. Horowitz tells the lurid but unfortunate story of Percival Lowell, of the Boston Lowells. At his own observatory in Flagstaff, Lowell overinterpreted fleeting glimpses during the best seeing of Martian surface patterns and colors into a fantasy (in books published from 1898 to 1908) of seasonal growth of vegetation, caused by flow of water in canals from the water-ice cap. Most of his contemporaries did not believe in the canals, but some planetary astronomers followed Lowell 50 years too long and believed in the water. They favored H_2O over CO_2 ice caps. They misinterpreted measured polarization of scattered light to give too dense and wet an atmosphere. Only in 1965 did astrophysicists (at Caltech and JPL) correctly interpret the spectrum of Mars as indicating an atmosphere dominated by CO_2, much too thin for liquid water to exist or for parachutes to land. Thus died the canals and the fading Martians. I have never liked science fiction; I showed Mars to Wernher von Braun through the 200-inch telescope at Palomar about 1965. He looked at the blurred, dancing image and said, "Is that all?" Even under the best seeing from Earth, the smallest detail visible is 150 km in diameter. Physical conditions are studied best with spectrograph, bolometer, and photometer, and Mars is, at closest, 55 million km distant. Its surface and atmosphere must be studied close up.

Horowitz's chapter 7 describes the biology experiments on the Viking Landers; it is called "Where are the Martians?" The atmosphere proved to be largely CO_2 at a pressure one percent of that on Earth with a tiny amount of water vapor. The experiments operated successfully and were sophisticated; they would have detected carbon-based organisms. Surface samples scooped up into the gas-chromatograph mass spectrometer revealed that carbon compounds were 1,000 times less abundant than in our desert soil. The Martian surface had at most a few parts per billion of organic matter; some meteorites have much more. Even the residues of such meteoritic dust have been destroyed on Mars, probably by the chemical activity of the soil. A biological experiment incubated Martian soil with "nutrients," which terrestrial micro-organisms would use, to detect the effluvia from Martian cousins. This gas-exchange experiment wet soil and nutrients and detected unexpectedly large amounts of released O_2. This is ascribed to chemically active oxides or peroxides in the soil.

The labeled-release experiments used simple organic compounds (including amino acids), such as are formed easily on Earth, but labeled with radioactive C. A nutrient was attacked by the soil, releasing radioactive CO_2; a second trial, presumably after soil peroxide had been used up, gave no release. Had micro-organisms been present in the soil, they would have survived to eat and produce more radioactive CO_2. The pyrolytic-release experiment attempted to duplicate Martian environment and to study absorption of feed-gases, radioactive CO and CO_2, into the Martian soil. If anything, it detected iron minerals, expected in red dust. But Martian Landers gave similar results — soil chemically active, no living organisms, and no organic carbon compounds. Horowitz describes and pictures one place in Antarctica as cold and dry as Utopia Planitia on Mars and lacking mirco-organisms. Mars is not utopia but a cold desert.

Mars is not the abode of life, nor is Venus that of love; one is too cool and has too little atmosphere, the other too hot and has too much. Our solar system is not the only one; other planets near other stars may be "just right." It will be a long time until they are explored biologically; meanwhile the emphasis will be on detection of radiofrequency communications, if other organisms are talkative. The Viking experiments were a great success in many ways; the Orbiters transmitted 50,000 pictures of the surface, some with resolution of 20 meters. They show great extinct volcanoes 27 km high and impact craters 100 km wide. There are lava ridges and flows, groups of deep canyons 700 km long, wider and deeper than our Grand Canyon. Most unexpected are runoff and outflow channels almost certainly cut by water (which no longer exists) and more than 3.5 billion years old. "Where has the water gone?" is a question parallel to "Where are the Martians?" Mars is for planetary scientists now but was our best chance to study other biologies. Norman Horowitz has beautifully explained that quest. □

