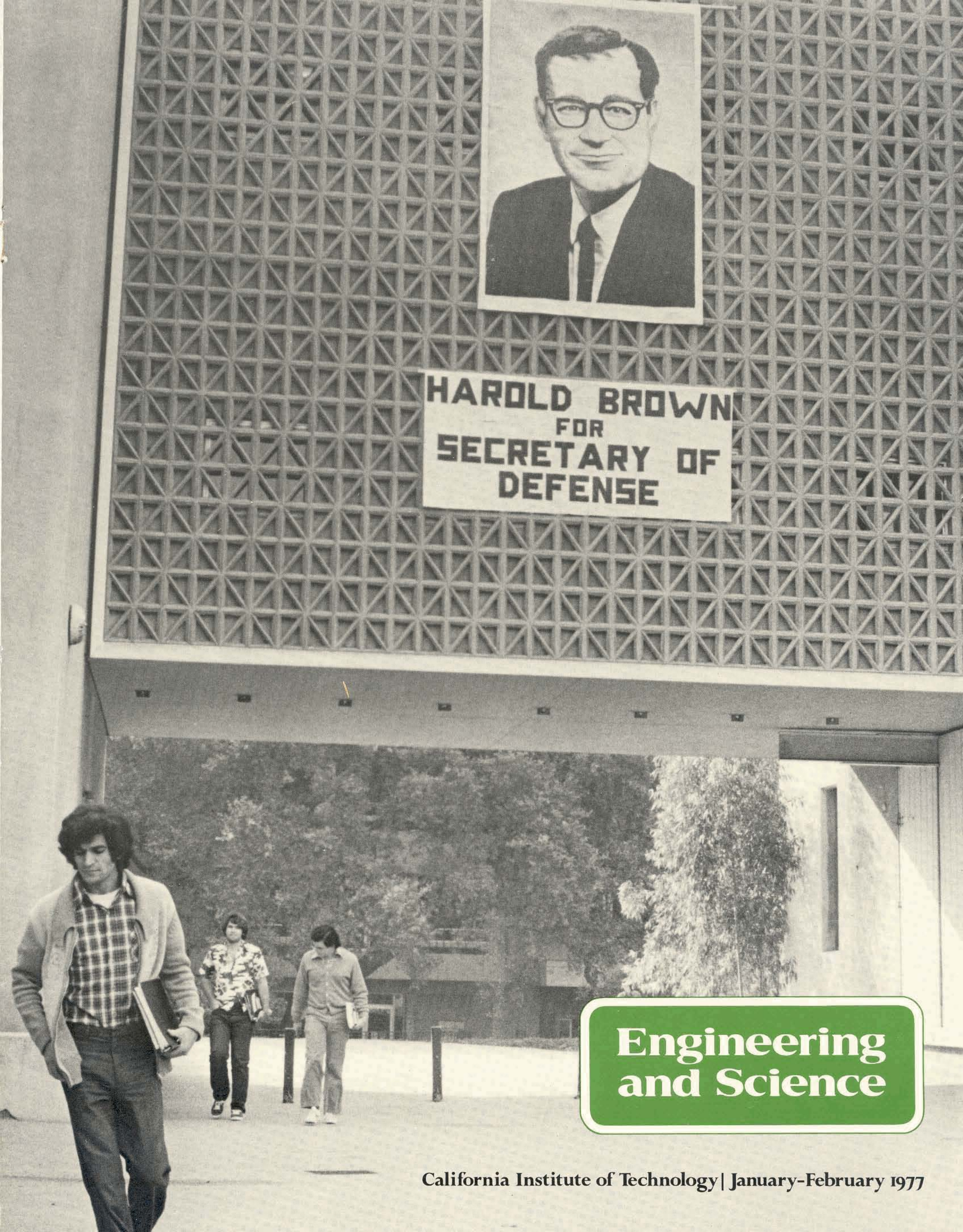

Engineering and Science

California Institute of Technology | January-February 1977

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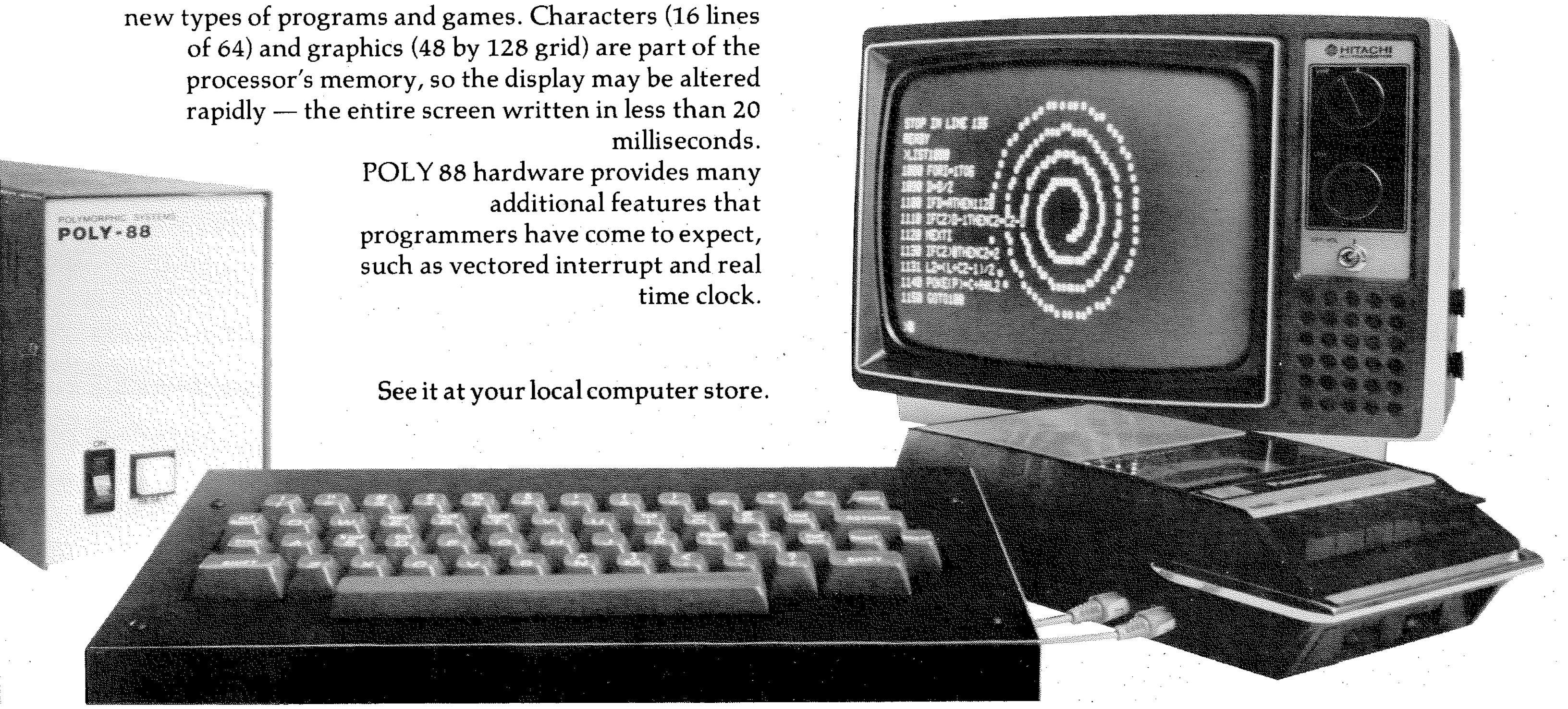


