CALIFORNIA INSTITUTE OF TECHNOLOGY

Engineering and Science

OCTOBER 1970

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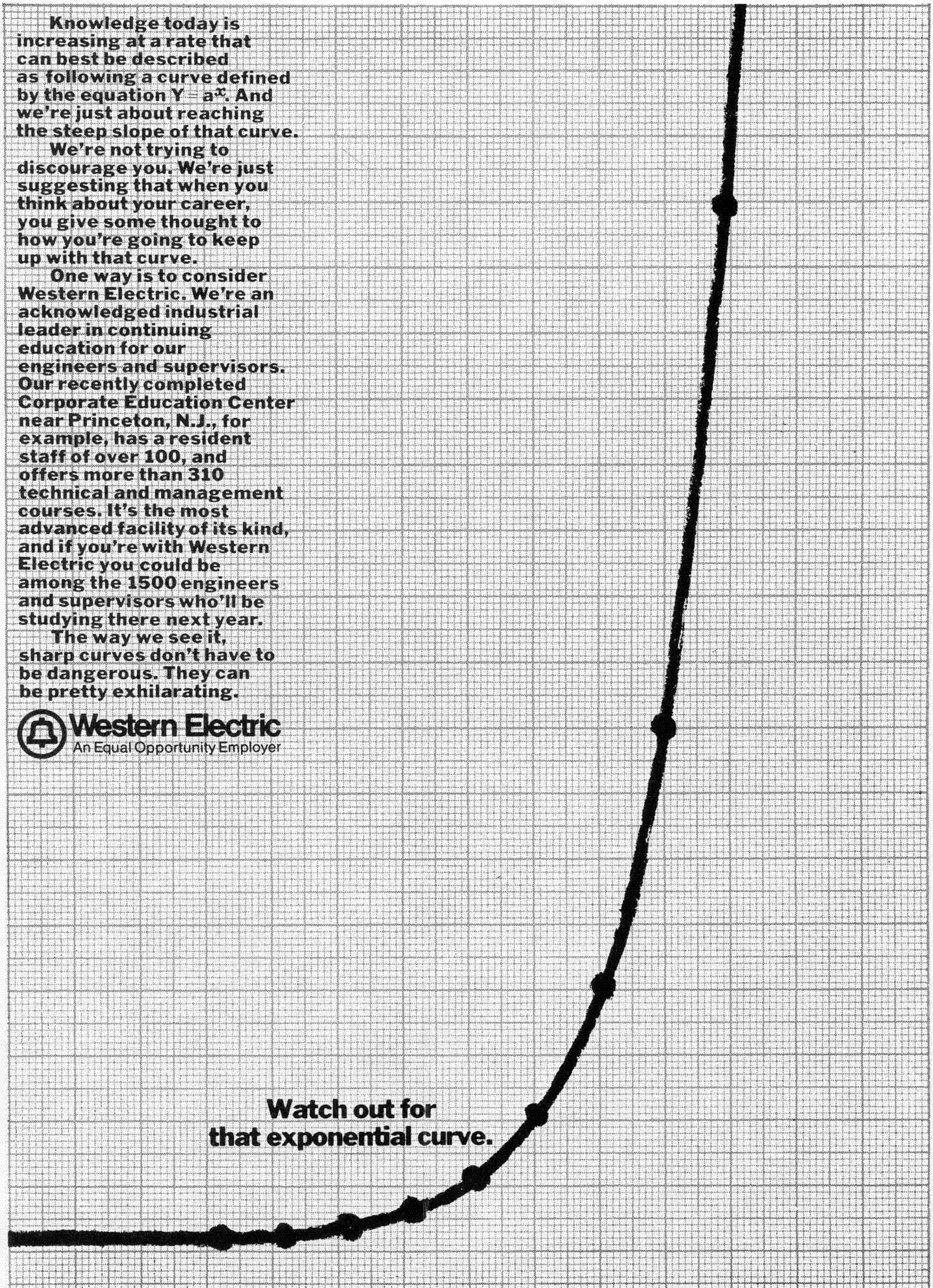
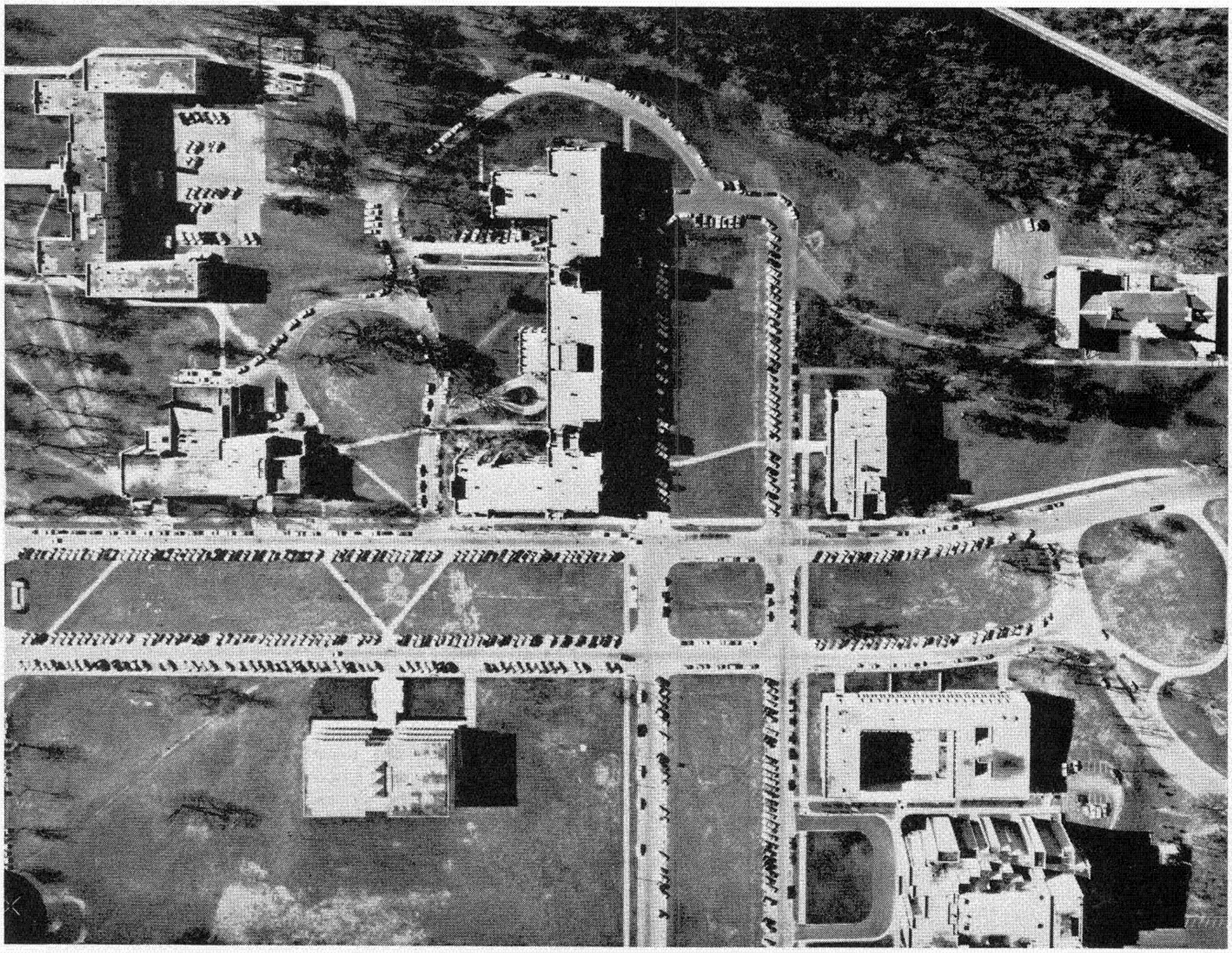
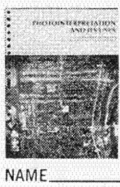


Watch out for that exponential curve.





OCTOBER 1970/VOLUME XXXIV/NUMBER 1

Engineering and Science

In this issue

Making History

On the cover—a girl. A historic girl. The product of student pleas, faculty debates, 17 years of experience with women graduate students, trustee action—and the passage of time. And so we present our first cover girl—a member of the class of 1974, and one of the first 32 undergraduate women to be admitted to the Institute.
Welcome!

Biology and Medicine

Robert L. Sinsheimer's "The Implications of Recent Advances in Biology for the Future of Medicine" (page 6) is adapted from a talk given on Alumni Seminar Day last spring. Sinsheimer is professor of biology and chairman of the biology division at Caltech.

Man on the Moon

Ray Bradbury's "Reflections from a Man Who Landed on the Moon in 1929" is also adapted from a talk given on Alumni Seminar Day. The popular science-fiction writer and Caltech formed a mutual admiration society several years ago, and Bradbury now makes periodic visits to the campus to give one of his rip-roaring talks—like the one on page 14.

The Clean Air Car Race

A double report on the 1970 Clean Air Car Race by two of Caltech's most energetic participants. On page 25, Mike Lineberry, graduate student in engineering science, describes the trip from Pasadena to Boston and back. On page 28, James Henry, an undergraduate in engineering, tells what went on under the hood.

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6—(top) *JEOL News*, Vol. 7B, No. 1, 1969; (bottom) I. R. Gibbons and A. V. Grimstone, *Journal of Biophysical and Biochemical Cytology*, Vol. 7, p. 697, 1960.
7—Igaku No Ayumi, *JEOL News*, Vol. 7B, No. 1, p. 4, 1969.
8—(top) *JEOL News*, Vol. 7B, No. 1, p. 11, 1969; (bottom) W. A. Jensen and R. B. Park, *Cell Ultrastructure*, Wadsworth Publishing Co., Inc., Belmont, Calif., 1967.
11—(bottom right) G. M. Edelman, *Proceedings of the National Academy of Sciences*, 63, p. 79, 1969.
12—R. Schwyzer, *Nature*, 199, p. 173, 1963.
23—Floyd Clark, James McClanahan/28, 29—Mike Lineberry/All others—Floyd Clark.

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Goodbye, lake.

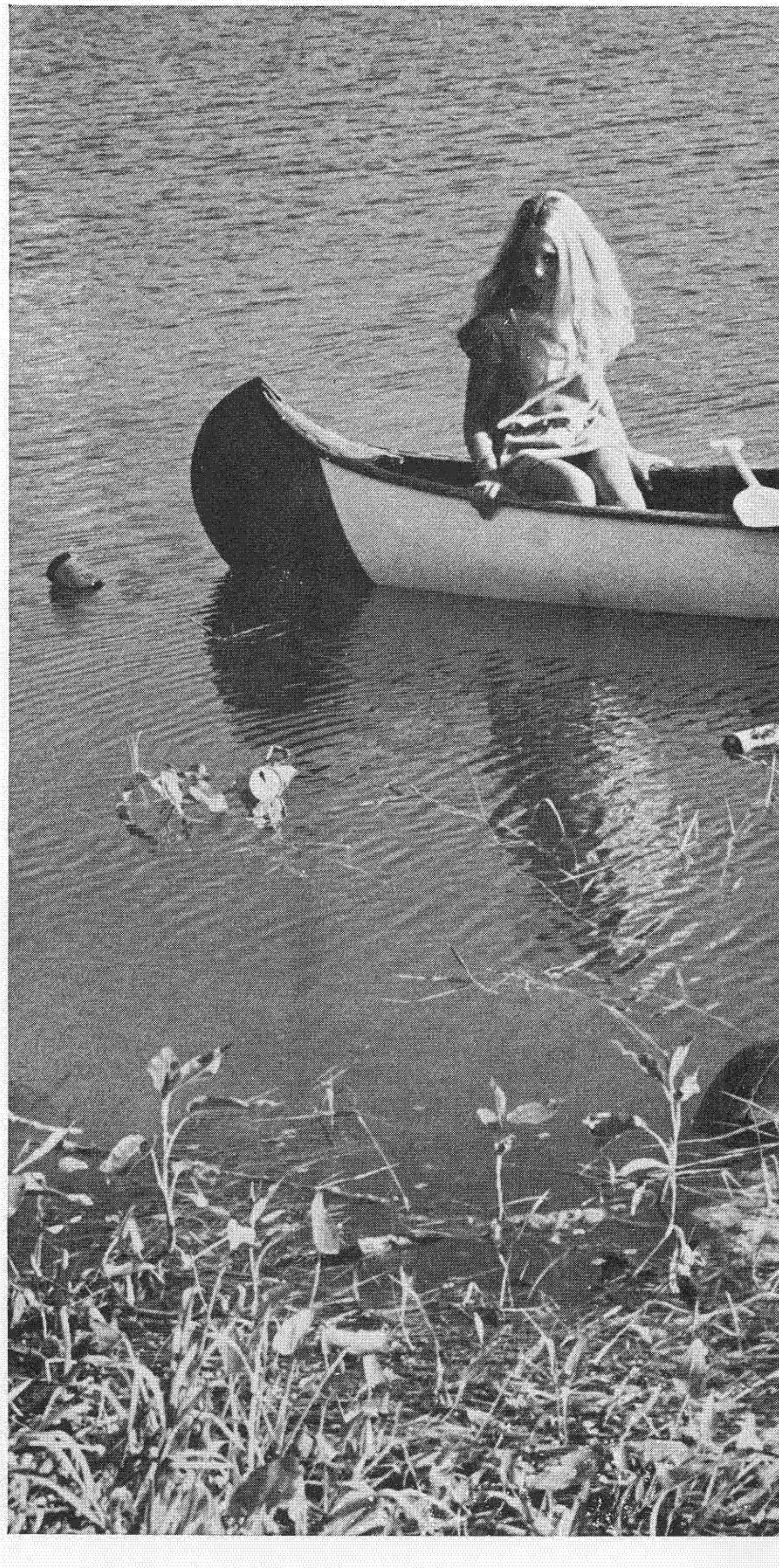
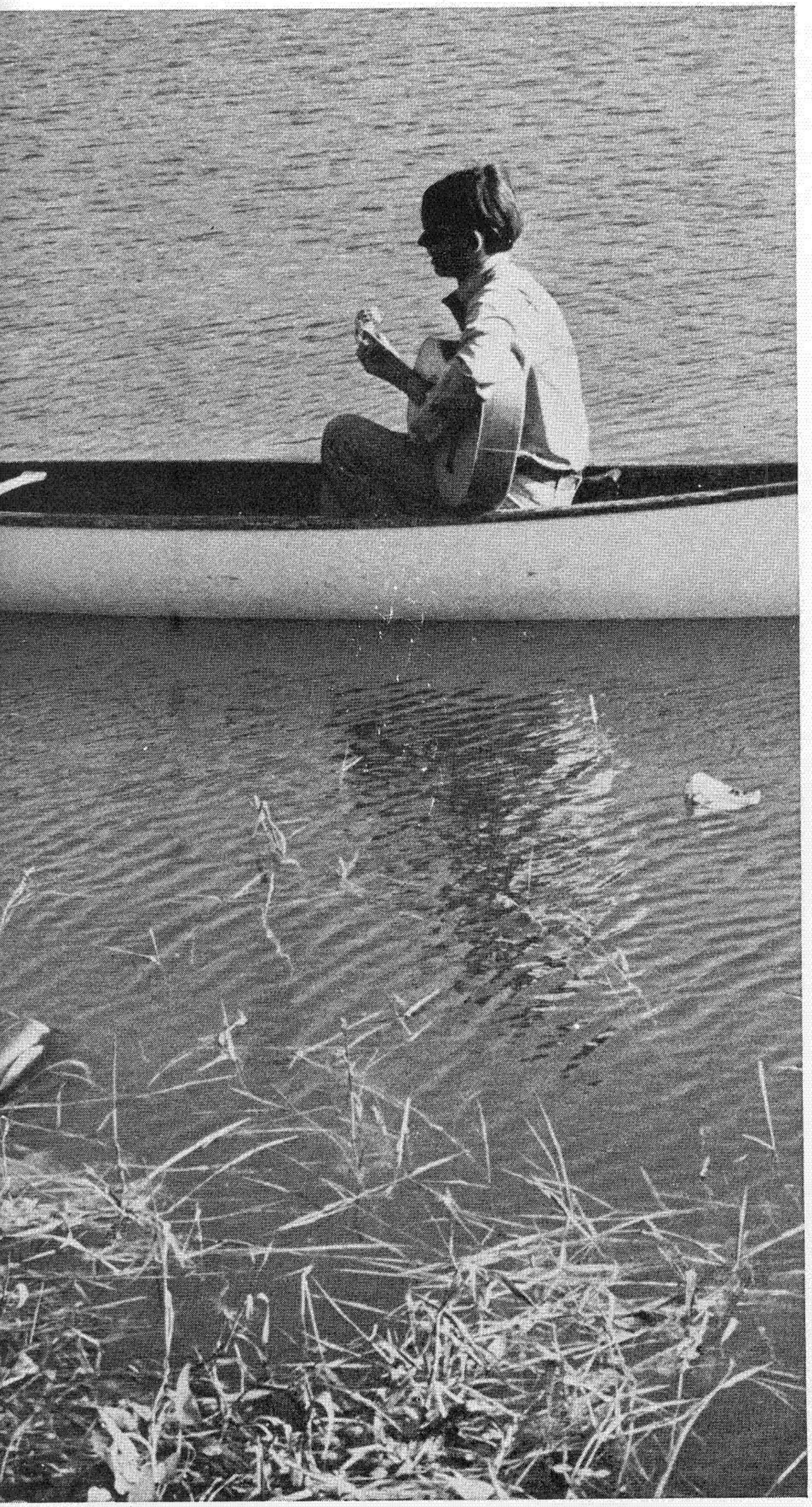