Jesse L. Greenstein
The Lee A. DuBridge Professor of Astrophysics, Emeritus

Research in Progress

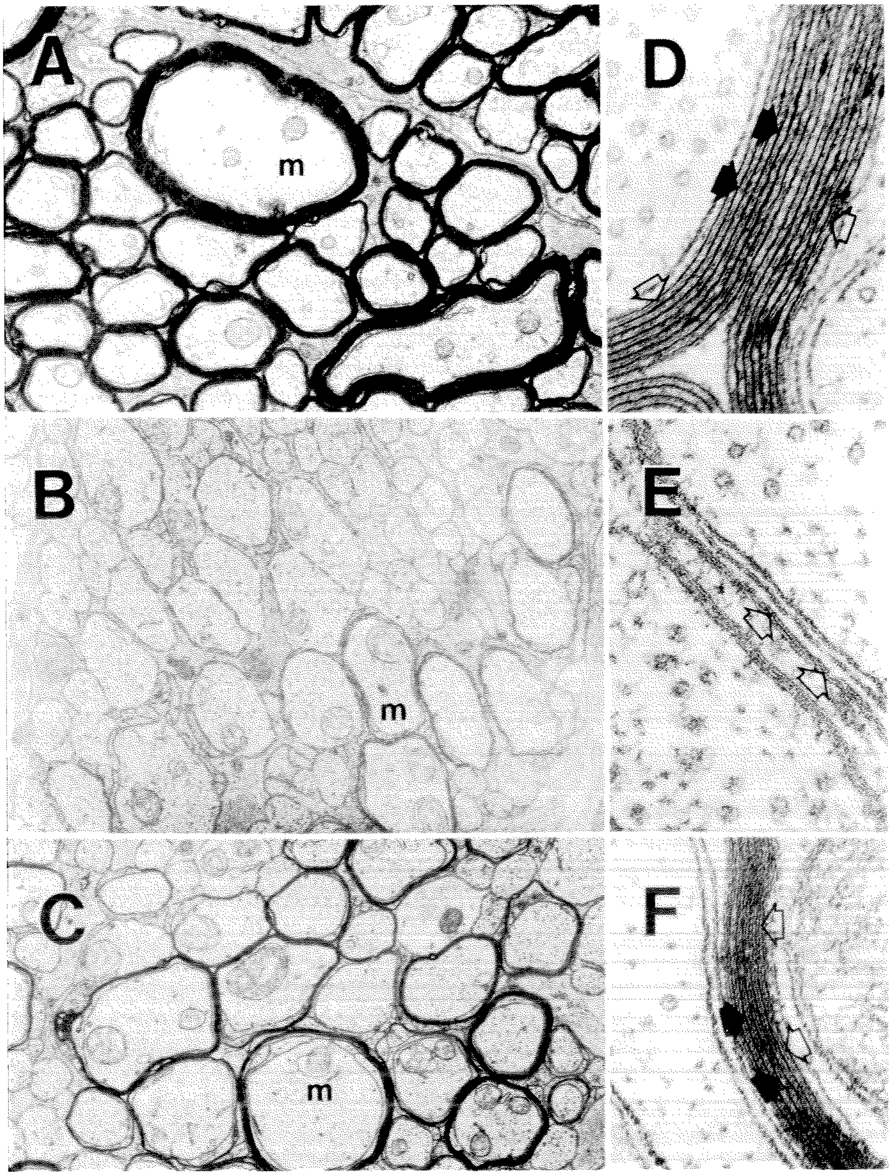
Genes, Incorporated

__Right:__ The shiverer mouse (left) suffers from a genetic neurological disease that causes tremors and premature death. Genetic surgery has cured the shiverer mouse on the right.

THE TWO MICE appear virtually identical in still photos. They're both brown, and they're both about the same size, since they are, in fact, cousins. But in a moving picture their differences become immediately apparent. One looks normal, and the other shivers uncontrollably. If we were to follow these two mice throughout their lives another difference would reveal itself: The normal-looking mouse will, in all likelihood, live out its normal lifespan of two to three years, while the shivering mouse will develop convulsions and die at just three to six months of age.

The mouse who shivers does so because it is homozygous for a defective gene, the gene that normally codes for myelin basic protein (MBP). MBP is a major component of the myelin sheaths that insulate central nervous system axons, and in its absence the transmission of electrical impulses along those axons becomes severely disrupted. The amazing thing about the apparently normal mouse is that it too is homozygous for the defective MBP gene. But, in a stunning feat of genetic engineering, Caltech scientists have managed to insert correct copies of the MBP gene into its chromosomes. Although for unknown reasons these genes produce only about 25 percent of the normal amount of MBP, this is enough to prevent the appearance of the shivering disease.

The research group was led by Leroy Hood, the Ethel Wilson Bowles and Robert Bowles Professor of Biology, and it included Carol Readhead, member of the professional staff; Brian Popko, Carmie Puckett, Raul A. Saavedra, Eric Lai, and Stephen W. Hunt, III, research fellows; Naoki



These electron micrographs show cross-sections of the optic nerve of a normal mouse (A and D), a shiverer mouse (B and E), and a cured shiverer mouse (C and F). Inserting correct copies of genes for myelin basic protein, which the shiverer mouse lacks, into fertilized eggs results in myelin sheaths that are far better formed than those of the shiverer mouse, but not as well-formed as those of the normal mouse.

Takahashi of Tokyo University; and H. David Shine and Richard L. Sidman of Harvard.

The researchers accomplished their feat by using recombinant DNA techniques to attach the MBP gene, including flanking regulatory sequences, to circular pieces of DNA known as cosmid vectors. They then injected these cosmid vectors into fertilized shiverer mouse eggs. The eggs were then implanted into foster mothers and allowed to develop normally.