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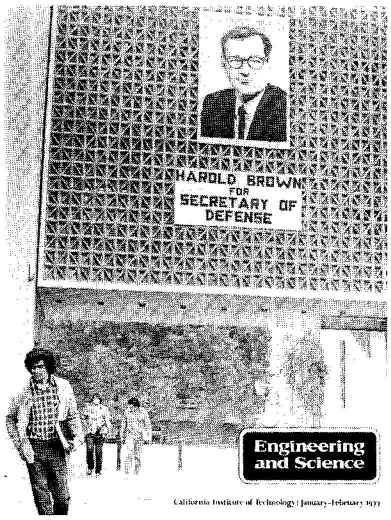

The President Becomes a Secretary
President-elect Jimmy Carter officially announced his selection of Harold Brown as Secretary of Defense on December 21 — just two weeks after the *un*official announcement of the same news was made by the Caltech undergraduates. The student prediction came in the form of an 8-x-10-foot airbrushed poster (involving something like 30 hours of steady work), which appeared overnight on the grillwork facade of the passageway between Firestone and Guggenheim laboratories. We feature it on our cover not only to share the news of our president's imminent departure, but also to point up — once again — the remarkable prescience of our student body.

Inside Story
A humanist who is both amusing and informative about the role of the humanities in the life of 20th-century man is rare indeed. Fortunately, Caltech has such an example of temperance, wisdom, and good humor in the person of W. T. Jones, professor of philosophy. Also fortunately, in "What's the Use of the Humanities? A Primer for the Perplexed" on page 4, *E&S* is able to present a thought-provoking sample of the perceptive professor at work.

Will Jones has been at Caltech only since 1970, when he began a two-year stint as a visiting professor. He was appointed Andrew W. Mellon Professor for the year 1972-73, and then became professor. Before coming to the Institute he had been on the faculty of Pomona College since 1938, taking time out only for service in World War II. And again and again during those years, his grateful students voted him their favorite professor. While he no longer teaches at Pomona, the school hasn't let him go entirely. In 1972 the Board of Trustees elected him to membership.

Prophetic Biologist
"In the Footprints of Future Man" on page 9 is adapted from a Watson Lecture given on October 6 by James Bonner, professor of biology. On the occasion of that talk Bonner was introduced by his long-time friend and colleague in biology Norman Horowitz, who said in part:

"I won't even attempt to enumerate all James Bonner's achievements, but one statistic sticks in my mind — that he has published over 400 scientific papers plus several books.

"The subjects of his work group themselves into three major themes. The first, which occupied his graduate years and from then until about 15 years ago, centers on plant biochemistry and physiology. The second and more recent theme is concerned with the chemistry and organization of chromosomes, not only those of plants but also of animals. And the third theme, which is interwoven among the first two and nourished by them, has to do with his long-term interest in population problems and the world's resources.

"The subject to be discussed here is from this third general area, and his approach is characteristically bold and unconventional. He long ago discovered the importance of keeping the public informed on vital scientific issues as they impinge on man's existence, and his talents in this arena qualify him as one of our foremost seers and prophets."

Grist from Gray
The high visibility on Caltech's campus of Harry Gray, William R. Kenan, Jr. Professor and professor of chemistry, is due to several factors. One is the excellent rapport he establishes with all segments of the Institute community. Another is the respect he has earned for significant work in chemical research. Both made it a pleasure to work with him to adapt his Watson Lecture of May 24 to article format. "Chemistry in Action" on page 16 is an example of one area of chemistry explained with precision and simplicity — plus, of course, a touch of Gray's well-known sense of humor.

For another example of *that,* take a look at the photographs in "The Big Copper Caper" on pages 22 and 23.

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What's the Use of the Humanities?

A Primer for the Perplexed

by W. T. JONES

Q. First of all, what are the humanities?
A. At Caltech the humanities are quite substantial bits of literature and history, and much smaller bits of philosophy and anthropology.