PHOTO: JOHN HARRISON



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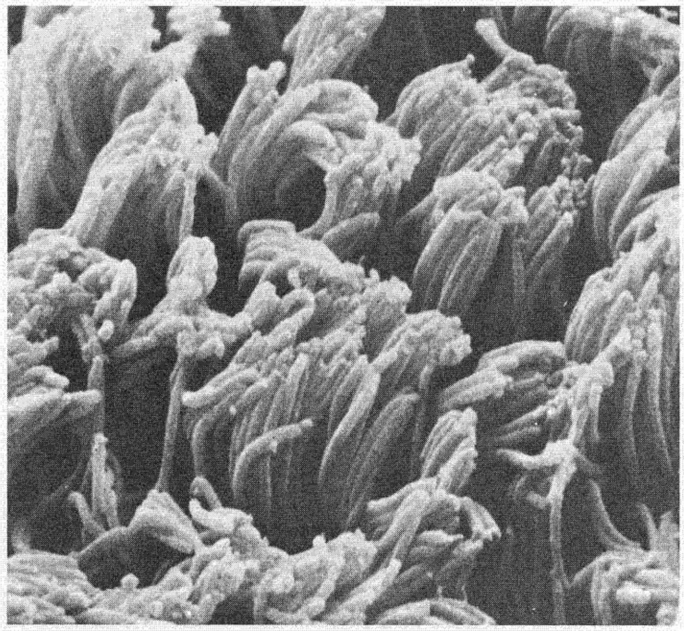
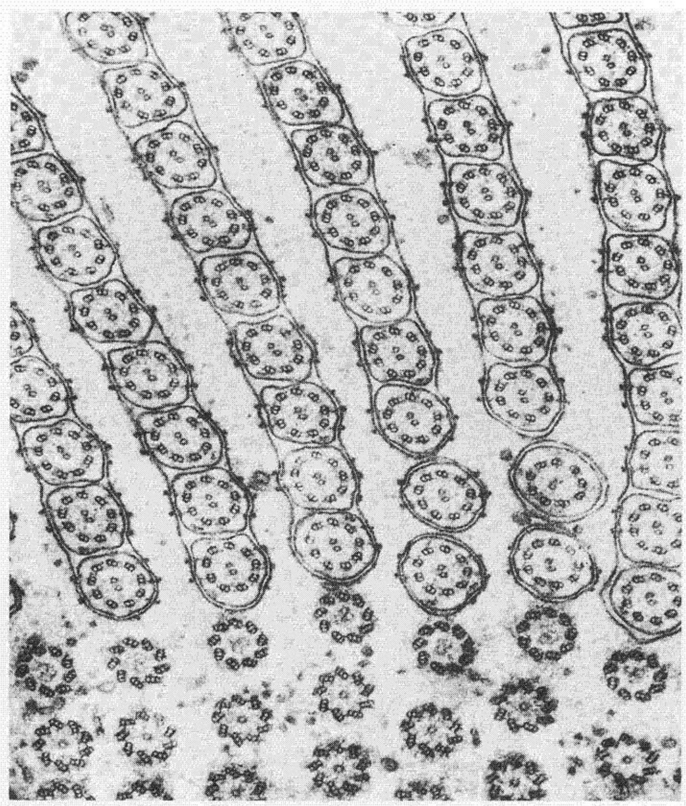
The Implications of Recent Advances in Biology for the Future of Medicine

by Robert L. Sinsheimer



The cilia that line the trachea can be observed in detail with the use of a scanning electron microscope.



A cross section through a bed of cilia shows even deeper levels of structure with the transmission electron microscope.

I cannot resist an inner smile at the pretentious title which adorns this talk, for I know very well of what fragile threads is such conceit woven. Of all our human conceits surely our persistent resort to prophecy must be among the most droll in the light of our abysmal record of success. The very persistence of the prophetic trait must I think be ascribed to some innate human urge—to a curious pride in our enlarged perception of time or perhaps to a nascent evolutionary drive to extend the craft of biological adaptation into a new dimension.

But the urge is real and the pace is swift and the future we really do believe to be written in the past and present, if only we have the wit to read. What then may we see if we stand today on the frontier of biology and look about us with the eyes of the healer?

I think we will see that we are surf-riding just behind an immense wave of progress in fundamental biological knowledge—a wave that began slowly to take form nearly a century ago and whose momentum will in the near future sweep away very many of the ancient obstacles to medical progress. In so doing it will provide the physician with unprecedented skills, unprecedented powers, *and* unprecedented responsibilities—responsibilities whose very weight may well reshape many of our enduring values.

For physicians it has been the better part of wisdom since Hippocrates to acknowledge that each cell in the body is far better informed as to its function than we are in any conscious sphere—and that the genius of innate homeostasis, accumulated in the long course of evolution, far exceeds our capacities to intervene. And thus derived the well-founded belief in the healing power of nature, if not tried too sorely, and the wisdom of the physician's restraint—his bent to facilitate the natural recovery.

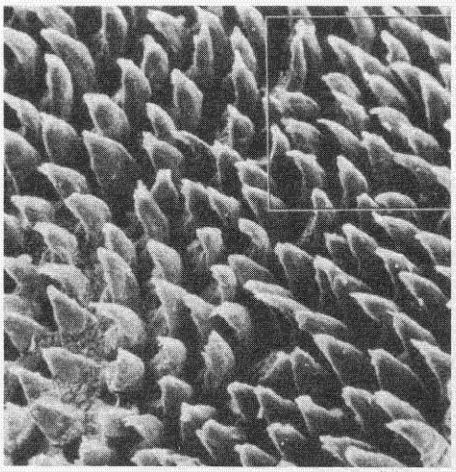
But in our time the balance is beginning to tip. Analytical biology, founded a century ago in the work of Pasteur, Darwin, and Mendel, has developed with ever increasing momentum. It has received powerful and essential support from the great discoveries of physics and chemistry in the early part of this century, which revealed the basic nature of matter, inorganic and organic. It has penetrated to the core of the living cell, and it is now providing us an insight into the substance and nature of life, into the genesis and pattern of function—and malfunction—that can begin to bear comparison with the silent wisdom of the body.

In this conscious knowledge, infused with intelligence, are the seeds of a newer medicine, a medicine impelled to a more active philosophy that will—soberly and thoughtfully, but deliberately—seek to improve upon nature's design. For nature makes mistakes; the elasticity of homeostasis is all too finite, and two billion years of evolution have not yet achieved perfection.

In recent years we have adapted the powerful tools of modern physics and chemistry to probe ever deeper into the special architecture of life. We have thereby revealed with increasing clarity and detail the remarkable forms underlying the remarkable functions, so long known but so long mysterious. And at every level we find both order and intricacy, and we have gained both insight and aesthetic delight.

For instance we have known that the trachea is lined with cilia to control the passage of errant particles. The scanning electron microscope enables us to observe these in unprecedented detail (left). Deeper levels of structure can be seen in cross sections (below left) in the transmission electron microscope. Cilia of course beat in a synchronized motion. In this delicate and elaborate design must lie the secret of this function—or occasional malfunction.

The tongue is lined with minute papillae with which we taste. Here again we can now see (below) unexpected nuances of detail—although I should emphasize we are of course not yet at the level of molecular discrimination.



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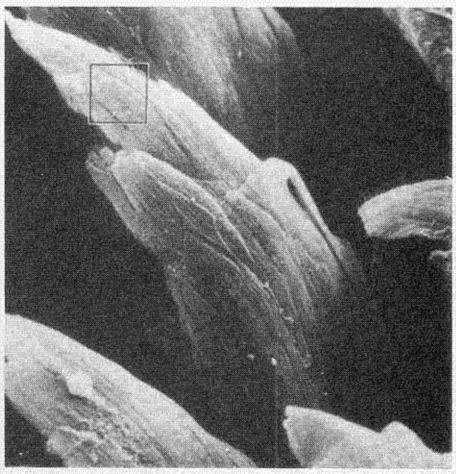

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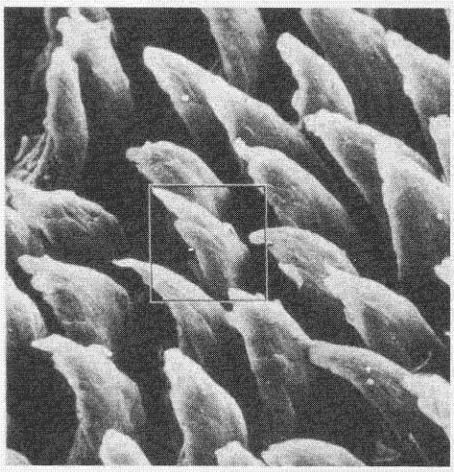

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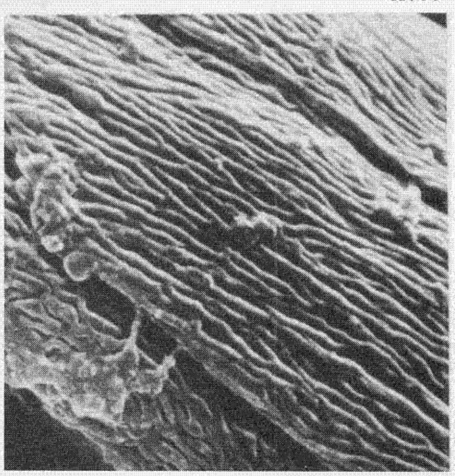
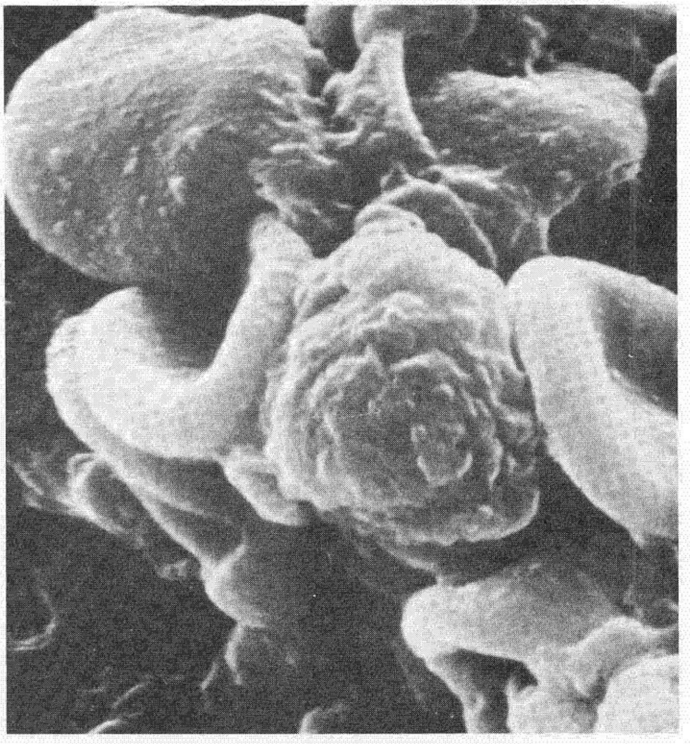
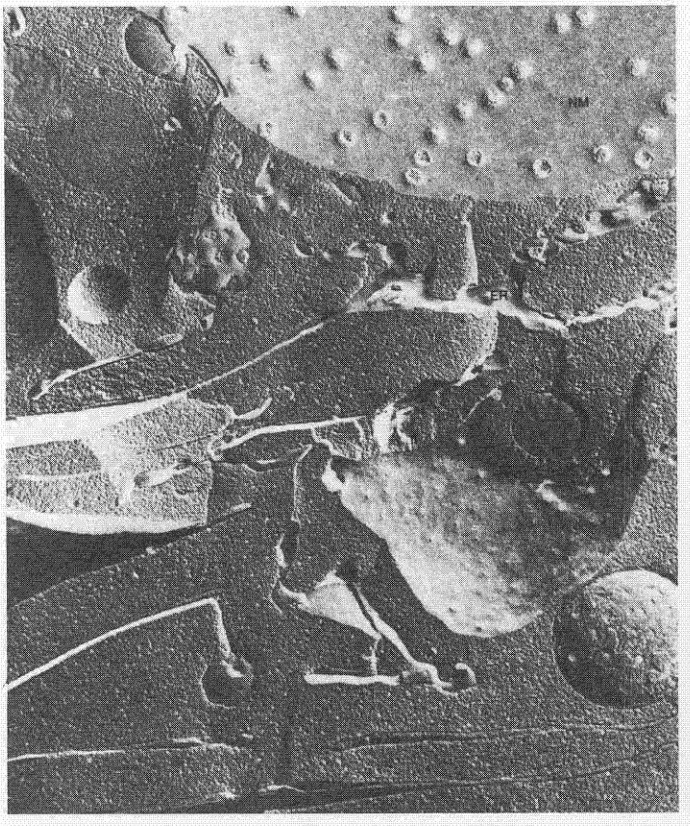


X7,000

The tongue is lined with minute papillae with which we taste. Shown here at increasing magnification are the papillae of a rabbit tongue.



The textured surfaces of red and white blood cells can be understood more clearly when magnified 9,000 times.



The inner world of a cell (shown here in cross section) is strangely reminiscent of the moon and, until recently, was just as unfamiliar.

In the textured surfaces of the red cell and the white cell (left) we can begin to see hints of important design —although we cannot yet discern the sodium pump of the erythrocyte membrane, nor the antibody we know to be present on a lymphocyte.

If we slice across a cell (below left), we can see an inner world strangely reminiscent of the moon and until recently as unfamiliar to us, but now increasingly mapped and charted.

In our search to understand the nature of life we seek ever deeper levels until we reach down to the molecules and the atoms. And then we know we have come to the end of the quest. For carbon atoms are carbon atoms— and in this scale function must arise in spatial structure and temporal disposition.

If a molecule of viral DNA is put into a host cell, it will generate hundreds more just like itself. Should we call it alive? Although we cannot see them, we know this DNA ring is in fact a linked chain of subunits.

We cannot yet penetrate to that level with our visual aids. We can, more indirectly, deduce their pattern through

In vitro Q_{β} RNA: SEQUENCE AT 5' END

10, 20, 30, 40

PPP G G G(G)A C C C C C C U U U A G G G G G U C A C[(A C)(A C)(C U C)]A G C A G U A C U U C A C U G A G

50, 60, 70, 80, 90

U A U A A G A G G A C A U A U G C C U A A A U U A C C G C G U G G U C U G C G U U U C G G

100, 110, 120, 130

A G C C G A U A A U G A A A U U C U U A A U G A U U U U C A G G A G C U C U G G U U U C C A G

140, 150, 160, 170

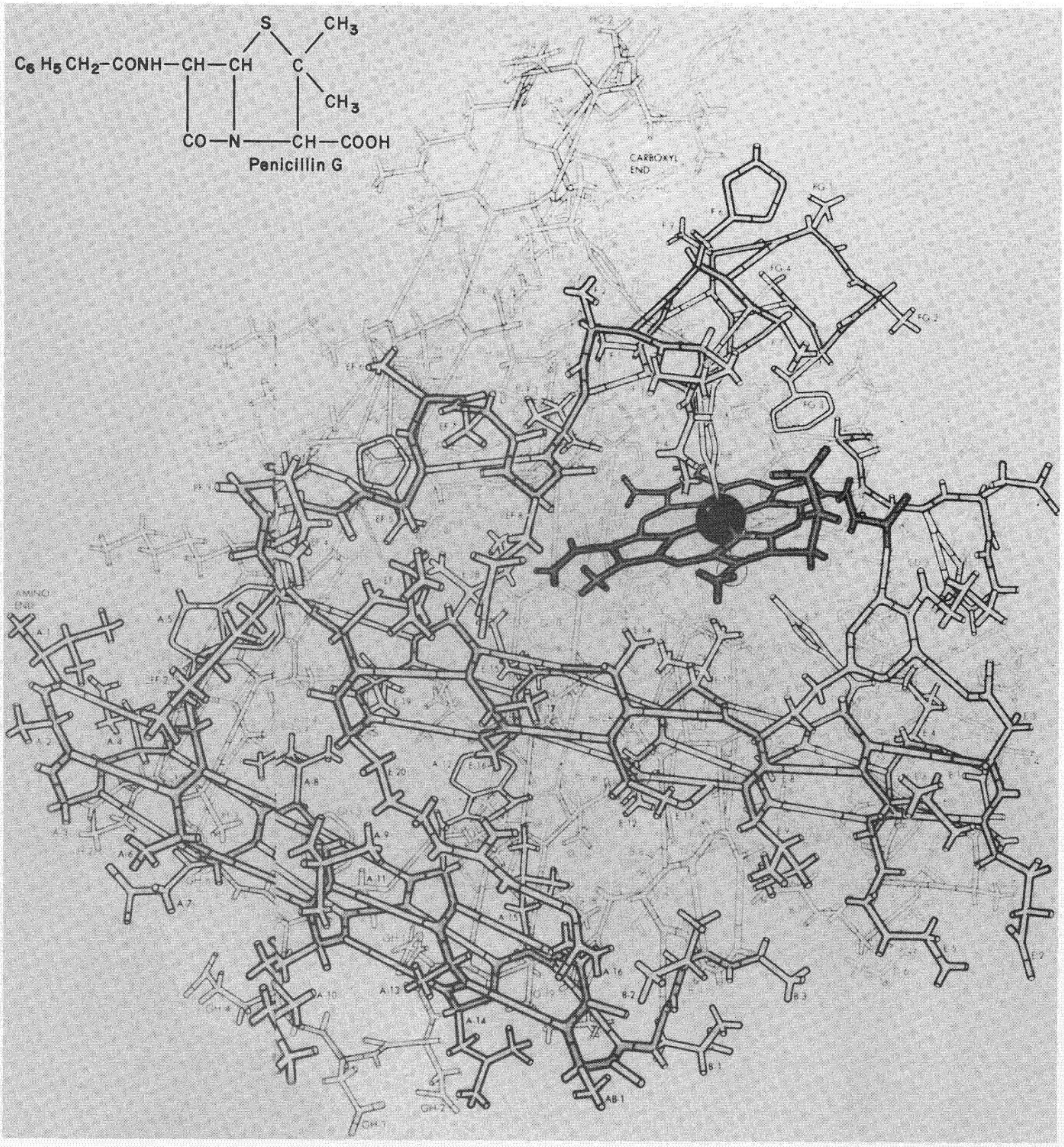
A C C U[(U)(U)(C)]U A U C G A A U C U U C C G A C A C G C A U C C G U G G