This form of genetic surgery is known as germline therapy, since the genes were inserted into an animal's germ cells — its ova or sperm. The other form of genetic surgery is called somatic-cell therapy — the insertion of genes into specific body tissues, such as the bone marrow or the pancreas. Germline therapy will not be used in humans for the forseeable future. For one thing, only about one in 150 injections "takes." But, more significantly, germline therapy in humans is prohibited by ethical considerations. Extraneous genes inserted into the germline can be passed on forever, from generation to generation, with consequences that are impossible to predict. It is widely expected, however, that somatic-cell therapy will be attempted within the next year or so in efforts to cure people suffering from specific genetic diseases.

In addition, the Caltech researchers have, in the shiverer mice and in various strains of "cured" shiverer mice, a convenient experimental system for studying the consequences of decreased levels of myelin and myelin basic protein. The shiverer mutation is not a direct analog of any human neurological disease, but there are several human diseases in which demyelination is an essential characteristic; these diseases include multiple sclerosis and Guillain-Barré Syndrome.

Says Leroy Hood, "In a sense the shiverer mouse is a test tube by which we can come to understand the basic functioning of the gene for myelin basic protein. We'll use these mice to understand how this protein is expressed and how it functions. Beyond that, we've learned that we can actually construct mice that have differing levels of myelin — 5 percent, 20 percent, or 30 percent — and we'll use these specially constructed mice to understand 1) how the myelination process, which is very complex, works, and 2) the normal roles that myelin plays in facilitating nerve impulses."

These mice will also be valuable in studies of gene regulation. When preparing the gene for insertion into the cosmid vector, the researchers were careful to include large portions of DNA from areas flanking the area actually encoding myelin basic protein. They did this because they know that these areas contain "promoter" sequences and other regulatory elements that ensure that the MBP gene will be transcribed and expressed. Yet, even mice that were specially inbred to be homozygous for the inserted gene (and its accompanying regulatory sequences) produced only 25 percent of the normal amount of MBP. Although this is enough to ameliorate the symptoms of the shiverer disease, it presents something of a puzzle: If these mice have two full copies of the correct MBP gene, just as normal mice do, why don't they produce *100 percent* of the normal amount of MBP?

A clue may lie in studies that indicate that the inserts do not become incorporated at the normal location of the MBP gene — on chromosome 18 — but at some other, most likely random, location. And this may indicate that some as yet undiscovered regulatory sequences are necessary for the full expression of the gene. It is entirely possible that these regulatory sequences are as much as 10 kilobases from the gene's normal location. Another possibility is that the inserted gene may simply have been incorporated at an unfavorable location within the genome. Further research already underway with shiverer mice may well resolve these questions.

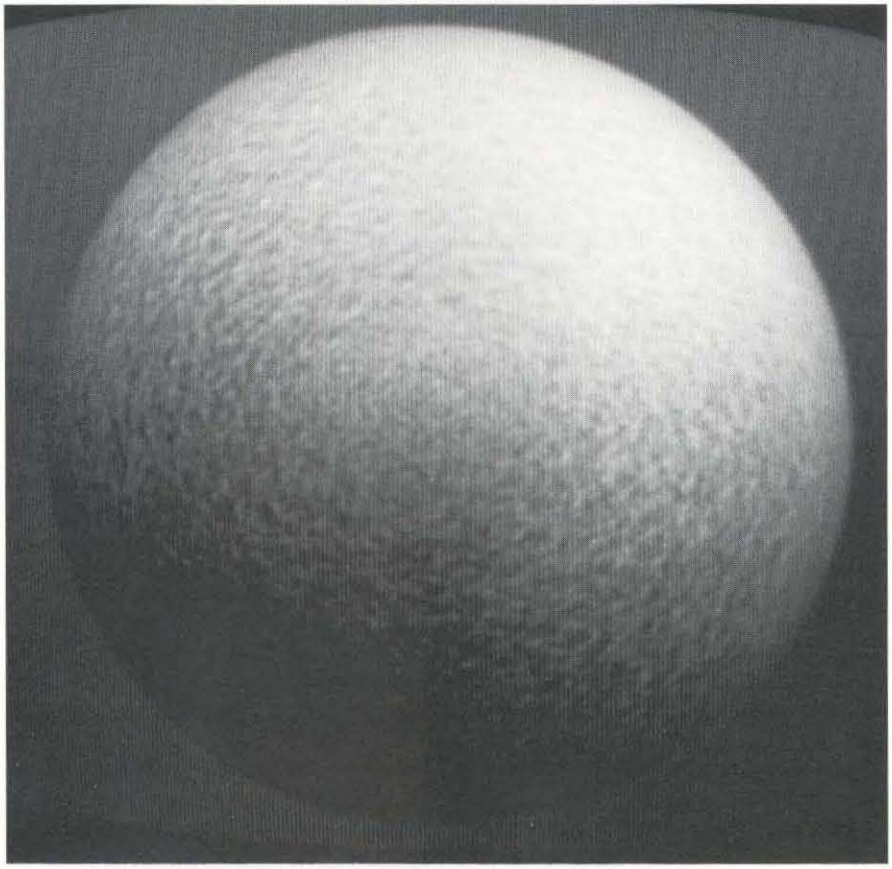
So even though the cure of the shiverer mouse can make no *direct* contribution to the cure of human disease, its *indirect* contribution is likely to be sizable. Not only will the shiverer mouse help scientists understand how myelin works in the nervous system, it will advance the art of genetic surgery and it may go a long way toward increasing our fundamental knowledge of gene regulation. □ — *RF*