Q. Why do you say "at Caltech"?
A. Because the humanities mean different things at different institutions. At Oxford the humanities are the classics and nothing but the classics. Others are less restrictive. According to the American Council of Learned Societies, for instance, the humanities are "philosophy (including philosophy of law and philosophy of science), aesthetics, philology, languages, literature, and linguistics, archaeology, art history, musicology, history (including history of science, history of law, and history of religions), cultural anthropology, and folklore."

Q. Well, that's certainly inclusive enough. But do all the people in all those disciplines agree? Isn't the ACLS making imperialistic claims for the humanities that philologists, linguists, and archaeologists would reject?
A. Yes; many of them do regard themselves as scientists, not humanists. And so do some anthropologists, some philosophers, and some historians — quantitative historians, for instance, and cliometricians. For such people, "humanist" is less a description than a term of abuse.

Q. Why are the humanities in such bad odor?
A. Humanists are suffering from an identity crisis — they no longer know who they are or why they are. When people ask them what the humanities are *good* for, they feel threatened and react defensively, laying claims to special sensibilities, special insights, from which scientists and other lesser breeds are excluded. This deceives nobody, probably not even the humanists themselves.

Q. Was it ever thus?
A. On the contrary. In the 15th century the humanities, so far from being defensive, were progressive and radical, even revolutionary.

Q. The 15th century was quite a long time ago.
A. How right you are.

Q. What was innovative about the humanities then?
A. The humanities offered an alternative to the medieval world view, one that substituted reason for revelation, classical authors like Cicero and Quintilian for scholastic authors like Aquinas and Duns Scotus, politics for theology, and more generally, a man-centered world view for a God-centered world view.

Q. What went wrong?
A. Two things went wrong. In the first place, the humanists did not differ as much from the scholastics as they thought they did. They still conceived the aim of inquiry to be the discovery of an eternal and unchanging essence — they were just interested in a different essence, not the essence of God, but the essence of man. And they still relied heavily on authority — they simply appealed to a different set of authorities.

Q. And in the second place?
A. In the second place, of course, the humanities were outflanked by what turned out to be a much more radical attack on the medieval world view.

Q. You mean Galilean and Newtonian physics?
A. Exactly. Of course, this didn't become clear all at once. For a while, it looked as if humanism and natural

science could divide the spoils — the humanists uncovering truths about man by their method and the physicists uncovering truths about nature by their method. But by the 19th century it was clear to everyone except possibly the humanists that if there are indeed any universal truths about human nature they were going to be discovered and formulated by the chemists and biologists, not by humanists.

Q. Yet after more than a century humanists and the humanities are still with us.
A. Yes. The humanities aren't merely a group of disciplines; they are also a collection of bureaucracies. You know how difficult it is to dislodge entrenched bureaucracies, especially in conservative organizations like colleges and universities. Besides, the humanities weren't very costly; they were luxuries that prosperous colleges and universities could afford. They came to be prized, curiously, just because they had been demonstrated to be useless.

Q. You sound rather like Thorstein Veblen.
A. Well, I think Veblen was right about conspicuous consumption. The humanities became, along with Newport "cottages," Pierce Arrows, and *Blue Boys*, a mark of wealth and affluence — things it was important to show one could afford to pay for, precisely because they *were* useless.

Q. Did the humanists lend themselves to this revised view of their social role?
A. I'm afraid many of them fell into it naturally. They became purveyors not of truth but of culture, "the best that has been thought and said." They offered themselves to the public as civilizers of rude but vigorous barbarians. They guaranteed to apply a veneer of culture to the prospective engineers, lawyers, and physicians who were emerging from the universities and who, everyone agreed, were the real makers and shakers of society. But they also guaranteed that the veneer would be thin — it would leave untouched the real technocrat below the surface.

Q. Now you sound like Nietzsche.
A. You mean that you think I'm harsh. I agree. But I don't believe I'm grossly unfair.

Q. You admit that the humanities are not the purveyors of truth that they once claimed to be; you scorn the humanities as the purveyors of culture that they now present themselves as being. What role, then, can you see for the humanities in the contemporary world?
A. I think that loosening paradigms is a very important social role, and that the humanities are peculiarly well fitted to loosen paradigms.

Q. I haven't the faintest idea what you mean by "loosening paradigms."
A. For me a paradigm is simply the world view that happens to be dominant in any society at any particular time. It includes the way of doing science at a particular time and also the particular set of beliefs about the world that are held to be "true" at that time, but it includes more than that — it is the whole perspective, learned at mother's knee and then refined and corrected at school and college, from which one looks at the world. It is a complex lens through which we view the world. This perspective is so pervasive that most of us, most of the time, see through the lens without noticing it. That is, most of us are, metaphysically speaking, naive realists: We assume that the world we see through the lens of our particular paradigm is "out there" just as we happen to see it. To loosen a paradigm is precisely to become aware of the lens, to become aware of the fact that the world we are seeing is merely the world as seen from a particular perspective.

Q. You obviously think there is something noble and virtuous about loosening paradigms. Why?
A. You are putting words in my mouth. I am only saying that naive realism, as I have defined it, is a dysfunctional metaphysical attitude, especially in periods of rapid change. Naive realism and cognitive innovation are mutually incompatible, because people who believe that their view of the world is not a view, but the world itself, find it easy to reject alternative views as "obviously" false. And so they are likely to regard the innovators themselves with deep suspicion, not only mistaken but also somehow immoral. When one looks back over the history of Western culture, one hardly knows whether to laugh or to weep. What we see is a sequence in which an innovation is first rejected with scorn and contempt, then grudgingly tolerated, then generally accepted. At this point the cycle begins again. The new paradigm now deals with innovations as it was once dealt with — it condemns them as errors, instead of welcoming them as alternatives. The psychological and sociological costs to all parties are high. What I am saying is only that paradigm looseness can reduce these costs a bit.

Q. Now you sound rather like Wittgenstein.
A. You mean what he says about wanting to help the fly escape from the fly bottle?