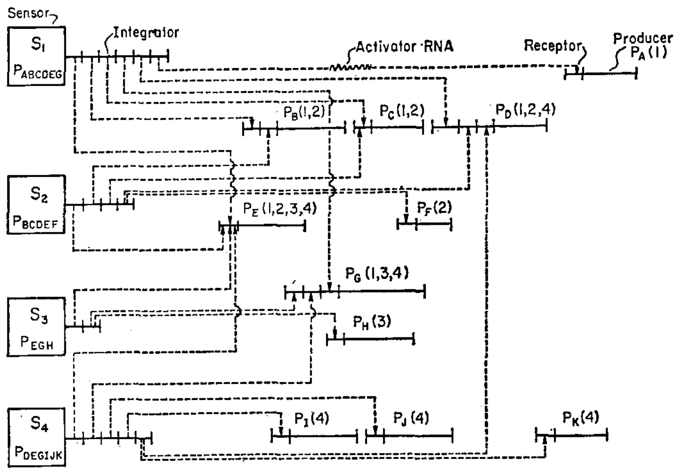
the arts of chemistry (above). Or at this level we can resort to another subtle technique borrowed, with adaptation, from physics—that of X-ray diffraction analysis. From the measured scattering of X rays by the atoms of a crystal we can reconstruct the positions of the atoms in the crystal and thus the three-dimensional structure of the molecules into which the atoms are grouped, even one so complex as the protein myoglobin (right).

This technique has been used to deduce the three-dimensional structure of an enzyme, a biological catalyst, ribonuclease and to probe its interaction with its substrate. This is leading at long last to a detailed chemical understanding of the mystery of the catalytic interaction, a process that underlies and is essential to the maintenance of life under physiological conditions.

We are not only exposing the ingenious structures underlying biological function, we are also unraveling the complex interrelations between these structures that integrate the many functions into a self-contained, self-

This three-dimensional model of whole myoglobin was reconstructed using a technique borrowed and adapted from physics—X-ray diffraction analysis.





In this proposed model of interactive gene control, the dotted lines represent the diffusion of activator RNA from its sites of synthesis to the receptor genes. The numbers in parentheses show which sensor genes control the transcription of the producer genes, and at each sensor, the producer genes activated by that sensor are listed.

controlled organism. We have found complex cycles of chemical reactions, and we are discovering interlaced hierarchies of control. Some are intracellular; other similar networks must exist at intermediate and higher levels within the body and within the brain.

These are but examples. Upon this base of knowledge we can even now begin to see disease, its cause and cure, in a very different perspective. We might usefully reclassify disease into the classes shown on the chart below.

Classes of Disease

The microbial diseases
The molecular diseases ——→ { **viral**, **biochemical**, **immune**, **genetic** }
The cybernetic diseases

The *microbial* diseases (for example, pneumonia, syphilis, influenza, scarlet fever) have been recognized and understood for some time. They are the consequence of invasion by our microscopic foes, and we have developed a variety of moderately simple agents for their therapy.

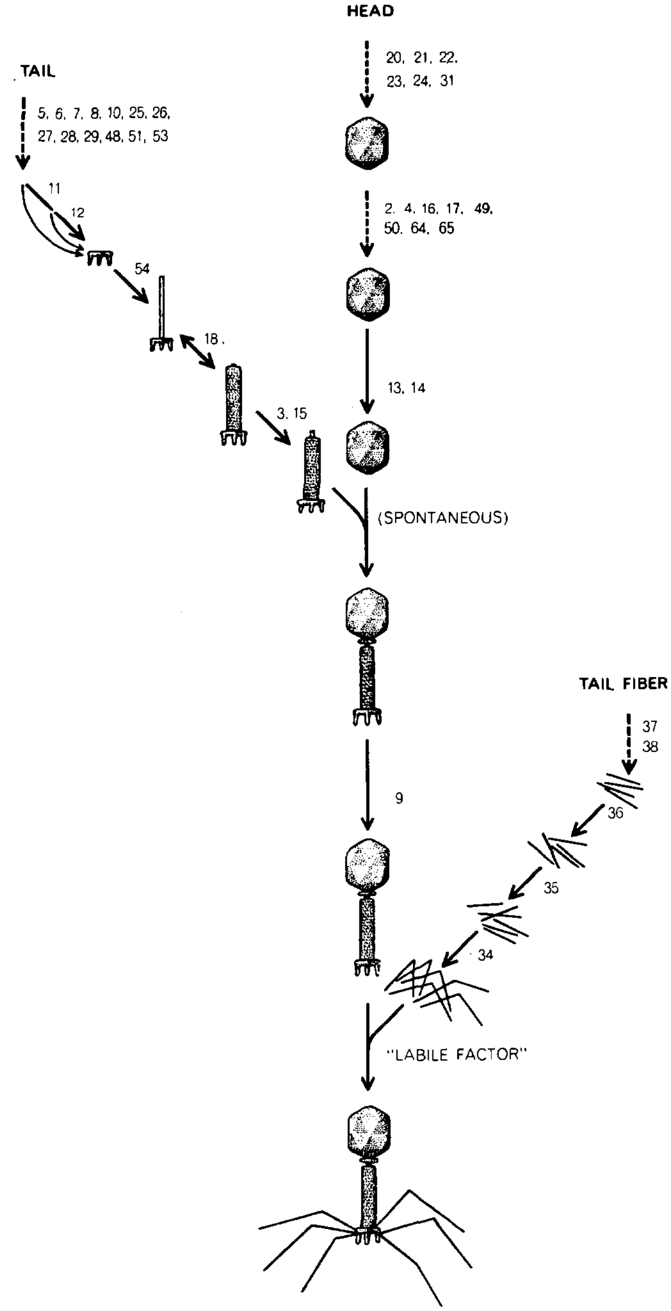
The basic principle that underlies the action of these agents—penicillin, streptomycin, sulfanilamide—is that they interfere with a metabolic process either unique to or of far greater importance to the microorganism than to man. Thus we may tolerate doses lethal to the microbes. It is fortunate that the metabolism of these species is in some respects sufficiently different from our own that this crucial distinction can be made with relatively simple chemical molecules of modest complexity.

The *molecular* diseases comprise that set of malfunctions which are the consequence of the presence—or sometimes absence—of critical molecules. I include the viral diseases (such as polio, measles, mumps, kuru) in this category because I find it more consistent to consider a virus as a self-reproducing particle within a living environment than to consider it as an autonomous life form.

Indeed it is precisely the subtle nature of the interaction of the virus with its host cell that has so far frustrated our attempts to find or devise agents that could make, as with the microbes, an effective distinction between the viral biochemistry and the host biochemistry and thus provide a selective basis for therapy.

I believe such a distinction can and will be made, but it will require a more intricate subtlety. If we contrast the structure of a penicillin and the structure of a myoglobin, we may see what will be needed. The synthesis and assembly of a virus particle requires delicate and precise interactions between molecules of this degree of complexity, interactions which specifically recognize other virus components and which, also specifically, exclude the omnipresent normal components of the host. In these interactions can lie the Achilles heel of the virus, for with understanding we should be able to devise anti-viral agents, molecules of an intermediate complexity specifically designed to interact with the viral components and block their normal function and assembly, yet, like the viral components, of sufficient specificity that these agents do not interact with the cell components and block vital functions.

The design and application of such sculptured molecules to combat viral disease—or to affect the other molecular diseases—is potentially feasible. It will require the development of a new sector of biochemistry, even of what might be called bioengineering, for it is the engineering of matter into new and complex forms for a specific purpose. But actually this has already begun. The synthesis of the adrenocorticotropic hormone, ACTH, a polypeptide of 39 amino acids, has been accomplished. The synthesis of the enzyme ribonuclease, a chain of 124 amino acids, has been achieved, admittedly in very low yield at this time. But the possibility for the design and the construction of a vast variety of biologically active enzymes, and hormones, or their analogs, and anti-viral agents, and anti-tumor agents at this new level of complexity is at hand. This achievement is certain to open whole new vistas in medicine.



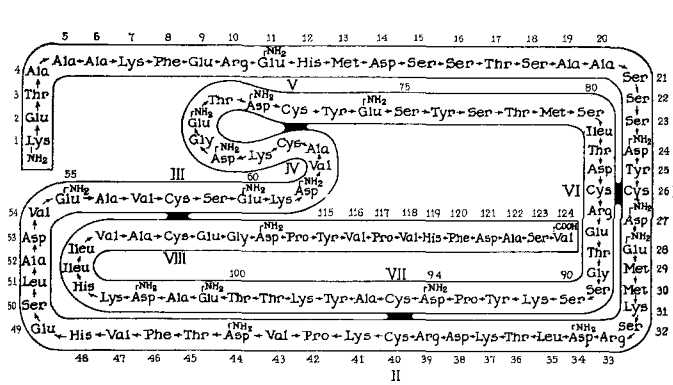
This diagram of the stages in the assembly of T4 virus shows the three different branches that lead independently to the formation of heads, tails, and tail fibers, which then combine to form complete virus particles. The synthesis of such a virus particle is a step toward devising anti-viral agents specifically designed to interact with the viral components.

The *biochemical* diseases are today often of uncertain etiology. It may be that in time many will be traced to genetic origin or to external cause—to malnutrition or trauma—but at this time we recognize them as a biochemical surplus, a deficit, an imbalance, or an abnormality. There may be a hormone deficiency, an excess of uric acid or cholesterol, an under-supply of dopamine, an unusual degree of cross-linking of collagen; and they result in opacities of the eye, in stiff joints and clogged arteries, in palsy, and in aberrant behaviors.

That these are still prevalent diseases attests to the partial state of our knowledge here. I did *not* cite scurvy, which *was* a molecular disease. But further knowledge will bring understanding and in that understanding will, in the sense I have been describing, lie therapy.

I do not wish to oversimplify this issue. Some of these problems—such as the deposition of cholesterol—may well be the long-term consequence of basic imperfections in our biochemical program. We call such imperfections aging. We were not designed to live forever. And while we may invent palliatives to slow such deposition, a true solution may require some far-reaching changes of biochemical design for which we are hardly yet equipped. But the basic problems are clearly written in molecular language, and with knowledge we surely will be able to mitigate the more extreme syndromes and to slow the erosion of time.

The *immune* diseases (exemplified by allergic encephalomyelitis and lupus erythematosus) are a consequence of a biochemical perversion whereby one of the principal agencies of the body for defense against invasion is turned against normal body components. Our immune system becomes sensitive to one or more of our own molecules and may then seek out and destroy that component throughout. The rarity of this circumstance is a consequence of the normally remarkable capacity of our immune system to distinguish between the indigenous and the foreign. This distinction in each animal dates from an early developmental stage in which a tolerance is created for the indigenous molecules—the cells potentially



The design of molecules to combat viral disease is feasible, although it will require many advances in bioengineering. Already, however, the enzyme ribonuclease has been synthesized.

capable of forming antibodies against the normally available antigens of the individual are at this time killed off—to leave only a set programmed to respond to foreign antigens.

The occasional failures of tolerance which result in the autoimmune diseases, and our desires—whetted by the potential of transplants but currently frustrated by their rejection—to be able to host foreign tissues or substances for long periods, all emphasize our ignorance of the biochemistry of tolerance and immunity.

We *are* learning. The general structure of antibody molecules is now established (below). The origins of antibody diversity are still debated, but the decisive experiments are in sight. The specific proliferative response to antigen to form clones of antibody-producing cells is well documented but not yet understood. Here and in the equally obscure tolerance response are the keys to the induction of specific tolerance to specific antigens. When that door is opened, we will see the demise of immune disease and the resolution of immune rejection, whether of self- or alien-antigen.

And whenever it is that the skill of the surgeon can be wedded to this specific control of rejection, we can then easily foresee a golden age for surgery. The extension of life or the repair of defect or injury by the transplant, or the artificial implant, will then become a routine medical practice.

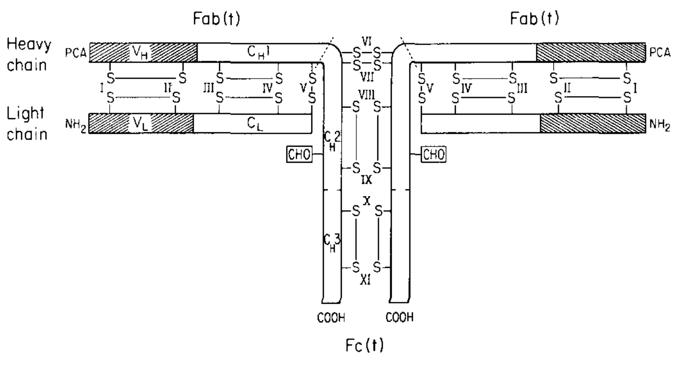
The *genetic* diseases are very simply those that we can trace directly to the inheritance of a defective gene or genes, or to an abnormal complement of chromosomes. And as we have become more knowledgeable in this field, the roster of genetic disease has markedly increased—phenylketonuria, hemophilia, histidinuria, Lesch-Nyhan disease, Tay-Sachs disease, Huntington's chorea, Downs disease, Kleinfelter's syndrome. The list is long and growing.

The defect here is most basic, and therapy correspondingly is as yet more remote. If—as in hyperlipidemia—the disease is likely a consequence of an abnormal enzyme, we might be able specifically to inhibit it. If—as in other instances—the disease is a consequence of an enzyme deficit, we shall have to supply either the enzyme or the gene. Either is conceivable. The gene might be supplied via a transplant when that becomes feasible, or it may be supplied by the deliberate introduction of a specifically designed beneficial virus. To design a virus is a step beyond the molecular engineering I mentioned before, but it is not beyond our reach.

As we scan yet another sector of human frailties, we can see their origins in what I have called the *cybernetic* diseases. Not all of our concepts come from physics and chemistry. Another major source of insight to modern biology has been the development of computers, information science, and the science of control systems. In our analysis of living organisms we have become increasingly aware of the importance, the vital necessity, of control mechanisms—within the cell, within the embryo, within the body, within the brain—to maintain proportion and stability and yet permit growth and response and adaptation.

And one of the principles we can learn from cybernetics—the theory of control—is that complex control systems involving branch points and multiply interconnected feedback loops can often exist in a variety of alternative metastable states. As the result of some previous trauma or upheaval, such a system may well be in a state that may be far from optimal for its function but with no direct path available to it to return to a more effective condition. Nothing is intrinsically wrong in this condition; all the elements are working according to design, but the system is—unless and until jolted by some cataclysm—trapped in an ineffective state.

I think it is not unlikely that we will come to recognize some of our disease states as aberrations of this class: that some forms of cancer may represent such a derangement of the control mechanism of the cell to an alternative state; that some forms of hormonal imbalance are similarly self-perpetuating; and particularly that some forms of mental disease—depression, neurosis, psychosis—may be a reflection of such a cerebral circumstance. To what



The general structure of the immunoglobulins (the antibody molecules present in blood) is now established.

therapies such insight may lead in these cases remains to be seen. We must first understand the inner cycles and identify the critical interactions. But when this is done, we should be able to simulate mathematically such a disease state and to locate the most favorable points for intervention.

Life usually outwits our efforts to classify, and some pathologies may well encompass several of these categories I have described. Cancer may in some instances be a viral disease; in others, a genetic disease, a consequence of somatic mutation; in others, as I have suggested, a cybernetic aberration. Regardless of etiology, there is increasing evidence that the appearance of cancer signals a breakdown of some sector of our immunological defense. In such complex circumstances the design of therapy may well require refinement of our pathological analysis, and this in turn the design of new techniques for such purpose.