Sounding the Sun

"The sun is a star, the only one we can study in detail."
George Ellery Hale

UNTIL VERY RECENTLY, almost all detailed studies of the sun were confined to its surface features and outer atmosphere. Even questions as basic as the rotation rate of the solar interior remained nearly as mysterious as if the earth's nearest star were 8 thousand light years away instead of 8 light minutes. So did a host of other conditions in the solar interior, including the strength of its magnetic fields, the relative abundances of hydrogen and helium, and numerous details of the thermonuclear fusion reactions in the solar core. Nearly all work on these topics was carried out through theoretical modeling, for which there were little observational data or support.

In the last five years, however, the field of helioseismology has opened the sun's previously inaccessible interior to observation. Just as geologists study seismic waves to map the interior of the earth, solar astronomers are now investigating solar acoustic waves to



In this photo of the oscillating solar surface, Libbrecht's Doppler shift data have been processed so that light regions represent material moving toward earth, and dark regions represent receding material. The variations in brightness are caused by the sun's rotation.

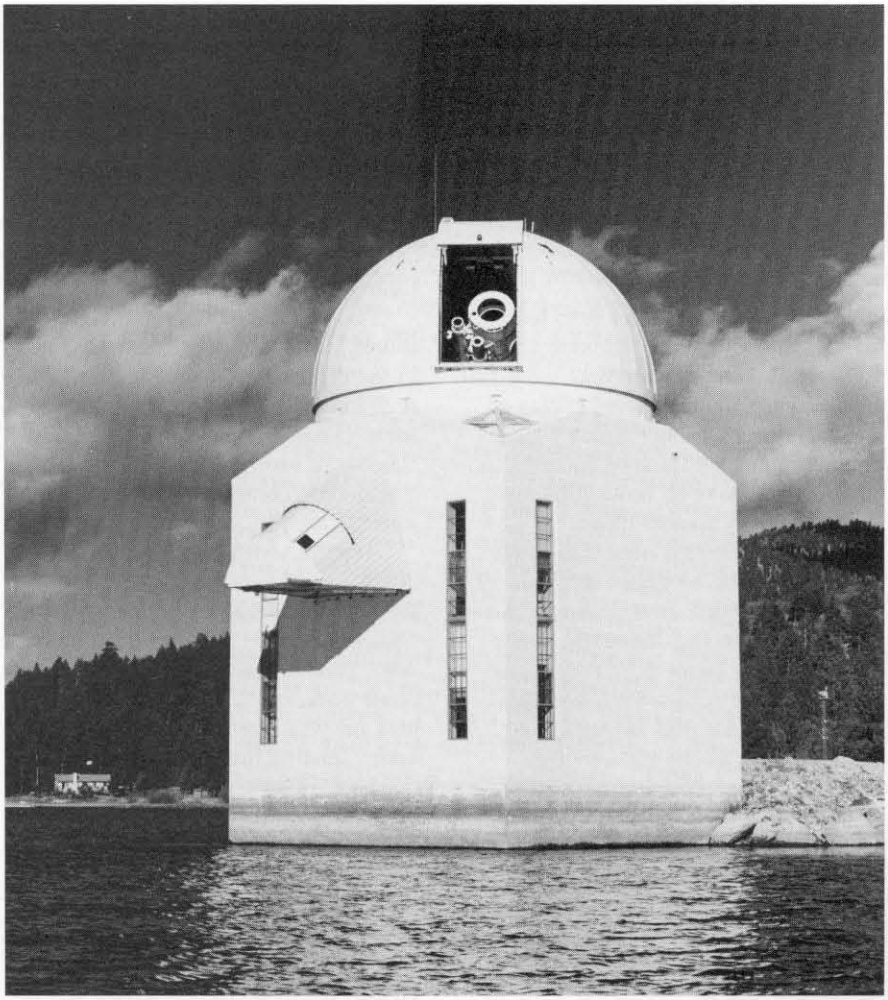
probe the dynamics and internal structure of the sun.