Q. Yes. Aren't you saying that we are, all of us, imprisoned in those fly bottles that he called "forms of life"?
A. Yes, but Wittgenstein equated a form of life with a language — "to imagine a language means to imagine a form of life," he said; and he believed that the linguistic therapy he practiced in *Philosophical Investigations* would free us from our fly bottles. For my part, I am less optimistic. The most seductive, the most dangerous, of all fly bottles is one which has a label, printed on the inside of the bottle, "I am not a fly bottle." Doubtless an exceptional fly now and then escapes from his fly bottle, but his period of free buzzing is likely to be short; sooner or later he lands in another bottle. As for the average, run-of-the-mill fly, the most that can be done is to help him come to some realization that he is stuck in a fly bottle, and the way to do this is to show him other flies in other fly bottles.

Q. What, if anything, has this to do with education?
A. I am saying that one of the great aims of education should be to help students to learn how to enjoy — *enjoy,* not merely tolerate — cognitive dissonance, cognitive ambiguity. The present educational system is very good at teaching students the particular tricks of their particular trade — those parts of the dominant paradigm of their time that they need to know in order to be successful engineers, lawyers, physicians, or philosophers. It tends, however, to leave them the naive realists they were when they entered as freshmen; indeed, the better a university is at teaching relevant portions of the dominant paradigm, the more likely it is actually to foster naive realism. We should certainly continue to teach the relevant parts of the dominant paradigm — obviously we want an educational system that produces highly competent engineers, lawyers, physicians, and even, I suppose, philosophers. But we should also encourage paradigm looseness. We want an educational system that does not allow its graduates to live within their various competences as in a castle, protected by moat and drawbridge, but one that encourages them to look outside, even on occasion to step outside and view their castle from without.

Q. I still don't see how you would design a system that would produce the attitudes you desire, nor what role you envisage for the humanities in it.
A. I think that the educational system should be based on the principle of the joke.

Q. The joke? Surely you're joking?
A. No; I'm serious. Or rather, I'm making a serious point, but choosing to make it by making a joke — granted, only a small one — about jokes.

Q. Please explain.
A. I recall a cartoon I saw in *The New Yorker* a few years ago, published during the hunting season. There is a drawing of a car speeding down a road in a forest, returning from a successful expedition. The hunter is lying prostrate across the hood of the car, and in the driver's seat is a debonair, slightly smirking deer, antlers and all.

Q. Ha, ha.
A. Thank you. If you were actually a bit amused, that is because you aren't a literal-minded person. If you were literal minded, you would not smile; you would say in a puzzled way, "But deer can't drive." (To be literal-minded about jokes is to be a very, very naive realist.) To be able to see the point of that joke you have to be able to shift, however momentarily, from your normal perspective to a different one. The shift is not just from the perspective of a human being to that of a deer; the deer, after all, is behaving exactly like a man. No; the shift is from the perspective of a hunter, whether man or deer, to that of the hunted, whether deer or man. Most of the time we — you and I — are comfortably and securely located in an upper-middle-class perspective, one in which we are either actual or potential hunters. What the cartoon does is to jolt us out of this familiar perspective and project us briefly into another. All jolts — this is the point of my joke about jokes — are liberating.

Q. Well, suppose I accept your analysis of jokes. What then?
A. In the case of this joke, the jolt is small, but small as it is, it is nonetheless liberating; that is why we smile. Bigger shifts in perspective cause bigger jolts; very big jolts may be experienced as alarming, not as amusing. What we want is an educational system that helps people learn how to cope with very big jolts — to experience them as exhilarating, instead of as threatening, that helps people to welcome jolts instead of encouraging them to retreat from them.

Q. I suppose that what I want from you at this point is an example of a very big joke, one that is relevant to the educational system.
A. Very well. Consider Galileo's report of his discoveries during January 1610, when, as he says, "I betook myself to observation of the heavenly bodies . . . On the 7th day of January the planet Jupiter presented itself

to my view." What he saw that night was this — two pinpoints of light just to the left of Jupiter and one to the right:

★ ★ O ★

On the 8th he saw this:

O ★★★

On the 10th (the 9th was cloudy and he could not observe) this:

★ ★ O

And on the 11th this:

★ ★ O

Anyone who interpreted his experience from the perspective of the medieval world view — and that was still the dominant perspective in 1610 — would have had quite a jolt when he saw those pinpoints of light move. For what he would have perceived, in terms of that perspective, were not pinpoints of light but fixed stars — fixed stars that moved. How could this be? We must suppose, therefore, that Galileo had a high tolerance for cognitive dissonance; indeed, that he even enjoyed it. When, on the second night, he saw that the pinpoints of light which shouldn't — indeed, couldn't — move, had nonetheless moved, he was not frightened; he was curious. He looked forward "with longing," he says, to his next opportunity to observe. How different was this reaction from that of those professors at the University of Padua who were naive realists. Imbedded as they were in their world view (which they of course did not regard as a mere world view), they knew that the pinpoints of light which couldn't move didn't move. Galileo's claim that fixed stars move was so threatening that they refused to look through his telescope.

Q. Yes; that was indeed a joke on a cosmological scale. The jolt was so great that it is still reverberating.
A. And literal-minded people are still not amused.

Q. If I understand you, you are maintaining that, though there is an enormous difference in scale, there is no difference in principle between seeing the point of a joke or a pun and shifting from a geocentric to a heliocentric world view.
A. That is certainly part of what I am saying. But I am also pointing out the rather obvious but important fact that one can shift perspectives only when one recognizes that it is only a perspective that is shifting — not the world itself. That is the utility of paradigm looseness.