I have here considered principally what biology may contribute to the future of medicine. I believe there will be a flow of knowledge and insight in the other direction as well. Biology has quite naturally directed its attention to the most general principles and phenomena. Medicine is inherently concerned with the individual.

Medicine can contribute to biology not only its knowledge of pathology—which often illuminates the normal from a new direction—but also, through its concern for the individual, it can emphasize the importance of biochemical individuality. It can emphasize the influence upon the integrated human being of the *cumulative consequence of numerous small departures* from the statistical norms. A sense of this uniqueness of the individual will become particularly important as we extend our interests into the basic biology of the mind—the most adaptive and hence the most distinctive organ of all. In our study of the biology of mind we shall of course continue to seek for very general principles, but we shall have to discover these behind the enormously varied faces of human experience.

I have been trying to survey for you the frontiers of biology as I imagine they might appear to the eyes of the healer. It is an unprecedented view. In every direction one can see the groundwork for truly new approaches to avert and to relieve the long-standing trials of man. Through foresight, understanding can bring prevention as well as therapy.

It is in a sense a poignant view. We have always known our earthly frailty and mortality. Familiarity has bred a reluctant acceptance. But there is now for us an added poignancy in the sober realization that with added knowledge—and now not so very much more—in some not-so-future time, disease will not cripple for so long and death will not come so early for so many.

Indeed someone is sure to ask: "Must death come at all?" And feasibility aside, the resounding echoes of that question should jar us to perceive that a medicine equipped with the full power of modern science would be as far beyond, and as different from, the medicine of this time as is the medicine of today from the tribal witchcraft of old.

As the discoveries accumulate, as new means of biological intervention arise, we can envision such possibilities as the almost indefinite prolongation of life for at least a few, as the deliberate predetermination of sex, or the design of human genetic change for varied purposes. With these will come the necessity for multiple social decisions of the most profound consequence. We are already faced with grievous decisions of the allocation of limited medical resources. This trend can only grow, for we have learned—as, for example, in the great lunar expeditions—how to focus the combined talents and efforts of vast numbers of men behind the deeds of a few. The same no doubt can be done in medicine. But who shall pay the cost, and who shall be the beneficiaries? Who shall make these decisions? I cannot say. But I can easily envision the physician at the focal point of responsibility.

There are now in our society three groups to whom we have traditionally delegated the grave concerns of life and death: the military, the judiciary, and the physicians. The military is like the dinosaur, obsolete although clearly not yet gone. In more humane societies the power of the judiciary over life and death has been progressively curtailed. But the concerns of the physician seem destined to expand and with them his role in the social order.

The aim of the physician has been simple—to preserve and extend human life by all means and at almost all cost. This has been a clear mandate—and feasible because in truth his capacities to do so have been cruelly limited. With greater abilities will come greater responsibilities. The equation is ineluctable. In the future the physician will have each day cause to consider the quality of the life he may extend or he may bring into the world and the effects of his decisions upon all our futures. For, to reflect John Donne's phrase, "No man is an island"; not only does each man's death diminish every man, but on a small planet each man's life touches every man.

Reflections from the Man Who Landed on the Moon in 1929

by Ray Bradbury

I gave up writing about landing on the moon more than 35 years ago, when I was 14. I wanted to go on to other places.

I'd like to start with a story which is apropos of nothing whatsoever. But it happens to be true and I love to tell it. I have lived in Los Angeles for roughly 35 years. I came here when I was a kid with my parents, and I was movie-struck. I put on my roller skates and went out to Paramount Studios. I got out there and I thought, "Oh boy, I'm going to see movie stars! Beautiful!" And there, standing in front of the studio, were three gentlemen—Ben Bernie, an orchestra leader; Irvin S. Cobb, the writer; and the hero of all of us, Mr. W. C. Fields. Well, I tell you, he was as much of a hero to my generation as to the generation coming up today. I ran up to him and said, "Mr. Fields, can I have your autograph?" He took the pad and pencil, signed, handed them back to me and said, "There you are, you little son of a bitch."

I've tried terribly hard to live up to that name because it isn't every day of your life you're knighted by a man like that.

Well, here I am—a writer of science fiction, whatever that term means. I find that I'm a writer of mythologies, actually, and that over a period of years I've been able to come up with the metaphors which represented certain ideas that I saw around me in my own time. I'm a child of the technological age. I'm a child of the machineries that surround us. I'm a child of the Space Age. And what's more natural that in growing up I would care about these ideas? I find them fascinating, irresistible; there *is* no other fiction to write. It always aggravates me that people don't realize that sometimes fiction is at the center of events—and has been for the last 40 or 50 years. I think a lot of you have been provoked into thinking about science on many levels by the sort of work that you read when you were a child.

My first encounter with scientific ideas was in the old pages of *Amazing Stories* in 1928. In 1929 Buck Rogers came on the scene, and I went mad with seeing him every day of my life. These pivotal dreams that occur to us at a young age are so important, and are so often ignored. As educationalists, as teachers, as writers we forget the seedbed that we came from. So I was excited by the primitive exercises of scientific ideas that I found locked into the science fiction magazines, into Buck Rogers, into Flash Gordon. Thus, when I began to write stories when I was 12 years old, the first thing I did was take a man off and land him on the moon! What was more natural?

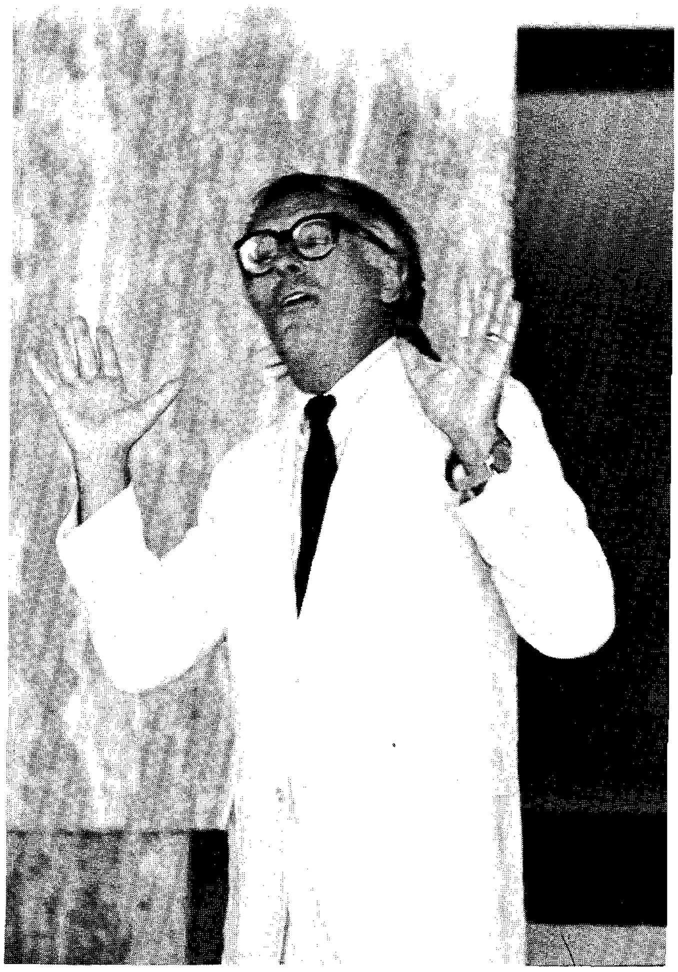
I gave up writing about landing on the moon more than 35 years ago, when I was 14. I wanted go from there to other places. I flew off to Mars. I wrote a whole book called *The Martian Chronicles* without knowing that I was writing it. I just wrote a series of stories over a period of years—various kinds of poetic fancies that seized and shook me. Then I went off to New York to sell a book of stories to Doubleday but they said, "Well, if you don't have a novel to give us, we can't publish your short stories. Short stories don't sell."

I went back to the YMCA that night. It was a hot summer evening—20 years ago this month. I sat at my typewriter and began to make lists of all the stories I had written over the years, and they began to fall together. Suddenly I realized that I had written 25 short stories about the planet Mars. I began to reassemble them on the page and retype the titles. The next day I went to Doubleday and said, "Hey, you know what I did last night in the middle of the night? I wrote a novel, *The Martian Chronicles*. Here's the outline. What do you think?" They bought the book right then and there. By the end of summer I had finished retyping and fusing all of these stories that my subconscious had handed me as a very special gift.

That's the way I work. I'm an emotionalist; I'm an intuitive writer. I never know what I'm doing from one day to the next. These ideas run up and beg to be born. They seize me; they shake me; and they put me down two hours later when the story is finished.

Let me give you a few other examples of the sort of thing in our society that provokes and fascinates me. If President Roosevelt 35 years ago had tried to put a law through Congress outlawing money, he would have been out of his job and out in the cold the next day, wouldn't he? But we are living in this remarkable time where through our technologies, through new types of inventions, through new types of computers, money is vanishing from the earth. It's a fascinating thing to watch. Very few people ever comment on it, and I think if you could get people to sit down and discuss it logically, we would realize that there are days that go by (even if we have money in the bank—and let's imagine that we *do* have some, hm? . . . after taxes) when we just never use cash. If we travel, especially, we take that credit card with us.

The credit card is going to dominate our lives more and more. This conception of the credit card came into being about 100 years ago. (I believe it was mentioned for the first time, as far as I remember, in Bellamy's *Looking Backward*.) But when we read that as science fiction when I was a kid, we thought, "Oh, it will be years



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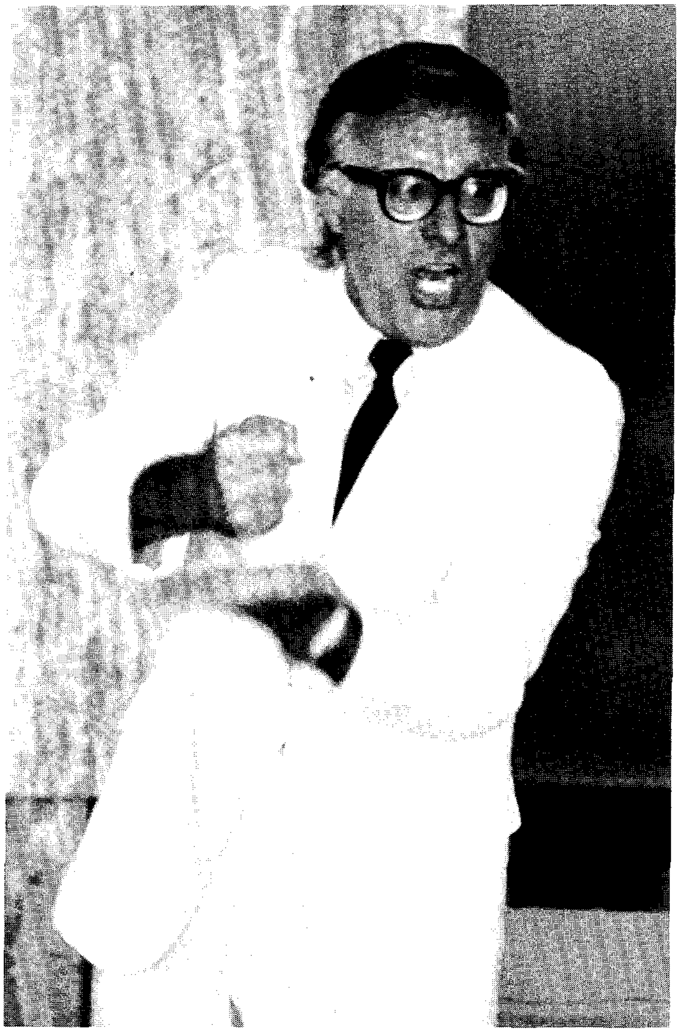


before anything of this sort happens, when we live by faith alone." But suddenly we've moved into this age of faith. Because it *is* an act of faith, just as accepting a check is an act of faith, isn't it?

Now, within 20 years money will have vanished from the world completely, and everyone will just carry the little credit card around. When you want a Fresca or a Coca-Cola or what have you, you will just put this little thing in the machine, the machine will record your signature and computer number. This will be sent to the bank. At the bank they will just change some figures, move the decimal a point one way or the other. Now, that's fantastic—that money would absolutely vanish from the world, and we would all sit calmly by and not comment on it and be astonished at this new age of faith and trust that is coming upon us. Talk about your revolutions!

When this fact reaches its completion in 20 years, crime must change. That means all of you who plan careers of holding up liquor stores will have to find some other occupation. You won't be able to go in and burgle a liquor store and go out with the money. You'll have to drink your way to the exit.

Let me give you another broad idea. We never dreamt, did we, 30 years ago that the face of war would be so completely changed, that a weapon—a science-fictional weapon utterly impossible 30 years ago—would come along and change the way we use politics and war? It used to be that war was an extension of politics. Now we find that technologies are becoming extensions of politics, that we no longer make war on a large scale. The major nations of the world are engaged in little guerrilla activities here and there. Vietnam, as much as it dominates our thinking, is not an immense war. It's a very small one—the reason being that the hydrogen bomb came along as the most Christian teacher of the most Christian principles in the history of the world, and like it or not, it made Christians of us *all*!

What did the hydrogen bomb say to us in a very soft voice so that all the world could hear? "Everyone sit down." And we've *been* sitting mainly, you know. We've been *sitting*.

Think of any war that has occurred during the last 25 years: Korea, Vietnam, the Middle East. Less than these provoked gigantic wars in the past. Such provocations no longer provoke. Now we fiddle about with little guerrilla activities all because of this thing standing over us in our time. I don't know how long this balance of power will stay. My own feeling is that it will last for several hundred years, and hopefully for a thousand years, while we all teach each other some sort of Christian principles to live by. I am hopeful that each of the small wars that grows will be snuffed out in turn, even as the Korean War was snuffed out.

But this is a science-fictional idea. This is the sort of of thing that fascinates me when I see politics changing before my eyes, when I see that the peoples of the world who loved to live by political principles can't live by them any longer. We are witnessing the proliferation of technological ideas in all of the major countries of the world, so that we will all meet at a peak, beautifully covered with smog, within 30 years. My favorite date will be that magical date when Red China and the United States discover how much alike they are; and that will be the day, 25 years from now, when Mao Tse-tung's grandson drives into Peking and can't find a parking place for his goddamned car.

So, like it or not, we're all being victimized by our machines, and all of our major problems are science-fictional problems. You name a problem and I'll name the machine responsible for it. Almost everything that's wrong with our country today is the result of a machine doing something in the wrong way. I'd say 9 out of 10 problems, at least, have something to do with the malfunctioning of a technology somewhere down the line. Our cities are being destroyed by cars. We all know this. The whole country's being destroyed by the automobile. Last year we put four million people in the hospital with the automobile. Now that's fantastic. That's a major war we're fighting here. It turns out that the war in Vietnam is small in comparison to the technological warfare we have here at home. So, naturally, I'm going to write about it. I'm going to be interested in this.

Let me give you some other ideas that I've been concerned with. I was speaking of the credit card, and I'm fascinated with the fact that with the proliferation of the credit card in the next few years the vast middle class will become the aristocracy of all time. And one of the things the middle class is going to do that no other class has ever done is travel. This is the privileged group. The total population of our country will be privileged in another 20 years. We will be sending people all over the world. In fact, it's an old idea, isn't it, and not fresh with me—the idea of sending a million of our students every year to all the countries of the world to study and bringing millions of students here to study, so that we begin to understand that we all have the *same* problems.

The idea is this, though—that when we have credit established, we can borrow from the future. I think the history of the world will show that FDR and people around him were wonderful people if for only one thing—they knew how to borrow from the future in order to make work now. In many of the countries of the world that I've visited, I see that rocks are not being moved, roads are not being repaired, factories are not being built because of the inability of the government to say we will borrow some sort of credit from day after tomorrow to make these people move today. Because after all money *is* fantasy anyway, and always has been.

So the credit system is a magical thing, isn't it? You make a mysterious promise about tomorrow, and you give the money to the people here today so the work gets done, and you're automatically made rich by this activity. So, the generations to follow us will, with their credit cards, go off and travel the world and come back with all this knowledge and pay off on the debt.

I don't know how many of you know, but back about 16 years ago, I wrote a screenplay of *Moby Dick* for John Huston, so I got to be on very familiar terms with Herman Melville and with that whale and with the whole mythology of Melvillian concepts. Over the years since, I've written much poetry, and I've begun to write some plays dealing with the subject of Moby Dick and the future; and I thought it might be fascinating to try a few pages on you here to show you the sort of thing I'm up to. I've tried to carry the mythology of Melville ahead 200 years to roughly the year 2199 when rocket ships are moving further out in space.

My play starts in this way, surprisingly enough:

"Call me Ishmael.

"Ishmael in this year 2199 when strange new ships sail towards the stars instead of under them, attack the stars instead of fearing them? A name like Ishmael?

"Yes, my parents flew with the first brave ones to Mars. Turned less than brave, gone sick for earth, they turned back home. Conceived in that journey, I was born in space. A child so birthed in desolations, homeless between yestermorrow and noon's midnight must have a proper name. My father knew his Bible and recalled another outcast who wandered dead seas long years before Christ. And I being so far the only child conceived, fleshed, and delivered forth in space, how better to name me than as my father did, touching the dark warmth where I hid in the days before my birth. And he did, indeed, call me Ishmael."