One of the researchers in this new field is Ken Libbrecht, assistant professor of astrophysics at Caltech. Working at the Institute's Big Bear Solar Observatory, Libbrecht is measuring the frequencies of solar seismic waves to study the temperature, rotation speed, and chemical abundances of the solar interior. His research is being supported by the National Science Foundation, a fellowship from the Alfred P. Sloan Foundation Program, and a Presidential Young Investigator Award.

The foundations for Libbrecht's research were laid at Caltech more than two decades ago by Robert Leighton, now Valentine Professor of Physics, Emeritus. In 1962 using a camera he had developed for solar studies, Leighton discovered that the sun's exterior was not static but agitated by waves of gas rising and falling at five-minute intervals across the entire solar surface, a pattern that was dubbed the "five-minute oscillations."

Leighton's findings provided a new picture of a bubbling solar exterior that resembled a wave-covered ocean. But it was another ten years before astrophysicists discovered that these oscillations were not unrelated and incoherent surface waves, but the surface projections of an organized network of sound waves, or acoustic modes, resonating throughout the solar interior. The sun is now known to harbor at least 10 million of these modes, each with a unique "pitch" or frequency that depends on the sound velocity in the solar interior. Because the speed of sound in turn depends on the temperature and chemical composition of the solar plasma, the frequencies of these surface oscillations can be used to investigate such internal properties as temperature and the abundance of helium relative to hydrogen in the solar core.

To measure these frequencies, Libbrecht has developed a technique based on the Doppler shift of solar light. Viewed through a filter that splits sunlight into its component frequency bands, light from the rotating solar surface is shifted into the blue, or high-frequency, end of the spectrum as it approaches an observer on earth, and shifted into the red, or low-frequency range as it recedes from view. The measurement of the Doppler shift gives the actual velocity of the oscillating gas, which can then be used to calculate the frequencies of the acoustic modes reverberating through the solar interior.



The helioseismology telescope is the nose-like projection on the Big Bear Solar Observatory.

Using a specially constructed helioseismology telescope at Big Bear Solar Observatory and an extremely narrow filter that limits the entering light to a narrow range of wavelengths, Libbrecht has been able to measure the frequencies of more than a thousand such modes, to an accuracy of one part in 10,000. His measurements have been found to match theoretical projections of the frequencies to an accuracy of one percent, a rare occurence in the field of astronomy.

Surface oscillations are also being applied to studies of the sun's internal magnetic field, long believed to be the source of solar flares and the 22-year sunspot cycle. Sound wave frequencies are altered in the presence of a magnetic field, and the stronger the field, the more pronounced the effect. By measuring the extent to which the sun's seismic wave frequencies deviate from their predicted values, Libbrecht believes it should be possible to determine the accuracy of the standard "solar dynamo" sunspot model.

Although the scientific importance of solar oscillations is a recent discovery, the sun is by no means the only pulsing star known to astronomers. The best known such stars are the Cepheid variables. Their periodic and regular fluctuations in brightness, originally spotted in the 1920s, enabled astronomers to make the first accurate measurements of the relative distances between earth and stars outside the Milky Way galaxy. As astrophysicists begin to apply helioseismology's observational findings about the solar interior to the dynamics of stars, the scientific significance of the sun, originally foreseen by Hale, will at last come into its own. □ — *Heidi Aspaturian*

Letters

La Jolla, California

Dear Dr. Clauser:
The purpose of this letter is to tell you that I thoroughly enjoyed your article, "The Boat That Almost Was." I asked for and received additional copies of *Engineering & Science* which I have sent to friends and sailing aficionados because you have so beautifully rendered a murky subject clear.

You are the first person to make sense out of the 12-meter formula. (I am still interested, from a purely intellectual view, in the derivation of the dimensionless factor 2.37.) Of equal interest to me is your keen appreciation for the potential of (parochial) interpretation of the rules by the IYRU. My involvement with ship design and construction at Litton and Newport News Shipbuilding made it abundantly clear to me that naval architecture was firmly and inextricably based on the technology of yore; only heretics questioned the "rules."

Thank you for taking the time to write your article. You have brought a great deal of pleasure to a number of people. My wife and I recently returned from Australia where we spent a few days in Perth and Fremantle watching the races. I wonder whether or not the Kiwis knew of your findings. They certainly have a competitive boat.

Sincerely,
Bruce A. Worcester
Caltech '48

Dear Mr. Worcester:
I very much enjoyed receiving your letter. Your words of encouragement were pleasant to hear.

I, too, am interested in the origins of the factor 2.37 in the 12-meter formula. I have a hunch that it was chosen to fit some existing boat.

Best wishes for the New Year,
Francis Clauser

Greenwich, Connecticut

Dear Dr. Clauser:
I have read with great interest your article, "The Boat That Almost Was," in the November issue of *Engineering & Science*. It's too bad that boat, or some variation thereof, didn't materialize — in retrospect, the New York Yacht Club certainly needed help of some kind.