Q. Granting all that, I still fail to see how the humanities come in.

A. Really? I have been saying that one of the great tasks of the educational system is to make the largely invisible dominant paradigm visible, and that what is needed to make it visible is an alternative paradigm. Well, the dominant part of the dominant paradigm today is surely scientific. To isolate and to control changes in variables, to quantify, to design abstract models that have predictive power — these are ways of coping with experience that have come to seem natural, even inevitable. So much so that what cannot be handled by these means — what, as it were, is not in focus through these lenses — seems to us to be "subjective," "private," or even "illusory." We see it, but we don't believe it, just as Galileo's colleagues saw those moving pinpoints of light but wrote them off as unreal, possibly black magic. In such circumstances it seems to me useful and important to have available a paradigm in which what is "unreal" in the dominant paradigm comes into focus. In the 17th century that alternative paradigm was the heliocentric hypothesis. Today it is the humanities.

Q. If I understand you, you aren't attributing any special virtue to the humanities; they are effective paradigm-looseners only because they happen to be alternatives to the dominant paradigm.

A. I agree that any alternative to a dominant paradigm is a loosener. When, as in the 16th century, the humanistic paradigm was dominant, the natural sciences played a useful role as paradigm looseners. But I also think that the humanities are particularly well fitted to serve as paradigm looseners. This is because it is their nature to present alternative paradigms. Take anthropology, for instance. Anthropology displays to us societies whose behaviors and whose belief systems differ greatly from our own but in which nonetheless a coherent life — a good life — is possible, a life at least as functional for those societies as ours is for us. Take literature: *Lear* and *Hamlet*, the *Oedipus* and the *Antigone*, present us with alternative life styles, alternative systems of value, and present them in such a way that we come to understand them from within, not merely contemplate them from without, empathize with them, even while rejecting them as models we want to follow. To understand while rejecting — that is precisely what I mean by loosening a paradigm; not abandoning, loosening. Take history: In contrast to anthropology, which shows us contemporary societies different from our own, history loosens our own current Western paradigm by disclosing how much it has evolved and changed over time. Take philosophy: When I ask students to read Plato's *Republic,* I say, "Concentrate on the places where he seems to you to be talking utter nonsense; those are the important points. Assume that he was a reasonably intelligent man; if you can discover why what seems to you gibberish made sense to him, you will have uncovered a difference in fundamental assumptions."

Q. But you surely don't want your students to abandon their own assumptions and adopt Plato's?
A. Of course not. That would be to leap from one fly bottle to another. But to make explicit a set of assumptions which one didn't even recognize to be assumptions, because everyone one knows has made them too — that seems to me a useful learning experience.

Q. As nearly as I can make out, you are arguing that the humanities are good paradigm-looseners precisely because they don't make truth claims. But surely historians and anthropologists — and for all I know, philosophers — do make truth claims, don't they?
A. That depends. Certainly some historians believe that the job of history is to ascertain what really happened in the past. I think that we should classify historians who take this view of their discipline as social scientists. After all, I said at the start that some historians firmly reject the epithet "humanist," and I think they do this precisely because they are making truth claims. But other historians agree that history is at best no more than a likely story; I think what I have been saying about the humanities applies to them. It also applies to any anthropologists and philosophers who take a similar view of their disciplines.

Q. Perhaps. I do not know enough about these studies. But I still think that your best case is literature.
A. Very well; I won't debate this with you. My point is simply that as long as humanists think of themselves as purveyors of truth, they only offer us rival fly bottles, fly bottles that few people today have much confidence in. There is no point, as I see it, in loosening one paradigm — whatever it may be — if, at the end of the loosening process, the fly is only lodged in another fly bottle. That is what went wrong in the 15th century, when the humanists, not content merely to loosen the medieval paradigm, claimed to have discovered the truth about human nature.

Q. But once humanists free themselves from the burden of making truth claims about human nature, they are free — this is your point, is it not? — to concentrate on what they are particularly well fitted for, a study of the variety of paradigms by means of which over the ages men have organized their world.
A. Yes. Man is characteristically — not uniquely, but characteristically — an animal with culture. That is, his experience of the world, his interaction with the world, is mediated not merely by memories but by more or less complex systems of signs. Though we all know this, we are always forgetting it. The system of signs that we habitually use grows so familiar that it becomes invisible. At that point we are in danger of falling into the sin, to speak metaphorically and humanistically for a moment, of thinking of ourselves as gods. The social function of humanists is to recall us to an understanding of our humbler status as men.

Q. But aren't you, in a way, agreeing with those who describe humanists as purveyors of culture?
A. Yes, if you think of culture as a system of signs; no, if you think of culture as a thin veneer. It is a matter of what perspective, what paradigm, you use for thinking about culture.

Q. So you don't claim that what you have been saying about the humanities is true?
A. God forbid!

Q. If you haven't been trying to tell us what you think is true about the humanities, what on earth do you think you have been doing?
A. Oh, I have been making a joke about the humanities.

Q. A joke?
A. Yes; a small joke — not quite so small as *The New Yorker* joke about the deer driving the hunter's car, but still a tiny joke compared to Galileo's joke about the fixed stars that moved. And I suppose that, after all, I am making a kind of truth claim for what I have been saying. I think that what I've been saying about the humanities is true in the same sense that one might call a joke "true" if it calls people's attention to some feature of their experience that they have been overlooking.

Q. You mean that you want to jolt people at Caltech out of what you suspect is the normal Caltech view of the humanities and into a different one?
A. Yes, exactly. And not only scientists; humanists too.

Q. Do you think you'll succeed?
A. Ah.

In the Footprints of Future Man

by JAMES BONNER

We have in our hands the first rudimentary tools for escaping extinction and lifting ourselves to a new and better species. When will we start?