The newspaper the next morning said, "Armstrong walks at midnight. Bradbury walks at one o'clock."

And Ishmael boards a rocket craft and signs on to go off into space. In terms of Melville it was the ships seeking the whales and Ahab seeking the white whale. In my story it's the story of a blind captain of space who had his vision rubbed out 40 years before by a great trailing midnight presence that came down through our basement part of the universe—a great comet called Leviathan. And now my captain is going back out to strike through the mystery of the comet, to make do with it, to destroy his destroyer. But before they go out into space, all the men from the rocket ship go to hear a church service on the morning before they leave.

"In the pulpit at the center of the spaceman's chapel stands a man who had died 100 years before. Dead, yes, but so remarkable a man was he that they did computerize his soul. That is, they did up his voice on tapes, made circuitries of his merest breath and motion—then locked it all in plastic flesh and steel. So now before us stood Father Ellory Coleworth. A monster robot? No. Gentle essence of the man. And he speaks. 'Is God dead? An old question now, but once hearing it I laughed and replied, "No, not dead but simply sleeping till you chattering bores shut up." A better answer is: Are *you* dead? Does the blood move in your hand? Does your hand move to touch metal? Does the metal move to touch space? Do wild thoughts of travel and migration move behind your flesh? They do! *You* live. Therefore *He* lives. You are the thin skin of life upon an unsensing earth. You are that growing edge of God which manifests itself in hungers for space. So much of God lies vibrantly asleep. The very stuffs of worlds and galaxies they know not themselves. God reaches for the stars. You are His hand. Creation manifest, you go in search. He goes to find, you go to find Himself. Everything you find along the way, therefore, will be holy. On far worlds you will meet your own flesh, terrifying and strange, but still your own. Treat it well. Beneath the shape you share the Godhead.' "

There you get some of my ideas on how I feel about space travel. I have been excited by it constantly, of course, since I was a child, and I was privileged last July to be in London on the night when we landed on the moon; so I was asked over by David Frost to appear on his evening TV show around 9:30 p.m. London time.

I listened to the landing on the moon. I was in tears most of the evening—certainly one of the greatest nights in all of my life, a night I had been waiting for since I was 8, 9, 10 years old. Well, I waited an hour or so after the landing for David Frost to call me out on the show.

But *first* he introduced that great space expert, Engelbert Humperdinck.

And then he introduced that other great space expert, Sammy Davis, Jr.

I began to feel somehow the evening was going awry. I began to get a little sick to my stomach. I went out on the sidewalk. The producer came out. He said, "Mr. Bradbury, what are you doing out here?"

I said, "I think I'm looking for a taxi."

He said, "You can't leave, you can't leave. You're going to be on any moment."

I said, "Yes, but I don't like you people. You see, I don't like you. I think you've taken the greatest night in the history of mankind and destroyed it. Take your hand off my elbow. Find me a taxicab. Keep your money. And goodnight."

So I left. If you'll forgive my arrogance and my lack of humble, the newspaper the next morning said, "Armstrong walks at midnight. Bradbury walks at one o'clock." I was rather proud of that. It was a very small step for me.

Anyway, I went over to NBC, and waiting for me there in the studio was a panel of people—the Bishop of Geneva, Lord Ritchie Calder, and Bernadette Devlin. Well, my God, I've never heard so much lamentation. You'd think we were at a funeral. And listening to all these intellectuals, suddenly I get more anti-intellectual by the minute! The Bishop wasn't happy about the landing on the moon. Lord Ritchie Calder had *his* doubts, and Bernadette Devlin was lamenting that all that money wasn't going into the north of Ireland.

I turned on all three of them. I said, "Now look. Everyone shut up. You don't know a damned thing about what's going on here tonight, and that's why people like myself are needed in the world. I want to tell you what in hell it means. This is the *greatest* night you will ever know!

"There are two nights the Western world will look back upon a million years from tonight. A million years! I'm not talking about a hundred or a thousand years. I'm talking about a million years from tonight.

"The birth of Christ probably is a very important date that changed the world in many ways for the better and, in some ways, for not very much good at all.

"But the second most important date is this night that we're going through right now. Because it's the night when we become immortal—when we begin the steps that will enable us to live forever. Now, if you don't know this, you don't know anything about space.

"To hell with all the political talk. To hell with all the military talk. To hell with all this nonsense that you're giving me about the funds and priorities and all this. The money that's spent on this is miniscule compared to the money wasted on our war efforts the last 10 or 15 years.

"Give me the pittance to work with because I have long views, and I want you to have the long views with me; and the long view is this—at the center of all of our theologies, at the center of all of our philosophies for thousands of years, people have said, 'Why live? Why bother? What's the use if we're going to stay here and die and our philosophies be buried and stuffed in our mouths? What's the use? What is it all about?'

"Suddenly the space ship comes along—the gift we give ourselves and the total race and the gift of life, as mysterious as it is. We've been trying to figure it out for thousands of years now. We've had to take it on faith from the theologians and on data from the scientists, and we are still so ignorant.

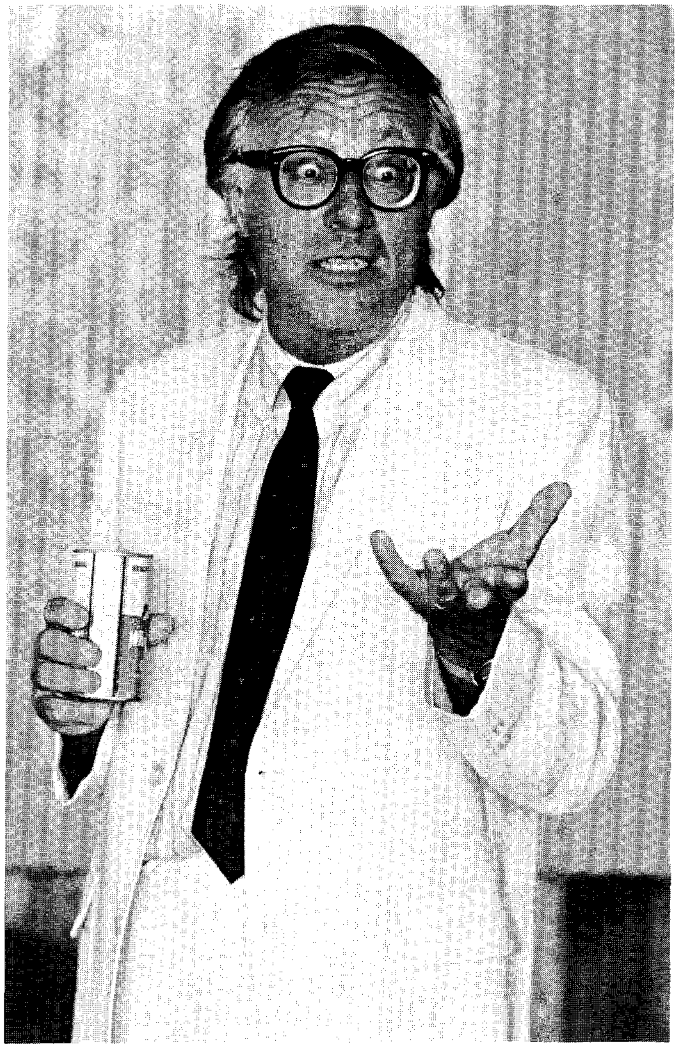
"We are still the ape man in the cave, and we have this torch given us—the rocket ship. Now, for God's sake, we use it to light the universe with. We don't know what's out there. We know it's pretty empty. And our part of the universe is full of us and this gift.

"I want that gift to go on. I want mirror images of myself and my children's children's children to go on. All of you. Now, we can't stay here and die, that's for sure. We are a danger to ourselves. We must go off to other worlds. We will go to the moon. We will go to Mars. We will go beyond Jupiter. We will be going beyond our own solar system and eventually, sometime in the next 100, 500, 1,000 years, we will build those starcraft we've been speaking of and head for stars so far away they are impossible to imagine.

"That's what it's all about. It's huge. It's a long-range thing. And the things that we do here on earth right now are housekeeping. I want to do them *both*! I want to clean up the house and improve the civil disputes and help the people, but help them also to survive not for 100 years, not for 1,000 years but for the 2 billion years that will be the Age of Apollo which opens before us this very instant. Is that enough answer for you?" And I shut up.

And their lamentations ended.

And they were silent.



ALBERT RUDDOCK
1886 - 1970

Albert Ruddock died on July 24, 1970, at the age of 84. He was Caltech's friend and benefactor for more than 40 years, beginning his long association in 1926 as one of the 100 founders of The Associates of the California Institute of Technology. In 1938 he became a trustee of the Institute, and from 1954 until he retired in 1961 he was chairman of the board. He was elected an honorary trustee in 1961, and in 1969 he became chairman emeritus, the first and only person to hold that office. One of Caltech's undergraduate houses is named in his honor.

The scion of a family of lumbermen, Albert Ruddock was born in Chicago. He graduated from Yale University in 1907. After receiving an MA from Columbia in 1909, he studied at the Ecole des Sciences Politiques in Paris as a prelude to entering the diplomatic service. From 1912 to 1916 he was secretary of the U. S. Embassy in Berlin, and he held the same post in 1917 in Brussels. He returned to Washington, D. C., to serve in the State Department in 1918, then from 1920 to 1923 was on the staff of the Legation in Peking. In 1924 he resigned from the foreign service to enter private business.

In 1924 Albert and his wife, the former Margaret Kirk, moved to San Marino, California, where they made their home for 28 years. He was a director of the Security First National Bank of Los Angeles and was active in the petroleum industry. In 1952 the Ruddocks moved to Santa Barbara but continued to maintain a residence and offices in Pasadena. Mrs. Ruddock died last year. Margaret and Albert are survived by two sons, Merritt who lives in Belvedere, Billings of Pasadena, and three grandchildren.

Albert Ruddock was a trustee or director of many civic and cultural institutions, including Occidental College, the Los Angeles County Museum, the Town Hall of Los Angeles, the Hollywood Bowl Association, the Southern California Symphony Association, the Pasadena Civic Music Association, the Santa Barbara Foundation, and the Santa Barbara Museum of Art. He served as president of Polytechnic Elementary School and the California Graduate School of Design. He was a president and campaign chairman of the Pasadena Community Chest and, in 1944, of the Pasadena and Altadena War Chest. In 1943 he received Pasadena's Arthur Noble Award. He was a chairman of the advisory committee of the Los Angeles County General Hospital, and a former president and chairman of the management committee of the Huntington Memorial Hospital of Pasadena.

Mr. Ruddock was a member of the Twilight Club, Annandale Country Club, and Valley Hunt Club of Pasadena; and the Sunset Club and the California Club of Los Angeles. He also belonged to the Valley Club of Santa Barbara and the Bohemian Club of San Francisco. He was attending the annual Bohemian Grove Encampment on the Russian River in northern California at the time of his death from a heart attack.

The Institute held a memorial service in Beckman Auditorium on July 31, at which there were tributes from President Harold Brown and from four of Albert Ruddock's long-time friends and associates: Arnold O. Beckman, chairman of the Caltech board of trustees; attorney Herbert Hahn, a trustee; Robert Huttenback, dean of students; and Robert Sharp, professor of geology.

The Month at Caltech

New Trustees

Caltech has added three new members to its board of trustees. James W. Glanville, Dean A. McGee, and James E. Robison bring the total membership of the board to its maximum size of 45.

James Glanville is a Caltech alumnus and a life member of the Institute Associates. After receiving his BS from Rice University, he obtained an MS in chemical engineering from Caltech in 1946 and an engineer's degree in 1948. He is a partner in the New York investment firm of Lehman Brothers and is a director of several oil companies and of the International Minerals and Chemicals Corporation.

Dean McGee is board chairman and chief executive officer of Kerr-McGee Corporation of Oklahoma City. He heads or is director of all Kerr-McGee affiliates in this country and abroad.

A graduate of the University of Kansas, McGee taught geology there for a year and then joined Phillips Petroleum Company. He was chief geologist at Phillips when he resigned to become vice president of Kerlyn Oil Company, predecessor to Kerr-McGee. He serves on the board of directors of the General Electric Company, the Oklahoma Natural Gas Company, and the Fidelity National Bank and Trust Company.

James Robison, board chairman and chief executive officer of Indian Head Inc., graduated from the University of Minnesota and holds an MBA from the Harvard Graduate School of Business Administration. He has remained active at Harvard University, formerly as board chairman of the Associates of the Harvard Business School, and currently as a member of the visiting committee of its Graduate School of Business Administration and of the executive council of the Harvard Business School Association.

Robison has served on the President's Advisory Committee for Trade Negotiations, and for six months in 1961 he was chief of the textile branch of the Office of Price Administration. Before joining Indian Head as president and chief executive officer in 1953, Robison was executive vice president of Textron, Inc.

Professor Emeritus

Frederick C. Lindvall, professor of electrical and mechanical engineering, becomes professor emeritus this month. Chairman of Caltech's division of engineering and applied science for 23 years, he retired as division head in 1968. Since then he has been on leave of absence as vice president of Deere & Company in Moline, Ill., and as a consultant for the President's Office of Science and Technology.

Lindvall received his bachelor's degree in railway engineering at the University of Illinois in 1924 and his PhD in electrical engineering at Caltech in 1928. He then joined the General Electric Company. In 1930 he returned to Caltech as an instructor. He became assistant professor in 1931, associate professor in 1937, and full professor in 1942. He was named division chairman in 1945.

As chairman, Lindvall guided the division through a diversification and broadening process that radically altered the nature of engineering education at the Institute and had nationwide influence as well. The old categories of electrical, mechanical, and civil engineering metamorphosed into such fields as fluid and solid mechanics, materials science, environmental health engineering, biosystems, and information science. To complaints that this hardly sounded like engineering Lindvall replied: "We have certainly not abandoned the concept of engineering. Basically we're trying to give an education that doesn't suffer from technological obsolescence. The engineer is vital in the process of putting a system together as well as designing components of it. But the old methods aren't applicable any more, so we're trying to find new ways of teaching our engineers how to design."

As a result of his work on revision of the engineering curriculum, Lindvall has become a widely travelled and prominent spokesman for engineering education in general. In 1966 he received the Lamme Award of the American Academy of Engineering Education for his contributions in both areas.

Lindvall's own research interests have been in the areas of vacuum switching, glow discharge phenomena, the dynamics of rail and road vehicles, and research management. He is a member of the National Academy of Engineering and of the National Research Council, and is a fellow of the American Society of Mechanical Engineers and the American Institute of Electrical and Electronic Engineers.

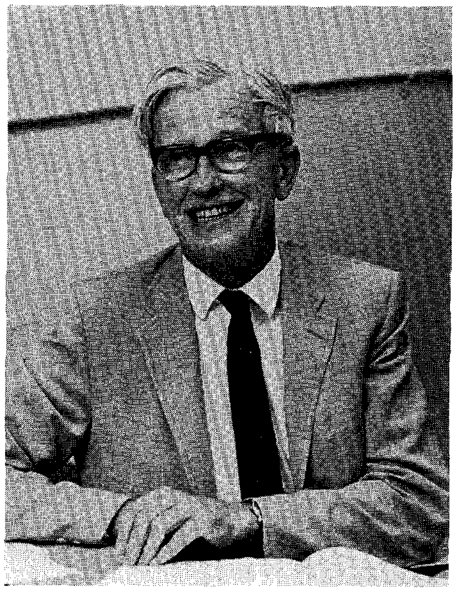
Four New Professorships

James Olds

Four new professorships have been established at Caltech, and four distinguished faculty members have been appointed to them.

James Olds is the first Bing Professor of Behavioral Biology. This chair is the gift of Peter Bing and his mother, Mrs. Anna Bing Arnold, through the Bing Foundation.

Olds' discovery of self-reinforcing brain centers has contributed to the understanding of the physiology of motivation, learning, and memory. He has also contributed productive theories and ideas about how the brain processes, analyzes, and stores information, and about how it makes decisions. His current experiments constitute a new attack on the locus and mechanisms of learning and memory storage in the brain.



Max Delbrück

Jesse L. Greenstein has been named Lee A. DuBridge Professor of Astrophysics. He is the first man to hold the new DuBridge Professorship funded by gifts of The Associates of the California Institute of Technology and named in honor of Lee DuBridge, president of Caltech from 1946 to 1968.

Greenstein is expert in the discovery of peculiar stars and the study of their composition from their spectra. In collaboration with Caltech physicists he developed the now accepted theory connecting differences in the compositions of stars with the nuclear energy-producing processes occurring in their interiors. At Palomar he has studied the spectra of low-luminosity white dwarf stars, with particular reference to the final stages of cooling and fading of stars.

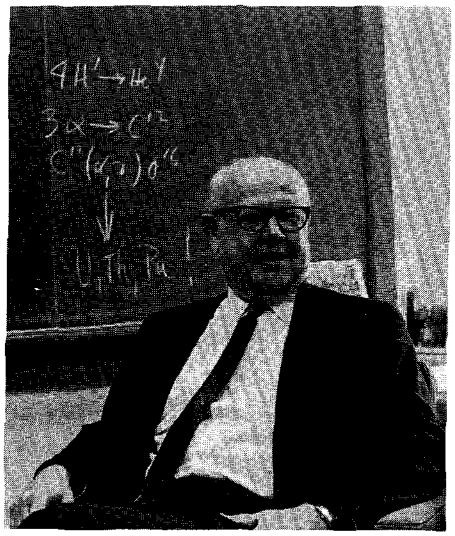
The first Institute Professorship, awarded by Caltech to give special honor to outstanding members of the faculty, is held by William A. Fowler, professor of physics.