Together with its accompanying charts and illustrations, the article puts forward a very lucid explanation of the complexities of 12-meter yacht design. Also, your explanation of how bulbous bows work, or do not work as the case may be, was most helpful to me in understanding that phenomenon.

Your other concepts of lightweight boats with outrigger pontoons and/or ailerons sound like great possibilities. You point out that the wetted area of these devices would be about the same as the amount that wouuld be saved if the lead were removed from the keel. Hence, the fluid friction would not be materially increased while other advantages would be gained.

So far so good, but I don't recall that your article got into the question of the torque resulting from dipping one of the pontoons selectively into the water on only one side of the boat. Similarly, if the upwind aileron were to rise out of the water, a significant drag turning force would tend to develop.

It seems to me that such turning forces would have to be counteracted by a hard opposite rudder position. If so, the boat wouuld be constantly fighting its rudder, with the net result that overall resistance through the water would rise appreciably, thus negating the other advantages gained.

If I have overlooked something in the article which answers this question, please forgive me. In any case, if you can take the time, I would appreciate receiving your comments.

Yours sincerely,
S. Kendall Gold
Caltech '42

Dear Mr. Gold:
I have received quite a number of letters about my article in *Engineering & Science*, but I believe yours was the most perceptive and penetrating. It was a pleasure to read your comments.

You are quite right that the important question of the yawing torque of the pontoons was not addressed in my article. Earlier, I wrote a memorandum to Johan Valentijn and George Tooby on this subject, but I deemed it a little too technical to include in the *E&S* article.

The fact is that this torque is actually favorable in that it takes load off the rudder instead of adding to it. When the boat is close hauled, the leeward pontoon will of course be in the water. By the same token, the mast and sail are also out on the leeward side. Thus, the center of effort of the sail is displaced to leeward and will cause the boat to want to head up into the wind. In all boats with stable helms, if the helm is let go free, the boat immediately heads up into the wind. As a consequence, a significant amount of rudder has to be used to counteract this tendency. There is a large increase in resistance from this rudder action.

Now the drag of the immersed pontoon tends to turn the boat away from the wind, i.e., it is opposite to that of the sail. Let us look at the magnitudes involved. The center of pressure of the sail is up about 18 ft., and if the boat is heeled 15 degrees this gives it a lever arm of about 4 ft. The pontoon will have a lever arm of about 35 ft., but its resistance will be about 1/8 of the total. If the effort of the sail just counteracts the total resistance of the hull, then it is clear that the yawing torque of the pontoon is very nearly equal and opposite to that of the sail. Thus the force required of the rudder is almost entirely eliminated, leading to a significant reduction in overall drag.

I hope this overly long discussion allays your worries that "the boat would be constantly fighting its rudder."

Cordially,
Francis Clauser

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Random Walk

Kamb Named Provost

Barclay Kamb has agreed to accept the position of vice president and provost, pending approval by the board of trustees at their meeting on March 9. Kamb succeeds Rochus (Robbie) Vogt, who has held the position for the last four years.

Kamb received his BS (1952) from Caltech and also his PhD — in 1956, the same year he joined the faculty. He has been professor of geology and geophysics since 1963 and was chairman of the Division of Geological and Planetary Sciences from 1972 to 1983. An article on Kamb's research on surging glaciers appeared in the May 1984 issue of *E&S*.

Vogt will continue as the R. Stanton Avery Distinguished Service Professor. A physicist known for his work on cosmic rays, he joined the Caltech faculty in 1962. He was chairman of the Division of Physics, Mathematics and Astronomy from 1978 to 1983 and was chief scientist at JPL in 1977-78.

Honors and Awards

Five Caltech faculty members were elected to membership in the American Association for the Advancement of Science: James Bailey, professor of chemical engineering; Roy Britten, the Distinguished Carnegie Senior Research Associate in Biology; Lee Hood, the Ethel Wilson Bowles and Robert Bowles Professor of Biology and chairman of the Division of Biology; John Hopfield, the Roscoe G. Dickinson Professor of Chemistry and Biology; and Henry Lester, professor of biology.

Lee Hood, in addition, received the 1987 Award for Medical Innovation, presented in February by the Louis Pasteur Foundation/Los Angeles.

Anatol Roshko, the Theodore von Kármán Professor of Aeronautics, has been named the recipient of the 1987 Fluid Dynamics Prize, sponsored by the Office of Naval Research.

Wallace Sargent, the Ira S. Bowen Professor of Astronomy, has been invited to present the 1987 George Darwin Lecture of the Royal Astronomical Society in London in May.

Wolfgang Knauss, professor of aeronatics and applied mechanics, has been elected a Fellow of the Society for Experimental Mechanics.