THE NORMAL expectation for an animal species such as our own is to arise through mutation, evolution, and selection and then to become extinct and to be replaced by a species more fitted to the existing environment. During the history of life on earth, mutation, evolution, and selection have invented literally millions upon millions of species of plants and animals, and almost all of them are extinct today. As a matter of fact, up to about 50,000 years ago there were two species of *Homo* living on earth — *Homo sapiens* (us) and *Homo neanderthalensis*. These two species lived together in the plains and mountains of central Asia, and they fought it out to see who would survive, and you know who won. It wasn't them.

They were replaced by a species that was more suited to the particular ecological niche, and so the normal expectation for us is that we will be superseded by a new species of mankind better suited for our ecological niche. (I like to think that it might derive from the Sherpas of Nepal, a super people.) Maybe the new species has already been invented, and we just don't know about it. Anyway, the only reason to think that we will come to a different end from that of past species is that we're the first species that really knows a lot about mutation, genetics, selection, and evolution. And therefore we should, in principle, be able to control our evolutionary destiny.

We have another thing going for us too — as Margaret Mead has pointed out — that human beings as a species have the ability to change their way of life. They're very adaptable; they learn how to cope with changed circumstances. So if new mutations come to us that enable us to do something new, our culture will probably be able to absorb vast changes. For example, I know a man who is the child of a headhunter of Borneo. He lived in Borneo until he was 5 years old, and then was taken to be educated first in Java and then at Harvard. Now he's a professor of mathematics at a great university. From headhunter to professor of mathematics in one generation is pretty good adaptation.

I don't want to get off onto the subject of genetic engineering, though I know it's a very fashionable subject and one that has both good and evil aspects. But one thing that we can be sure of is that genetic change will be a part of man's future, just as it's been a part of man's past. Just imagine the amount of genetic change and manipulation that has gone on, unknown to us, during the last 2,000,000 years when we changed from *Homo habilis* — the first primate *Homo* — to *Homo sapiens*. Even during the last 200,000 years there has probably been a great amount of mutation, selection, and evolution on the part of human beings — done not in any consciously directed way, but by the natural forces of selection and evolution. Genetic change is inexorable and inevitable.

A scenario for the future of human beings appears in an interesting book written by Olaf Stapledon, an English author. Called *Last and First Men*, the book was published in 1935, and republished by Dover Press in 1968. Olaf Stapledon starts out by writing about the history of the human species viewed one billion years from now (from 1935, actually). He notes that at one time it was necessary for children to enter into productive economic life at the age of 8, because they were going to die before they were 30, and for society to get some good out of them they had to start to work early and die early. They had a ratio of productive life to the educational part of life of about two to one.

In our society people have to be educated up to the age of about 25 before they can become societally useful, and they poop out at 65 or thereabouts. Again, the ratio of productive life to educational life is about two to one.

So, in the book, in about 20,000 years from now, the people realize that this is a very uneconomic state of affairs, and they want to deliberately alter the ratio of productive life span to educational life span to 250 to one. They want to really get their money's worth out of a person after they've paid to have him educated. Now by that time it takes 200 years for a person to become educated enough to be societally useful. So he has to live to be 50,000 years old in order to get all his work in.

Note that, to accomplish this end, the society uses selective breeding and deliberate alteration of genetic material, and note that Olaf Stapledon realizes the necessity of death at the end of 50,000 years. People have to die in an evolving society, so that the old models of people can be replaced by the new ones that have been invented in the meantime. That's true wherever there's evolution.

Incidentally, Stapledon also foresaw that our species would have to abandon the planet Earth because it got so polluted. Mankind goes from one planet to another, until the only remaining planet is one that has a very high gravitational field. People are unable to walk upright any more, so they have to learn to walk on all fours again. This is also accomplished by deliberate genetic manipulation. Stapledon says of mankind: "First up, last down."

But all this is science fiction, and I cite it merely to show that science fiction writers in general are far ahead of the rest of us in looking into the serious technological and philosophical problems of the future.

It is, of course, widely held that we can outwit our normal evolutionary expectation of extinction. I, for one, am convinced that what we know about human genetics can be used right now to better the human condition, and that it could better it even more in the foreseeable future.

First, however, let's be sure we're all broadcasting on the same biological wavelength. Everybody knows, because we learn it in high school, that the genetic material is composed of DNA, and that the genetic information is encoded in the sequence of building blocks that succeed one another down the long linear DNA molecule composed of four building blocks which we call A, T, G, and C. And almost everybody knows that the DNA molecule is a two-stranded molecule; that wherever there's an A in strand Number 1, there must be a T in strand Number 2. Where there's a G in strand Number 1, there must be a C in strand Number 2, and vice versa. This is the basis of replication of DNA, and that's why DNA is the only molecule in a living creature that can replicate itself.

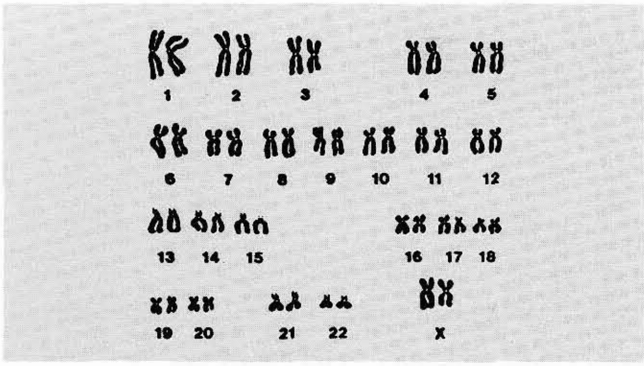
There are about three meters of DNA in each of our cells, and since cells are just a few microns in diameter, the DNA has to be packed up pretty tightly. In higher creatures the three meters are split up into individual chromosomes. We each have 46 chromosomes, and furthermore the DNA is complexed with proteins of a special class — the histones, for example — that make the DNA's shorter than they would otherwise be. These proteins compact the DNA to make chromatin. When it comes time for cell division, the DNA replicates itself, and condenses into what is called metaphase chromosome.