A pioneer in investigating the nature of nuclear forces of the light chemical elements, Fowler developed the idea that nuclear processes make the stars shine, and that chemical elements in stars evolve from the light to the heavier elements.

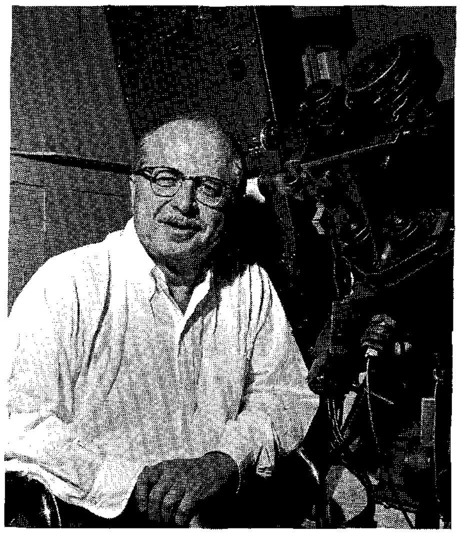
Fowler has also made contributions to current knowledge of nuclear forces and reaction rates, nuclear spectroscopy, and the structure of light nuclei. His current research centers on the general relativistic effects in quasar and pulsar models.

Max Delbrück has been appointed Albert Billings Ruddock Professor of Biology. This chair was given in honor of Albert Ruddock, a member of the Institute Board of Trustees from 1938 until his death in July 1970 and its chairman from 1954 to 1961.

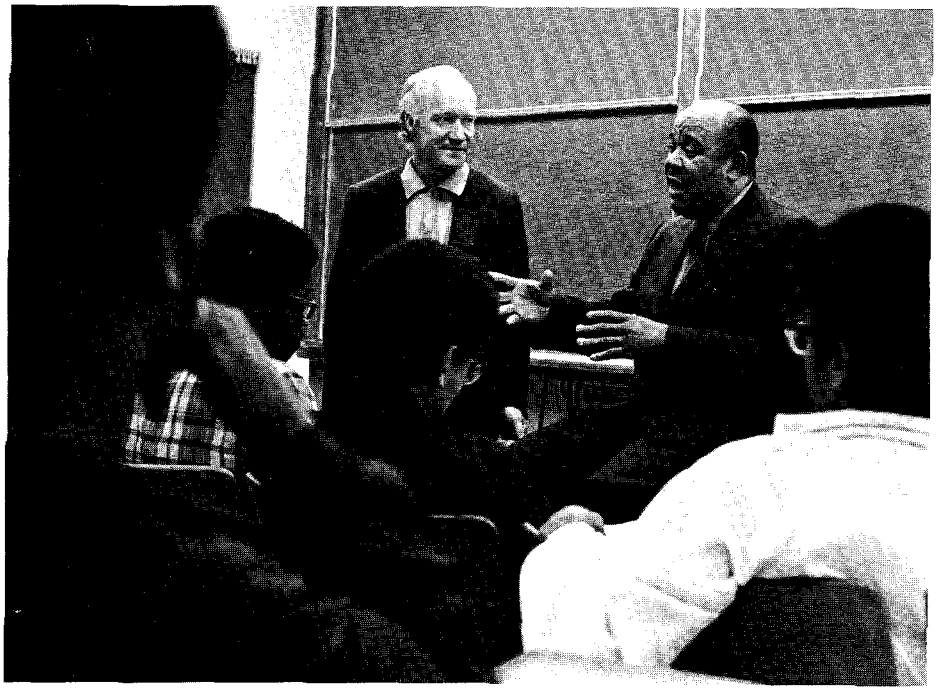
Delbrück, winner of the 1969 Nobel Prize in physiology and medicine, was honored for his discoveries concerning the replication mechanism and genetic structure of viruses that set the foundation for molecular genetics. Since that time his research interests have shifted to sensory physiology. Using sporangiophores of the fungus Phycomyces as a model system, Delbrück has studied stimulus transduction in order to clarify the molecular nature of the primary transducer processes of sense organs.



William A. Fowler



Jesse L. Greenstein



Robert Walker, professor of physics, and Lee Browne run a summer course for entering freshmen.

Lee Browne

Lee F. Browne, who was formerly high school science coordinator for the Pasadena city schools, came to Caltech in July as director of the Institute's new office of secondary school relations. He is working with Lyman Bonner, director of student relations.

A teacher himself, Browne has a special interest in developing methods of selecting and guiding students of minority groups. During the past year he has been working closely with Caltech on its junior high school science project. This program started in the summer of 1969 with 24 Pasadena ninth-graders—all bright, all interested in science, most from minority groups, and some not doing too well in school. After living on campus and working closely with some faculty and students for eight weeks, the young people elected to continue their Caltech liaison in Saturday morning workshops through the school year. In the summer of 1970, ten ninth-graders who showed aptitude for independent study spent seven weeks working in Caltech laboratories with faculty and students. Sixteen others spent their mornings for six weeks covering a one-year course in biology at Blair High School in Pasadena, and afternoons being tutored by graduate students at Caltech.

During the current academic year this program is being expanded so that about 100 seventh, eighth, and ninth grade students are coming to the Caltech campus for informal Saturday workshops in such subjects as mathematics, biology, chemistry, physics, electricity, computer science, and photography. The students can elect any subject that interests them and put in as much time as they like on it. The schedule is arranged so that there is tutoring from 10 a.m. till noon, then lunch, and more classwork from 1:30 till 3:30. They can continue working in the same class in the afternoon, take another, or just play, and they are free to change classes when they like. Because they are all highly motivated young people, they are encouraged to work with their instructors to develop the curricula.

In working to improve Caltech's secondary school recruiting programs, Browne is particularly concerned about students who show talent and motivation for science, but are not qualified for Caltech by the usual standards of grades and tests. Last spring, therefore, faculty interviewers offered admission to Caltech to three girls and ten young men who they felt would make the grade at the Institute with some bolstering in English, physics, and mathematics. The students arrived on campus in August to take part in another program set up by Browne in which they put in six weeks of intensive work with Caltech faculty and student tutors.

Some other Browne programs:

1. A monthly Wednesday afternoon lecture series in Beckman Auditorium for junior and senior high school students. Kip Thorne, professor of theoretical physics, launched the series on October 7, talking about "When the Sun Stops Burning." George Hammond, chairman of the division of chemistry and chemical engineering, speaks on "The Fruitful Fantasies of Science" on November 4. Jerome Pine, professor of physics; Norman Davidson, professor of chemistry; and John Benton, professor of history, are scheduled for future talks. Students will be asked to write essays about the talks, and in June prizes will be awarded for the outstanding essays.

2. Caltech's annual Students' Day will be replaced by a series of 12 Saturday programs for groups of students and teachers from a few high schools at a time. They will be given personalized tours, talks, science demonstrations, and lunch on campus.

3. Lecture teams, usually consisting of Browne, a professor, and a graduate and an undergraduate student, will conduct demonstration lectures at high school science assemblies.

4. In a cooperative program with the Pasadena school system, Caltech students—usually graduate—at teachers' requests, will go to classrooms on a short-term basis to teach certain specifics of science, mathematics, and social science. Caltech graduate students are also available to tutor junior and senior high school students upon request by their teachers.

5. Older high school students—eleventh and twelfth graders—who want to undertake independent study programs can talk about it with Browne, who will then try to arrange for them to work in laboratories on campus. At present six such students are in this program—three in chemistry, two with Jerome Vinograd in chemistry and biology, and one in information science.

6. Topping it all off—so far—is an art program in which high school students will be invited to join Caltech's evening art classes.

Faculty and Administrative Changes 1970-71

ADMINISTRATION

ROBERT F. CHRISTY—*vice president and provost*
ROBERT B. LEIGHTON—*chairman of the division of physics, mathematics and astronomy*
W. A. J. LUXEMBURG—*executive officer for mathematics*
JON MATHEWS—*executive officer for physics*

PROMOTIONS

To Professor:
JOHN F. BENTON—*history*
PETER FAY—*history*
RALPH W. KAVANAGH—*physics*
GERRY NEUGEBAUER—*physics*
JOHN H. RICHARDS—*organic chemistry*
KIP S. THORNE—*theoretical physics*
ROCHUS E. VOGT—*physics*
WILLIAM B. WOOD—*biology*

To Associate Professor:
DAVID W. BOYD—*mathematics*
JOHN H. SEINFELD—*chemical engineering*

To Senior Research Fellow:
CHARLES B. CHIU—*theoretical physics*
EVA FIFKOVA—*biology*
EVELYN M. LEE-TENG—*biology*
HARRIS A. NOTARYS—*physics*
CHANG-CHYI TSUEI—*materials science*
JOHANNES G. VANDERLEEDEN—*physics*

To Assistant Professor:
MICHAEL R. DOHAN—*economics*

NEW FACULTY MEMBERS

Assistant Professors:
STUART A. ENDE—*English,* from Cornell University
JOSEPH G. GORDON II—*chemistry,* from Massachusetts Institute of Technology
JAMES E. GUNN—*astronomy,* from the department of astrophysics and space science at Princeton University
DONALD V. HELMBERGER—*geophysics,* from Princeton University
L. GARY LEAL—*chemical engineering,* from the University of Cambridge
ERICSON J. LIST—*environmental engineering science,* from the University of Auckland, New Zealand
JEFFREY E. MANDULA—*theoretical physics,* from the Institute for Advanced Study in Princeton, New Jersey
RICHARD L. RUSSELL—*biology,* from the MRC Laboratory of Molecular Biology of the University Postgraduate School, Cambridge, England

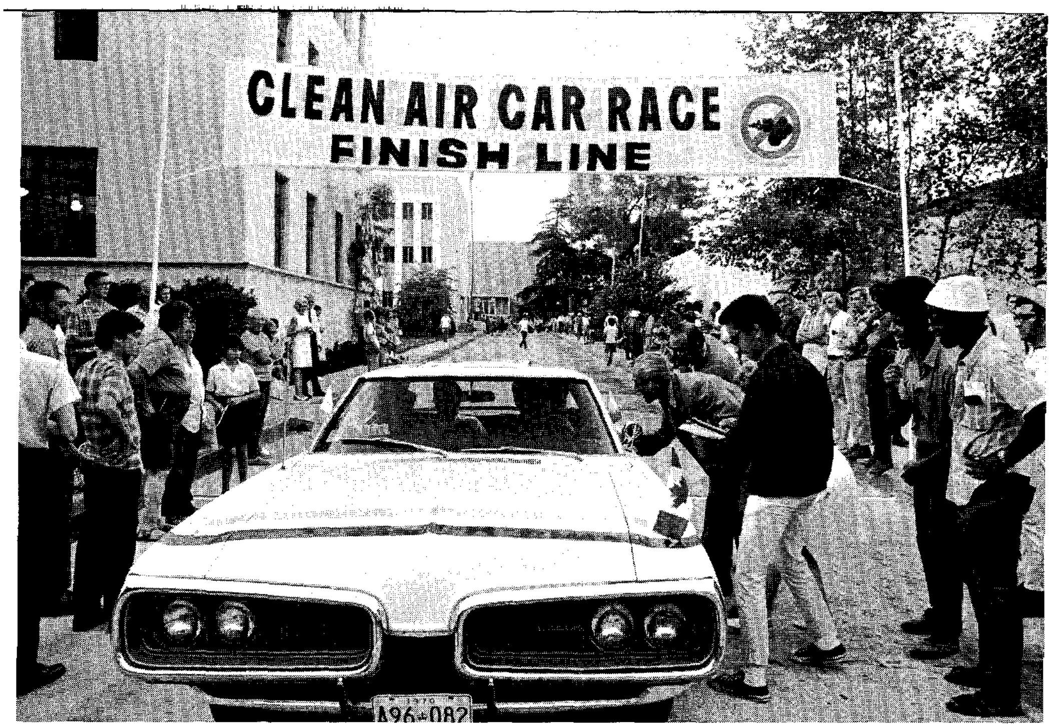
ON LEAVE OF ABSENCE

GUISEPPE ATTARDI—*professor of biology,* to carry out investigations in somatic cell genetics at Gif-Sur-Yvette, France
CHARLES BROKAW—*professor of biology,* to the department of zoology at the University of Cambridge
ROY W. GOULD—*professor of electrical engineering and physics,* to the research division of the United States Atomic Energy Commission in Washington, D.C.
JAMES W. GREENLEE—*assistant professor of French,* to do research at the Bibliothèque Nationale in Paris, France
MARSHALL HALL—*professor of mathematics,* to Yale University; Harvard University; Trinity, Cambridge; and the Mathematics Institute, Oxford
HAROLD LURIE—*professor of engineering science and associate dean of graduate studies,* to the Yankee Atomic Electric Company at Newton Center, Mass.
ROGER NOLL—*associate professor of economics,* to Brookings Institution in Washington, D.C.
ROBERT W. OLIVER—*associate professor of economics,* to the International Bank for Reconstruction and Development in Washington, D.C.
PHILIP G. SAFFMAN—*professor of economics,* to the Massachusetts Institute of Technology
FREDERICK ZACHARIASEN—*professor of theoretical physics,* to do research at CERN in Geneva, Switzerland
JOHN ZIEGEL—*assistant professor of English,* to do research and writing

RESIGNATIONS

ROBERT S. EDGAR—*professor of biology,* to the University of California at Santa Cruz
ROMILIO ESPEJO—*senior research fellow in biology*
EUGENE H. GREGORY—*assistant professor of physics,* to Hughes Aircraft
EBERHARD K. JOBST—*assistant professor of German,* to Germany
PETER LISSAMAN—*assistant professor of mathematics,* to Northrop Laboratories
DEREK W. MOORE—*senior research fellow in applied mathematics*
MARTIN SCHULTZ—*associate professor of mathematics,* to Yale University's computer science department
RICHARD T. SHIELD—*professor of applied mechanics,* to the University of Illinois
STEWART W. SMITH—*associate professor of geophysics,* to the University of Washington

THE
CLEAN AIR
CAR RACE
I



What Went On on the Road

by Mike Lineberry

The concept of a cross-country race to emphasize the possibilities of low-polluting automobiles began rather humbly last October with a phone call from Dr. Richard Thornton at MIT to Dr. Jerome Shapiro at Caltech. The next thing we knew, we had to set up a joint Caltech-MIT committee to handle the growing organizational work—and we had 44 entries from schools all across the country.

The Caltech group started out in October with about 20 interested students and faculty. We first had to agree on a propulsion scheme. (The development time—together with our goal of an economical, safe, and currently available system—made the only consistent choice of power plant an internal combustion engine.) We had then to select the fuel, but that decision was delayed for several months. I guess the excitement of possibly building a fantastic steam or hybrid-electric car was all that held some in the group, for soon we had only three or four active people.

Four months passed, and very little was accomplished. In February we finally got permission to ask for funds from trustees and friends of the Institute. Until then we had the feeling that our only friends were Jim Black and the Alumni Association, who had backed us financially and spiritually when it was most needed.

In March things began moving. Many contributions from trustees were received, and offers of technical support and equipment came in. Interest picked up quickly, and the ranks swelled again to something over a dozen people.

In April we decided to use compressed natural gas as the fuel for our race vehicles. Then began a pleasant and fruitful association with Pacific Lighting Corporation (parent company of the gas companies). Eventually they supplied us with refueling facilities, conversion kits, cash, and a second race vehicle.

During the summer months things went smoothly. A test engine facility was established for component and system tests. The race vehicles (a 1970 American Motors Hornet and a 1970 Ford Ranchero) were modified and refueling trucks were obtained. We refueled from storage bottles on board these 20,000-lb.-capacity trucks. Also, each truck was equipped with a compressor to repressurize the banks of bottles.

The race team consisted of undergraduates Jim Henry, Greg Kandel, Alan Coltri, and Joe Lyvers; graduates Dave Viano and myself; Mahlon Easterling, visiting professor of applied science; Laura Easterling, a freshman at Stanford; and Duane Higa, Ken Abernathy, and Jim Hiers of Pacific Lighting.

We departed for Boston on August 5 on a planned ten-day public relations-practice run. Our two race vehicles, two refueling trucks, and 24-foot mobile home (for rest and recreation) must have been a sobering sight to some sleepy early morning commuters.