Two faculty members have been named Fellows of the American Physical Society: David Hitlin, professor of physics, and John Schwarz, professor of theoretical physics. Barry Barish, professor of physics, and Steven Koonin, professor of theoretical physics, have been elected division vice-chairmen in the American Physical Society.

Two young faculty members, Kenneth Libbrecht, assistant professor of astrophysics, and Bradley Filippone, assistant professor of physics, have received fellowships from the Alfred P. Sloan Foundation. And two recent PhD graduates of Caltech can be added to the list of Presidential Young Investigators published in the last issue. They are Peter Felker, now assistant professor of chemistry at UCLA, and William Dally, assistant professor of electrical engineering and computer science at MIT.

Watson Lectures Set

The Earnest C. Watson Lecture series for the rest of the academic year has been announced. Francis Clauser, the Clark Blanchard Millikan Professor of Engineering, Emeritus, spoke February 25 on "The America's Cup — What Might Have Been and What Might Be." Clauser's article on this subject appeared in the November issue of *E&S*. (See Letters on page 28.) The rest of the season includes:

March 11: "Hubble's Constant: How Fast Is the Universe Expanding?" — Jeremy Mould, associate professor of astronomy.

April 1: "Prohibited Words" — John Sutherland, professor of literature.

April 22: "The Origin of Our Moon: A Big Splash" — David Stevenson, professor of planetary science.

May 6: "Expert Neural Systems" — Terrence Sejnowski, Cornelius Wiersma Visiting Professor of Neurobiology.

The lectures are held in Beckman Auditorium on Wednesday evenings at 8:00 and are open to the public. Admission is free.

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Friday, May 1 — Class of 1977

Saturday, May 2 — Classes of 1942 and 1952

Friday, May 15 — Class of 1962

Friday, June 5
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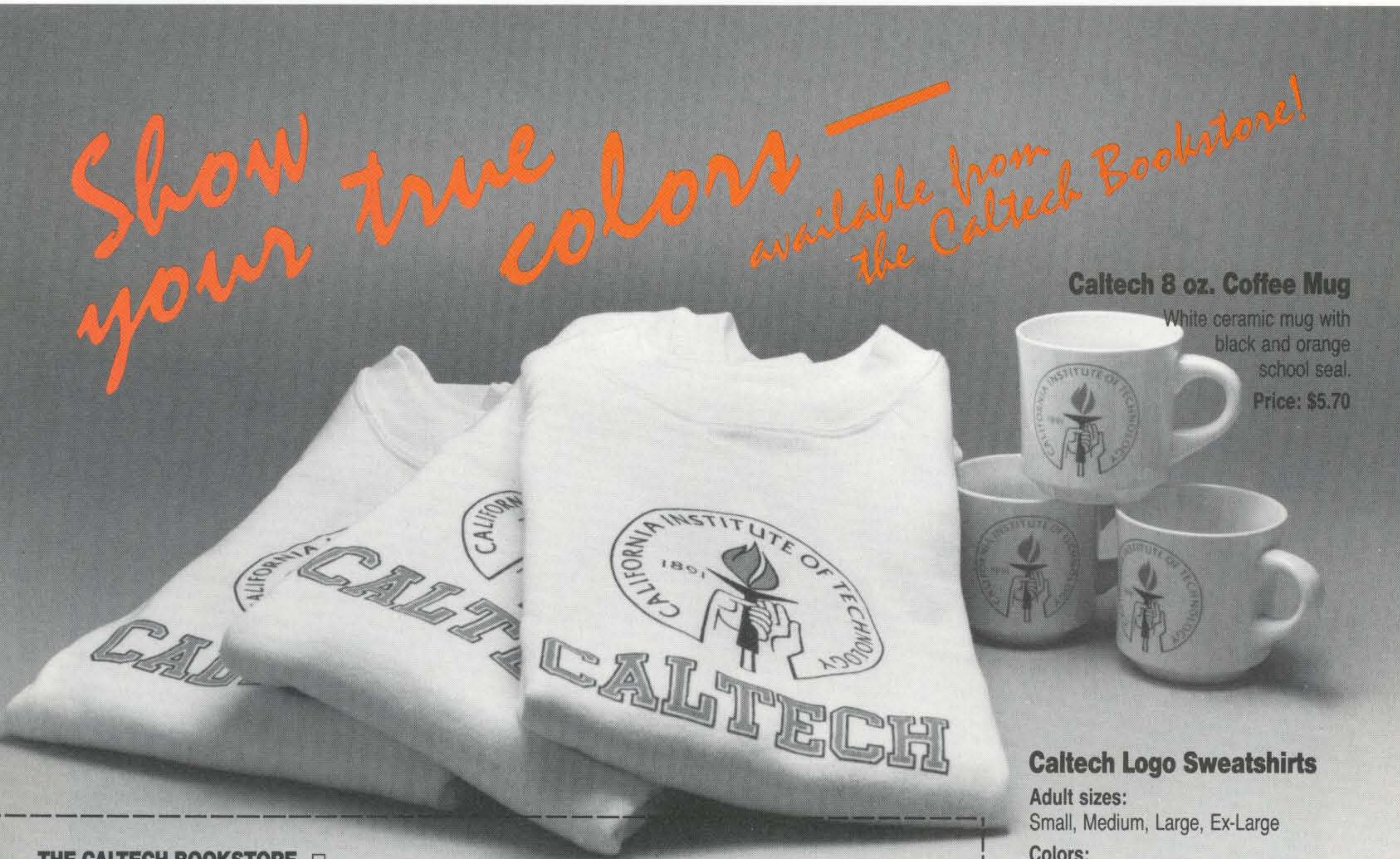