The metaphase chromosomes arrange themselves on the so-called metaphase plate in the middle of the cell. That's the stage at which people look at human chromosomes to see whether you have a normal human chromosome complement. They look at the metaphase plate in the dividing cell. Then the chromosomes separate from one another, and form two new nuclei. The cell splits in two; the chromosomes decondense into interphase chromatin; and we have two new cells each with a complete copy of the genetic information.

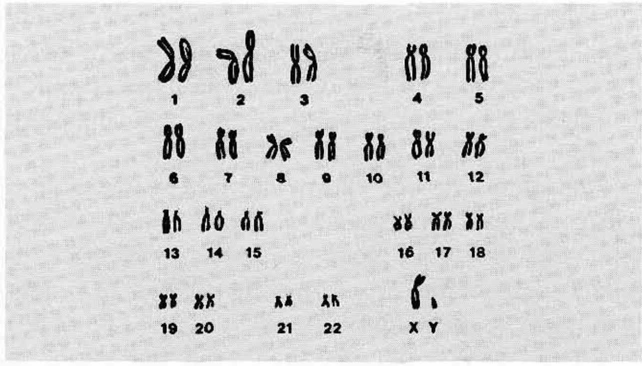
The DNA is not only split up into chromosomes, but each chromosome is split up into what we might call chapters of the DNA called genes. A gene is that length of DNA that contains the information about how to make some specific kind of enzyme molecule, and we have about 500,000 different genes in us. The three meters of DNA in the human chromosome set contain, I once calculated, about as much information as is contained in the *Encyclopedia Britannica,* which is quite a bit.

One further biological fact: Each of us has two sets of chromosomes, one set from our mother and one set from our father. So we have two chromosomes Number 1, and two chromosomes Number 2, and so forth. Obviously, when eggs and sperm combine to make the germ cells, the chromosome number must have been earlier cut in half so that the normal chromosome number for that species (46 in us) is restored by combination of sperm with egg. And this happens during the maturation of the germ cells by the process called meiosis. Before the first meiotic cell division, the chromosome Number 1, let's say from the mother, pairs with the chromosome Number 1 from the father, and at the division those two separate from one another. That's followed by a second division, but the end product is that we get germ cells that have half of the chromosome number characteristic of the normal body cells of that species. So that would be 23 chromosomes in each human sperm or human egg cell. Note also that

Female



Male



Karyotyping is an electronic method for drawing pictures of the metaphase chromosomes of human body cells and arranging them in linear order. The 22 pairs of non-sex chromosomes and two X chromosomes of the karyotype at the left indicate that it is that of a female. At the right is the karotype of a male, which also has 22 pairs of non-sex chromosomes, one X, and one Y chromosome.

the chromosomes from the mother and those from the father are absolutely and completely randomly reassorted in the making of sperms and eggs, so the sperm can contain some of the chromosomes from the father and some of the chromosomes from the mother and so forth. And this is one way of getting genetic diversity and one reason why our children don't all look exactly alike. They don't all get exactly the same arrangement of chromosomes.

Now the stage is set for us to look at the human chromosome complement. When we look at a metaphase plate of a dividing human cell, we see a vast mass of chromosomes, and it's pretty difficult for a person to know what he's looking at — unless the chromosomes are arranged by a process called karyotyping.

The human female has 22 pairs of non-sex chromosomes, called autosomes, and two X chromosomes. The human male also has 22 pairs of autosomes, a big X chromosome, and a very small Y chromosome. The process of looking at a metaphase plate of the chromosomes of a particular human male or female, drawing pictures of them, and arranging them in linear array is called karyotyping.

It takes about one day for a skilled human observer with a light microscope to make a karyotype of a single human being. Luckily, in Houston, Texas, there is a magic machine that can take a picture of the confused metaphase chromosome plate in the human cell, scan the chromosomes, and put all the information into a computer that knows how to recognize the individual chromosomes. This computer can look at the picture of the chromosomes of the metaphase plate and make a printout with all the chromosomes' numbers assigned, and do it within a minute or so. That machine needs to learn to replicate itself because we are going to rely more and more on rapid karyotyping to help us recognize chromosomal abnormalities.

For over 100 years it's been known that of all live births about 1 in 600 suffers from a characteristic set of abnormalities that includes a peculiarity in the folds of the eyelids, multiple developmental defects — particularly in the circulatory system — and very often mental retardation. This condition was described by a physician named Down in the 1860's, and is known as Down's syndrome. Its victims include both sexes, and it is not inherited. Nothing was known of the cause of Down's syndrome until 1959 when a French cytologist, Dr. Jerome Lejeune, karyotyped nine individuals of the Down's syndrome phenotype, and he found that they all possessed three rather than the normal two copies of chromosome 21.

It is now known that Down's disease is always characterized by this chromosomal condition. It is brought about by a mistake in meiosis in which both the chromosomes 21 go to one daughter cell during egg production while no chromosomes go into the other. The fertilization of such an egg by a sperm containing one chromosome 21 would result in three chromosomes 21 in the otherwise normal karyotype. This is called chromosome 21 trisomy, and it causes Down's syndrome.

Trisomys for chromosomes 18 and 13 are also known, but they are not as common as that of Down's syndrome. They are all attended by mental retardation, and generally individuals with these trisomys live for less than a year.

These are not the only chromosomal aberrations that beset human development. The best known are those that have to do with the sex chromosomes X and Y. One is the well-known Klinefelter's syndrome. Although the appearance of the Klinefelter's-syndrome-person is male, the testes are small and the breasts are in general enlarged. Karyotype analysis shows that these individuals possess two X's plus a Y, making them

XXY. They have the standard complement of 22 pairs of normal non-sex chromosomes (autosomes). I should also mention that if Klinefelter's syndrome is recognized very early in life, a male can have essentially normal development by being given supplemental male hormone therapy.