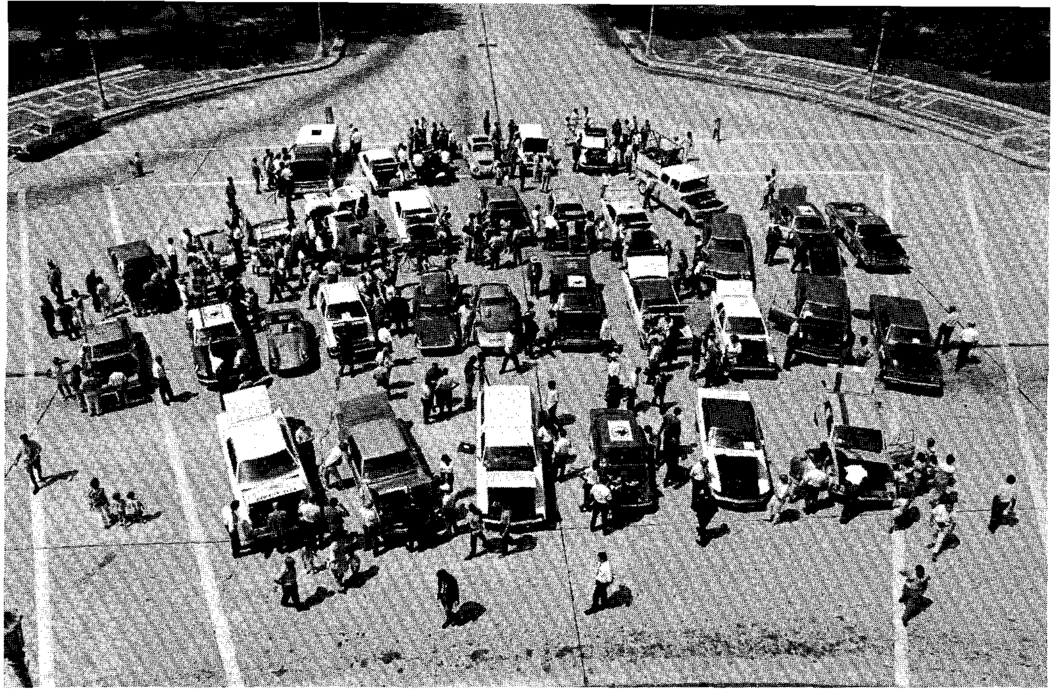
Our first day took us 541 miles to Tucson, Arizona. In order to check out the whole team, we changed assignments about every 100 miles. Everyone performed well, especially on the citizen band radio units. I think all of us rather quickly became enamored of our own voices.

The excitement and gaiety that surrounded our departure that morning had, by late afternoon, evolved into fatigue and restlessness. That quickly subsided when we reached the motel in Tucson and the team took over the pool. Later that evening Dave, Jim, and Greg flew back to Caltech to continue work. I flew on for a two-day public relations tour in the Midwest, and the rest of the team prepared for the next day's journey to El Paso. We would all meet again in Boston on August 16.

The next two days were most gratifying to me. Together with public relations men from Pacific Lighting, I visited Dallas and Tulsa. The tremendous coverage of radio, television, and newspapers pointed out the great interest that exists in the Midwest in air pollution abatement. It puzzled us how people in the area with the least pollution problem could show the greatest concern. This was demonstrated again when we were westbound during the race.

The race team proceeded steadily across country. On the next to last day on the road, the team spent five hours getting the refueling trucks into Canada. The Canadians gave the team some interesting alternatives—like paying a duty of one-third the cargo and vehicle value to import the whole works. That would have been a cool $20,000 or so. They finally let the team buy Ontario license plates and enter Canada.

On Sunday, August 16, the four of us



Clean Air cars cluster in Pasadena's City Hall plaza.

who were back at Caltech flew to Boston to meet the rest of the team, which had arrived two days before. We carried a small catalytic reactor that we had tested only two days before. This was to be installed on the Hornet to reduce carbon monoxide and hydrocarbons, and in testing it had done a good job. Catalytic oxidation of our unburned hydrocarbons, methane and ethane, is not an easy task, and this reactor was a special one loaned to us by Englehard Industries.

Coltri met us at the airport, and we went directly to MIT for the first meeting of entrants with the race committee. Forty-four teams were represented, and most came to this meeting feeling rather hostile about major rule changes that had been made. Not much was accomplished in the ensuing three hours, but it became apparent the committee was willing to consider various proposals for changes. That seemed to cool the tempers somewhat.

The race was to be scored by an emissions score, multiplying the sum of a race (or more correctly, a rally) score, a performance score, and a fuel economy score. The emissions factor would be determined by cold-start, seven-mode cycle emissions tests in Detroit, where carbon monoxides, hydrocarbons, and oxides of nitrogen concentrations would be measured, and then multiplied by a measured exhaust volume. The result is contaminants in grams per mile. Emissions tests in Boston and Pasadena would also be done, but no exhaust volume could be measured at either of those places, so the conversion to contaminants per mile is a shaky one based on vehicle weight. The intent was to let the Boston and Pasadena tests indicate any system degradation. Race score would depend on points gained on each leg of the seven-day return trip, with a possible maximum of 1,000. Performance tests, each carrying a 250-point maximum, consisted of acceleration, braking, noise level, and a slalom-course time event. Fuel economy was a 1,000-point test that checked thermal efficiency from Ann Arbor to Oklahoma City.

Our emissions tests were scheduled for Tuesday, August 18. We therefore spent most of Monday checking our vehicles and installing the reactor on the Hornet. We froze the systems late Monday night, and for the next 3,600 miles we didn't change engine settings.

On Tuesday morning we went to a Ford Motor Company mobile test facility for emissions tests. Both cars did nicely, with the Hornet doing superbly well in carbon monoxide (.1%) and hydrocarbons (10 ppm). Actually, the carbon monoxide was zero on their instruments ("Where's the goddamned CO?" bellowed the Ford technician.), the .1% reflecting the lower limit of sensitivity of the instruments. The low value of Hornet hydrocarbons pleasantly surprised us, and was either the new reactor doing a great job or the insensitivity of instruments designed to test the 400-600 ppm commonly found in gasoline-fueled power plants. It later turned out, ironically, that the low value of hydrocarbons cost us a victory in the race.

The next day we reported to Hanscomb Field for performance tests. Noise tests were first, and that took about two hours for the dozen or so cars there.

That night I flew to New York City. It was my first visit to Manhattan, and I was quite a conspicuous tourist. I spent a culturally stimulating evening attending *Oh! Calcutta!* and visiting a few discos. I felt great the next morning at five when I arrived at NBC studios for the "Today" show. Bob McGregor, race director, and Nancy Wood, a Worcester Polytechnic Institute entrant, were there too. The interview came off acceptably, and we then spent the day in Manhattan trying to see everything (a monstrous mistake) and returned to Boston that night. (My feelings about New York City summed up? I hated it.)

On Friday, Joe, Dave, and I went north along the coastline to Cape Ann. It was picture-book New England at its best. We returned to Cambridge refreshed and relaxed, and again traveled to Hanscomb Field for acceleration and braking tests. We didn't do very well in these, but we didn't expect to. We had tuned our vehicles for minimum emissions rather than maximum performance. In braking, the scale was so high that an anchor and plow would have been required for maximum score.

Friday evening provided us a lot of excitement—our motel burned down. It was a hell of a fire. Many people in the motel took the opportunity to bail out without paying their bills, and for a while pedestrians were in fear of their lives from arriving fire engines and departing guests.

Saturday and Sunday were spent attending meetings and taking care of last minute details. We all were getting a little anxious for the race to begin. Sunday night a kickoff banquet provided us the opportunity to hear the governor of Massachusetts speak. That was a worthwhile thing because most of us concluded that Reagan wasn't so bad a governor after all.

Monday, August 24

At about 6 a.m. we left Cambridge bound for Toronto. It cost an arm and a leg in tolls crossing Massachusetts and

New York. We spent a few minutes of "break-time" in Niagara Falls and were pleased to find no delays in crossing into Canada this time. However, ecstasy turned to horror when I then got one of the fueling trucks lost in Niagara Falls, Canada. The racing vehicles went ahead and finished the leg with me somewhat behind.

Tuesday, August 25

A short drive to Detroit for cold-start emissions tests. Most of us got about three and one-half hours sleep the previous night, and we were not in very good shape.

We arrived in Detroit about noon after a scenic drive through Canada. The race vehicles were taken to Ethyl Corporation for tests. After a seven-hour wait, during which Joe and I sacked out on the grass, our vehicles were tested. The Hornet did quite well; in fact, we found out several days later it was the cleanest car in the race. The Ranchero did fairly well, with hydrocarbon emission higher than we expected. We returned to Ann Arbor and impounded the vehicles for the night.

Wednesday, August 26

Left Ann Arbor at about 7 a.m. for Champaign, Illinois. Some minor mechanical problems with the mobile home became an everyday occurrence. Today it was a fan belt that failed.

Thursday, August 27

The longest day of the race—680 miles. We left Champaign for Oklahoma City at 4:50 a.m. The mobile home trouble of the day was the thermostat.

Late in the day a crack appeared in the flexible exhaust pipe used to install the Hornet catalytic reactor. The noise level picked up considerably. We decided to drive it that way the following day and fix it the next night in Odessa, Texas.

We dined on buffalo steak at the impound barbecue—a rather handsome meal.

Friday, August 28

The team, led by the Hornet sounding like a Sherman tank, proceeded to Odessa, Texas. After another barbecue (which the team was beginning to abhor), we spent about an hour fixing the Hornet tailpipe and replacing a defective check valve.

The mobile home defect today was bad points, replaced at night.

Saturday, August 29

This leg was frightfully uneventful, and the scenery didn't do much to remove the boredom. We learned that the Hornet was the unofficial leader in our class, and that picked up our spirits considerably.

Another barbecue in Tucson.

Sunday, August 30

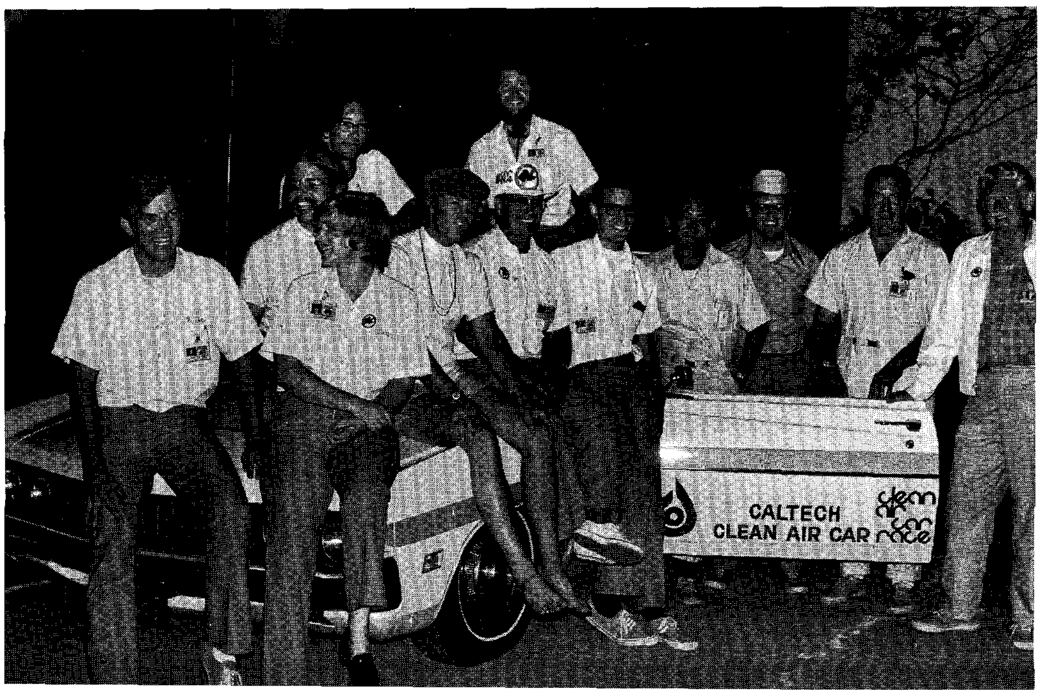
It became apparent on this last day that many teams wanted to be first to Pasadena. We did not feel obliged to participate in this foolishness, and proceeded as we had the previous six days. Our refueling trucks had some minor problems in the hills out of San Diego, and one had to switch to natural gas to avoid vapor lock.

The reception we received at Caltech was the most memorable event of the race. None of us had anticipated the enthusiasm or the crowd. We were all extremely gratified. We had traveled 7,200 miles without major trouble, and we had the distinction of owning the cleanest car in the race in Detroit. It was good to be home.

The next day the final emissions tests were conducted. We found that our hydrocarbon emissions had increased to 50 ppm for the Hornet, while the oxides of nitrogen had dropped to about half the Boston level. The emission-scoring formula was such that we went from the top of the heap to the bottom. We tried in vain to argue the injustice of the rating system but it was, in all honesty, too late. It was our conviction that one of the cleanest cars in the race was ranked below those that emitted two or three times the contaminants we did.

The selection of Wayne State as overall winner of the race was also something of a disappointment. They had run on unleaded gasoline (and failed to meet the 1975 federal emission standards). Suffice it to say that the circumstances surrounding the selection of the winner seemed to negate a portion of our effort—which was to make people aware of alternate schemes.

Now the 1970 Clean Air Car Race is history. We assume there will be future events of this kind periodically. The momentum generated in involving students in working toward solutions to the automobile emissions problem should be sustained. At the Institute there will be an active group of us going on in automotive emissions research and development. We hope this first step, while not large, has been a significant one.



Caltech's Clean Air Car Race team at the end of the run.

THE
CLEAN AIR
CAR RACE
II

What Went On Under the Hood

by James Henry

When MIT challenged Caltech to an "Urban Car Competition" in October 1969, they had a nearly completed hybrid-electric vehicle, and we had nothing. This seemed a fair challenge to Caltech students and so, in a hastily called meeting, the challenge was accepted. The next order of business was to decide what kind of car we should enter. This was quickly taken care of. It would be a clean car, cleaner than the 1975 emission control standards. It would also be reliable, cheap, and simple. It had to be. We didn't have the time, background, or money to complete anything else. At this point the group had the wisdom to adjourn and go to the library to find out just what the wonderful vehicle we had described and, while we were at it, what the standards were.

A week later Mike Lineberry and I came back with the answer. Keep the internal combustion engine, convert it to use a gaseous fuel, and begin modifying as necessary. And that was what we did.

For the next five months we spent our time investigating the equipment we would need to convert and modify our car. Another group simultaneously investigated how we would pay for our car and its modifications. Finally, in May, we gathered in the Old Steam Plant around a new American Motors Hornet loaned to us through the efforts of Orrin Fox, American's Pasadena dealer. We were armed with the conversion equipment given to us by Dual Fuel Systems, a subsidiary of the gas company in Los Angeles, and tools paid for by trustees, alumni, and many other friends of the Institute.

Three months later the Hornet and a Ford Ranchero loaned by the Pacific Lighting Company crossed the finish line of the 1970 Clean Air Car Race, having fulfilled the criteria we had set. So what went on under the hood?

The principal modification was the addition of equipment to allow the engine to operate on natural gas. For the Ranchero this was the only modification. The Hornet was also equipped with a catalytic reactor to further reduce hydrocarbons and carbon monoxide. With these simple changes both cars were able to meet the 1975 emissions standards easily. In the tests in Boston, both were able to better the 1980 standards.

In the Detroit emissions tests, which were far more comprehensive than those now used for the certification of vehicles, the race cars were tested after 1,000 miles of hard driving. Only seven cars were able to meet the 1975 standards in those tests. Two were using natural gas, four were using a similar system with propane, and one was using methanol. Of the seven, the Hornet was the cleanest, falling short of the 1980 standards by a mere seven hundredths of a gram per mile of oxides of nitrogen.

The cleanliness of gaseous fuel systems demonstrated in Detroit is an inherent feature of this type of operation. A vehicle with such a system needs no "smog device" other than the positive crankcase ventilation valve. The system is a proven one, having long been used in stationary engines, fork lifts, and on cars in areas where the gasoline supply is limited. Only recently has attention been focused on this type of operation for the reduction of emissions.

The system consists of a tank appropriate to the fuel used, a regulator unit which controls fuel pressure, and a gas-air mixer which serves the same function as a carburetor in a gasoline system. In our conversion we used equipment distributed by Dual Fuel

Systems. The fuel is compressed natural gas, and it is stored in conventional transportation bottles. Because of the high pressures used to store the fuel, the regulator is a two-stage unit. The high-pressure regulator is the type used in welding outfits. The low-pressure unit is a household-type natural gas regulator. The gas-air mixer replaces the air cleaner. Because the gasoline carburetor can be left intact, a pull knob is provided on the dashboard which allows the selection of either natural gas or gasoline as the fuel. In this way, if a supply of natural gas is not convenient, operation can continue on gasoline. Operation of the vehicle is unchanged on natural gas. A slight loss of power results, principally from the re-tuning to minimize emissions, but the car is quite drivable and acceptable in all respects.

Because the difficulties of vaporization and mixing of the fuel are eliminated, a much better control of the combustion process is attained. On natural gas operation the choke, fast idle, and manifold heat riser become unnecessary. To reduce emissions the system is adjusted to provide a lean mixture, normally 25 percent more air than is required for a chemically correct mixture, something which is impossible with gasoline. This ensures sufficient air to burn all the hydrocarbons and oxidize the carbon monoxide to carbon dioxide. Peak combustion temperatures are also reduced, inhibiting the formation of oxides of nitrogen. As an additional benefit, natural gas is about 90 percent methane. Methane has been shown to be nontoxic and unreactive as a smog-forming hydrocarbon. This means that emissions on natural gas are less harmful as well as being lower.