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Admiral Bobby R. Inman was the keynote speaker February 10 at this year's Research Directors Conference, sponsored by the Office for Industrial Associates. More than 200 attended the conference, the largest group on record for the annual event. Inman, chairman and CEO of Westmark Systems, Inc., and former director of the National Security Agency, spoke on "Technology — America's Competitive Edge."

New Hayman Chair

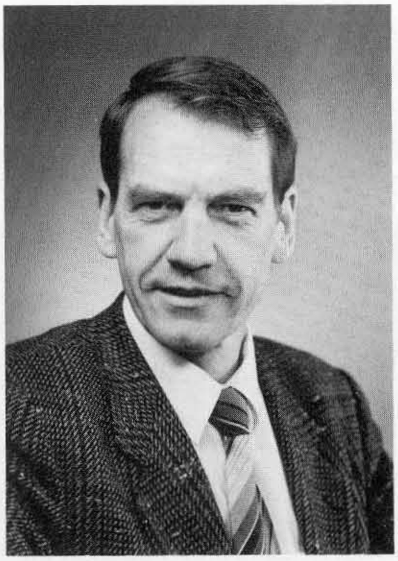
Mr. and Mrs. Richard L. Hayman have established a new chair at Caltech — the Dotty and Dick Hayman Professorship of Engineering. Hayman studied mechanical engineering at the Institute, and both he and his wife are active in The Associates. (Hayman has just completed a two-year term as president.) This is the second chair the Haymans have established. The Richard L. and Dorothy M. Hayman Professorship in Mechanical Engineering is held by Frank Marble. They also donated the Hayman Lounge in the Athenaeum in memory of Mr. Hayman's brother, Earl S. Hayman, '24, and have contributed generously to the Alumni Fund and the Summer Undergraduate Research Fellowship (SURF) program.

Oliver Wulf Dies

Oliver Wulf, senior research associate in physical chemistry, emeritus, died January 11, 1987, at the age of 89, after a short illness.

Wulf earned his PhD at Caltech in 1926. Before returning to Caltech as a research associate in 1945, he taught at UC Berkeley, studied in Germany on a Guggenheim fellowship, and taught meteorology to naval cadets during World War II. His research during his years at Caltech concerned solar-terrestrial relationships, geomagnetism, and large-scale circulation of the atmosphere. In 1967 he retired with emeritus status. Wulf continued to do research for the next 20 years, and his last wish, expressed shortly before his death, was to get back to his laboratory.

New GALCIT Head



Hans Hornung will be director of GALCIT (Graduate Aeronautical Laboratories, California Institute of Technology) starting August 1. He succeeds Hans W. Liepmann, the Theodore von Kármán Professor of Aeronautics, Emeritus, who was GALCIT director from 1972 until his retirement in 1985.

Hornung received his bachelor's (1960) and master's (1962) degrees in mechanical engineering from the University of Melbourne, Australia, and his PhD from the University of London, Imperial College, department of aeronautics. From 1967 to 1980 he taught and did research in physics at the Australian National University in Canberra. He has been director of the Institute for Experimental Fluid Mechanics in Göttingen, West Germany, and Honorarprofessor in physics at the University of Göttingen since 1980.

Theodore von Kármán, GALCIT's first director (1930-49), also had roots in Göttingen: He earned his PhD there in 1908 and began his investigations in fluid mechanics in Göttingen under Ludwig Prandtl.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CELEBRATE CALTECH'S

50th ANNUAL *Seminar Day*

PRESENTED BY THE CALTECH ALUMNI ASSOCIATION

General Session Speaker:

Dr. Francis H. Clauser
Clark Blanchard Millikan Professor of Engineering, Emeritus

"The Boat That Almost Was"
The story of Dr. Clauser's adventures as Chief Scientist for one of the yacht clubs trying to recapture the America's Cup

SATURDAY, MAY 16, 1987

For Program and Registration Information contact
The Caltech Alumni Association, Pasadena, CA 91125 (818) 356-6592