Benefits from natural gas operation do not end with clean air. They also include a clean engine, which therefore needs less maintenance and repair. At 5,000 miles our spark plugs had no deposits at all. At 8,500 miles we are still using the oil which was installed at the factory, and it is still clear.

A less obvious but equally dramatic benefit is improved safety. The necessary strength of the tankage reduces the likelihood of a tank rupturing in an accident to near zero. If the fuel is somehow lost, the buoyancy of natural gas, the range of inflammability, and the higher ignition temperature make the fire hazard far less than that with gasoline. Probably the best case for the safety of natural gas is that it is used to operate Disneyland's fleet of passenger-carrying vehicles—including cars, trams, and even boats. Here the conversion was done for reasons of safety and the reduced insurance rates which resulted.

The most important feature of the system is its practicality. Many firms that operate fleets of vehicles are converting them to use natural gas as fuel. The average cost of conversion is $350 and it takes about four hours. The cost can be recovered in reduced fuel and maintenance costs. Conversion equipment is the same for all vehicles and is now being commercially produced and sold. The conversion is so versatile that it has even been applied to diesel engines.

The only missing element is the resolve to forge ahead with the change. The members of the Caltech Clean Air Racing Team are now in the process of converting their personal vehicles to natural gas.

What are you doing?

The author in action—testing the theory that if it doesn't work, get a bigger hammer.

Research Notes

Optical Switches

The use of optical signals in communications systems and in computer design has aroused considerable interest among engineers because optical systems, in theory, are faster than electric ones, they can handle more information through their multiplexing capabilities, and they minimize unwanted feedback. The major restrictions to the use of optical signals, however, have been the large amount of electrical power required to modulate them and the lack of efficient guiding systems.

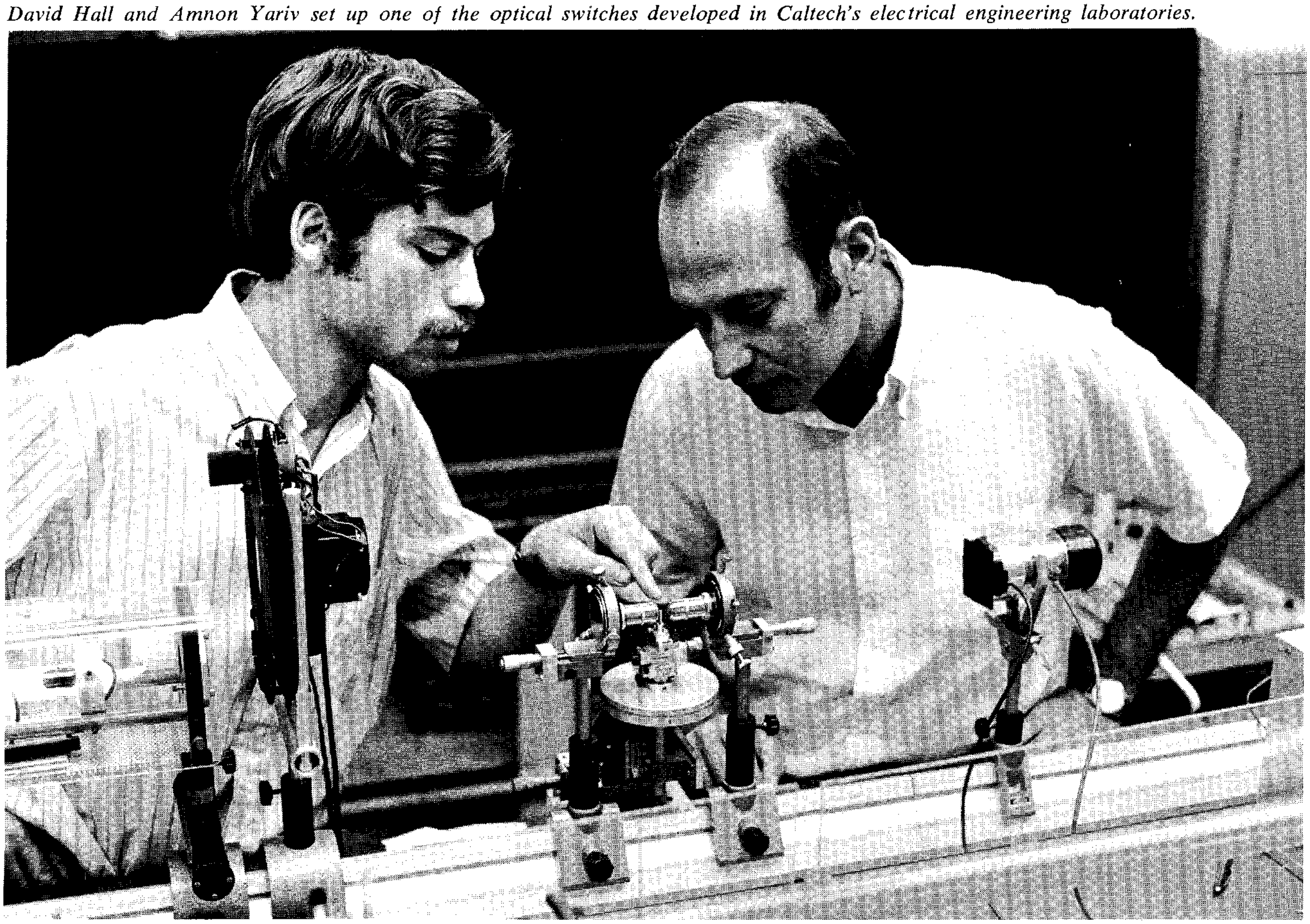
Amnon Yariv, Caltech professor of electrical engineering, has now developed unique crystal modulators that permit compact integrated circuits and reduce by more than a thousandfold the electric power requirements.

His crystal devices, only a few thousandths of an inch across, modulate and switch laser light on and off at speeds up to a billion times a second, much as transistors do for electric current. They operate in miniature integrated optical circuits that carry light instead of electricity in thin crystal films acting as wave guides. Working with Elsa Garmire, research fellow in applied science, and graduate student David Hall, Yariv has spent three years developing these optical switches.

The switches are based on electrodes attached to wave guides. The wave guide—which plays a role similar to that of a wire in an electrical circuit—consists of a crystal on which a very thin layer of another crystal (a few thousandths of an inch thick) has been grown, using heat and evaporation. The very thin layer will guide light, provided it has a greater ability to refract light than the substrate crystal layer.

Light from a laser is fed into this wave guide, which can carry light around corners and for considerable distances

David Hall and Amnon Yariv set up one of the optical switches developed in Caltech's electrical engineering laboratories.



with little loss of intensity. A thin coat of metal is evaporated onto the top and bottom of the composite crystal so that voltage may be applied to the crystal at one or more locations where switches are desired. Wires are attached to both spots of metal. Operation of the switch depends on the semiconducting properties of the thin film and the electro-optical effect.

The electric field causes minute changes in the crystal's atomic arrangement which, in turn, induces a slight change in the refractive index—that is, the velocity of light. This electrical control of the index of refraction can be used in several ways for modulating the light flowing through the wave guide.

Some of the applications envisaged for the new optical circuit element include: putting many channels of information on optical carriers to transmit information; developing compact optical circuits for information processing; and developing electrically controlled optical scanners and lenses for maneuvering the direction and amount of spread of optical beams.

The work of the research team is supported by the Office of Naval Research and the Advanced Research Projects Agency. The unique crystals used in the research were grown by the United Aircraft Research Laboratories.

Dancing Honeybees

Honeybees communicate with each other through their dancing. This conclusion by three young biologists may end a long-standing scientific argument over how bees direct other bees to sources of nectar and pollen.

Jim Gould and Mike Henerey, both 1970 graduates of Caltech, and Mike MacLeod, a 1969 Caltech graduate now attending the University of Oregon, conducted this research in the summer of 1969. The results were reported in the August 7, 1970, issue of *Science*.

The three students set up a series of carefully controlled experiments to test the validity of two opposing theories on the language of bees. One theory was developed in the 1940's by an Austrian zoologist, Karl von Frisch. Noting that bees danced after returning to their hives, he found a correlation between the directions of the dance and the food source, and between the tempo of the dance and the distance of the source. He concluded that the dance was used to tell other bees the direction and the distance of the food source.

The opposing theory, originally formulated by Von Frisch in 1920, was given new impetus in 1967 when Adrian M. Wenner and Dennis L. Johnson of the University of California at Santa Barbara repeated Von Frisch's work with some modifications and concluded that, under their conditions, the behavior which Von Frisch attributed to communication by dancing could be explained on the basis of the sense of smell alone. The hive bees, in other words, could have smelled the odor of the food source on the bee that had found it, and, after leaving the hive, they could look for the same odor outdoors.

The three students became interested in this controversy after it was discussed in a Caltech behavioral biology class by Seymour Benzer, professor of biology. He said that it was time for an objective third party to examine the question.

Neither hypothesis, the students agreed from the beginning, need exclude the other, and both might apply in different circumstances.

"Since there is general agreement that the dances do contain both distance and direction information, the real question is whether this symbolic information can be communicated to other bees."

Upon returning to the hive, a forager bee who has found food often performs a dance. He runs a short distance in the direction of the food, waggling his abdomen. He then runs in a semicircle back to the starting point and duplicates the maneuver, which may be repeated as many as 200 times. The dance excites the other bees to leave the hive in search of the food source.

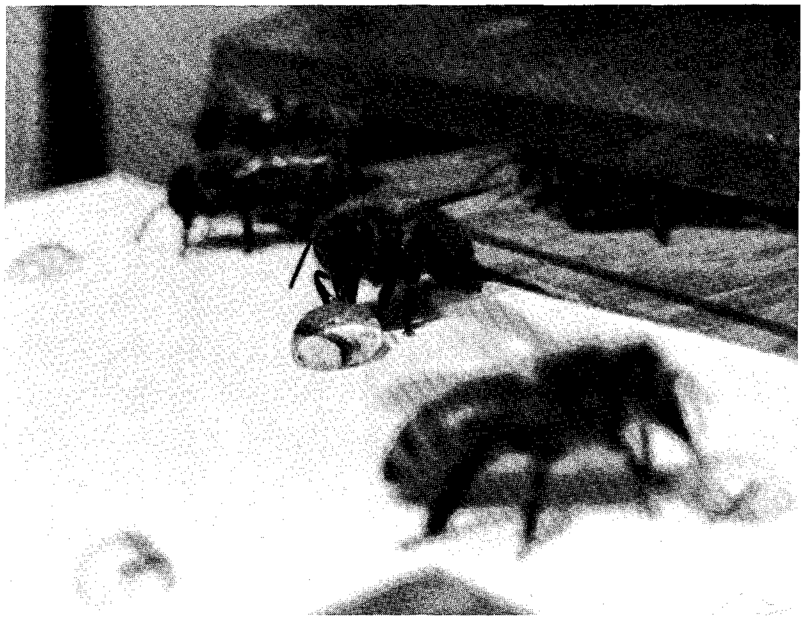
Gould, Henerey, and MacLeod decided to test the theory that the bees communicate with their dancing. They traveled to eastern Oregon where they found a flat, desert-like area 20 miles east of the town of Burns that was not near the orchards, lakes, cities, trees, or other topographical features, frequently found in earlier research, that might distract the bees.

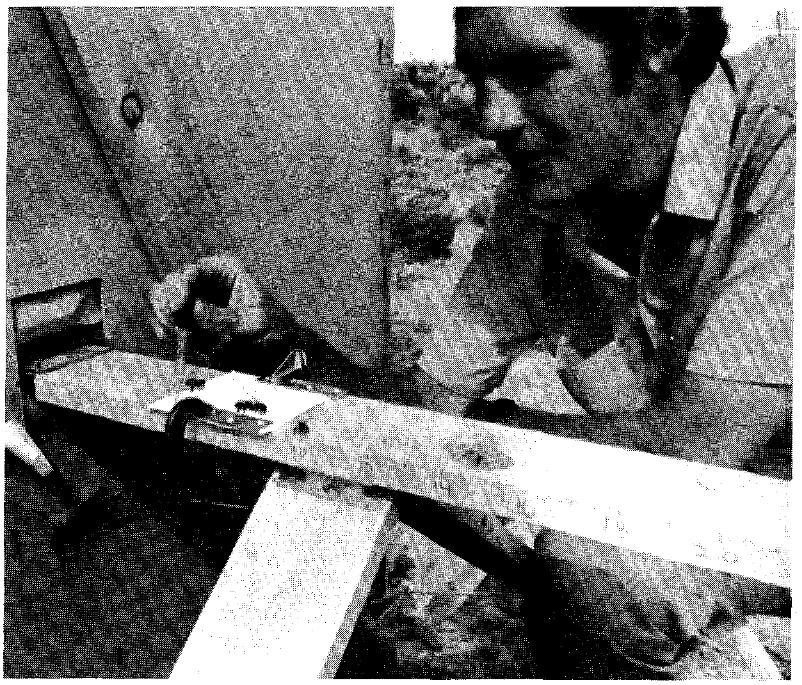
After establishing a camp, the team set out a glass-covered hive which they had designed and built so they could see the dancing inside. Four hundred feet from the hive they built four feeding stations, each at a different point on the compass in relation to the hive. Each station contained, at times, a sucrose sollution palatable to the bees.

The researchers tagged about 4,500 members of the colony for identification by gluing small tags of different colors and numbers on the bees' backs. This involved cooling each bee to immobility, to reduce the risk of stings.

Some bees were then selected as "foragers." After

The first step in training a honeybee to fly to a feeding station is to introduce him to a sucrose solution placed near the hive entrance. Jim Gould (below) helped develop the technique.





training, each forager flew only to "his" particular feeding station. Training proceeded by first placing sucrose at the hive entrance, and then moving it farther and farther away, coaxing the bees at last to the feeding station. The forager's task was to load up on sucrose at his feeding station, then return to the hive and dance, thus informing the bees in the hive of the availabilty of food, stimulating them to venture out in search of it.

Unlike previous research relating to the controversy, great care was taken in the experiments to eliminate differences in odors and visual cues which might prejudice the results.

In one series of experiments with recruits captured within four minutes after attending the dance of a forager bee, 90 percent of the bees arrived at the feeding station indicated by the forager's dance. However, of the recruits caught 12 or more minutes after a dance, ony 50 percent arrived at the station indicated by the dance, as would be expected by random chance. The researchers lay some of the blame to forgetfulness.

In a second series of experiments, foragers regularly visited two stations located in opposite directions. By offering only dilute sugar water at one and very sweet sugar water at the other, only the foragers that visited the latter station performed a dance; the ones that got the weak solution did not. Thus, potential recruit bees attending the dances received scent information valid for either station, but directional information for only one. If only odor cues were used, one would expect the stations to attract equal numbers of recruits. If, on the other hand, direction information from the dance were utilized, one would expect more recruits to go to the station indicated by the dance. In fact, 96 percent of the recruits were captured at the station indicated by the dancing of returning foragers.

The results therefore confirm the idea that the information in the dance is communicated from forager to recruit and is subsequently used by the recruit.

Carefully pointing out that their experiments do not exclude the possibility that, under certain circumstances, odor cues alone might suffice, the Caltech team noted that bees use light, gravity, odor, and an internal clock system in the food-gathering behavior. These experiments lend credence to the notion that, in addition, the honeybee is able to communicate precise abstract information through its dances.

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Radio Astronomy—Marking Time

Radio astronomy is a rapidly developing field, and major new radio telescopes are being completed in Europe and in other parts of the world—but not in the United States. American radio astronomers have proposed construction of a number of new instruments, and several of these have been approved by review committees of the National Academy of Sciences and the National Science Foundation—but none of them has been funded.

At the dedication of the Westerbork Synthesis Radio Telescope at Groningen, Netherlands, last spring, 11 astronomers and physicists took the occasion to compose a letter pointing out that the United States is falling behind in radio astronomy and urging that "construction of some of the proposed instruments be commenced." Three signers of the letter (published in the June 19 issue of *Science*) are from Caltech: William A. Fowler, professor of physics; Alan T. Moffet, associate professor of radio astronomy; and Maarten Schmidt, professor of astronomy.

Until several large instruments were built in the late 1950's and early 1960's, radio astronomy was virtually nonexistent in the United States. With those instruments this country was able to move rapidly to the forefront. However, the scientists say: "Our instruments of the 1950's cannot compete with the new ones now coming into use in other countries."

West Germany is completing the world's largest fully steerable dish antenna this year—328 feet in diameter. Italy and Australia have large new radio astronomy instruments. A major new instrument is being built in Cambridge, England.

Recognizing the problem for American radio astronomers, Caltech's Jet Propulsion Laboratory has made some of the equipment in its Deep Space Network available for ground-based radio astronomy experiments. About 5 percent of the time on the 210-foot antenna at Goldstone, California, will be allotted to qualified radio scientists. Eventually, some time may be available at other DSN facilities. Proposals for use of this equipment will be evaluated by a six-man committee from the major radio astronomy centers in the U.S. The panel is headed by Jesse Greenstein, Caltech professor of astrophysics.

Caltech's Owens Valley Radio Observatory has two 90-foot dish antennas, which have been in operation since 1958. A 130-foot dish, added in 1968, was the first of a proposed network of eight units.

Photography by W. Eugene Smith.

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