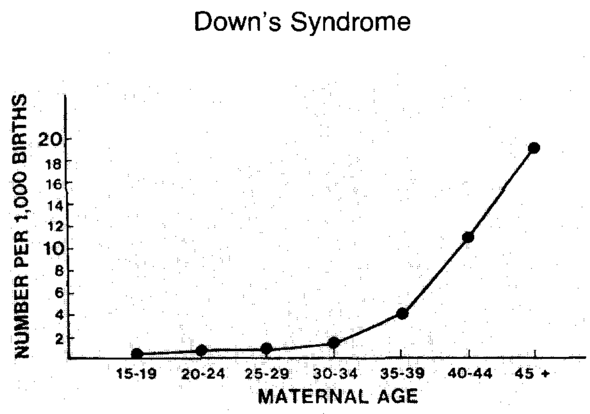
There are other abnormalities of the male chromosomal complement. A person can be afflicted not with just two X's plus one Y, but with three X's plus one Y, or even four or five of them and one Y. Or there can be an X and two Y's.

There are equally well-known aberrations of the female karyotype. There is Turner's syndrome, in which there is one X chromosome and no Y chromosome, and the afflicted person is female in phenotype and in appearance. Normal females have two X chromosomes. There are triple-X chromosome women, who are fertile and develop normally. And there are four-X women, about whom very little is known.

Abnormal chromosome complements, then, are very real risks that occur during the development of eggs and sperm and in their fertilization. Altogether, about one in 200 live births is attended by a major chromosome abnormality that leads to major developmental abnormality. The question is what to do about this situation.

Consider what nature is doing about it. Of all recognized pregnancies, about 20 percent or a little more end in spontaneous abortions. Of these spontaneously aborted fetuses, 25 percent or more have gross chromosomal abnormalities. For example, most of the XO fetuses are spontaneously aborted. A very considerable proportion of spontaneously aborted fetuses are triploids (with three complete sets of chromosomes), and almost half of the total are trisomic for the large chromosomes — that is, they have three chromosomes Number 1, or three chromosomes Number 2. Another common chromosome abnormality is to be a tetraploid — that is, to get four complete sets of chromosomes. All of these are incompatible with normal development. Other classes of chromosomal abnormalities are incompatible with development even to a recognized pregnancy. Such is the case with an embryo that is monosomic for an autosome. It has, for example, only one chromosome 1, or even only one chromosome 21. All the embryos of that class die before they are implanted in the uterus, and therefore they are never recognized as pregnancies.

Although 90 percent or more of chromosomally abnormal fetuses are spontaneously aborted, the remaining 10 percent form a large societal burden. Hugh Fudenberg, a physician who aspires to be an economist, has calculated that by abolishing the incidence of Down's syndrome alone we would save 45 million dollars a year. It would also save a great deal of societal suffering.



Down's syndrome is a tragic burden to individuals and to society, and the frequency of its appearance increases catastrophically with increasing maternal age.

Fortunately, there is something to do about gross chromosomal abnormalities. It is now possible to accurately locate the position of the fetus in the uterus by sonography and then to put a hypodermic needle into the uterine cavity in a place where the fetus isn't and remove some amniotic fluid. This fluid contains cells that have been sloughed off from the lining of the bladder of the fetus. They can be tissue-cultured and karyotyped. Such amniocentesis is optimally carried out in the 16th week of pregnancy, but it can be done at a variety of times. If the karyotype proves to be abnormal, the fetus can be aborted, if the parents wish.

Amniocentesis is now done in more than 50 centers in the United States. Five years ago it was done in just 3 centers. I am sure that it will become general practice soon in all of the developed nations of the world.

In the meantime, one group of mothers are specially at risk with regard to the possible conception of fetuses of abnormal karyotypes. These are the older mothers. Up to about age 30 the incidence of Down's syndrome is very low, but with increasing maternal age the fraction of babies born with Down's syndrome increases catastrophically. Because this is so, older mothers deserve particular consideration, and I am told that the Colorado state legislature some years ago provided that any woman who becomes pregnant and is age 35 or older can have a karyotype on the house — and an abortion on the house too if an abortion is indicated. I think this will certainly become standard for older mothers.

Chromosomal abnormalities are not the only bad things that can happen to us by the random workings of our genetic lottery. Our species is heir to lots of genetic defects and mutations, which cause the gene in question to produce either altered or inactive enzymes, and this causes some bad things to happen. These problems are all inherited, of course. Most of them, luckily, are recessive so that you have to have a double dose, from mother and from father, in order to show the symptom of the mutation. They range from hemophilia, for example, to sickle cell anemia, and a wide variety of enzymatic defects which cause mental retardation. We now know of more than 2000 human hereditary mutations.

My first genetics teacher, Thomas Hunt Morgan, former chairman of the biology division at Caltech and its founding father, always told me that human beings are no good for genetics research because you are never sure who the father was. That may be so, but it also turns out that human beings are good for genetic studies because the mutants always go to the doctor to find out what's wrong with them. The mutants come to you instead of your having to go and look for them, as you have to do with Drosophila and creatures like that.

For an increasing proportion of these hereditary genetic defects, the particular enzyme that is affected has become recognized. For many of these defects, especially mutations that cause mental retardation, the presence or absence of the relevant enzyme can be detected in the cells that are tissue-cultured by amniocentesis.

We can't diagnose all genetic defects yet in the amniotic cells. For example, we can't diagnose sickle cell anemia because the gene for making adult hemoglobin is not turned on in the amniotic cells. Since they do not produce the adult hemoglobin, you can't find out whether the adult hemoglobin will be normal or not. But as we find out how to turn on genes that are turned off, we'll be able to determine, I think, the entire genetic constitution of the fetus, and discover whether it has a good genetic constitution or not. This will make amniocentesis a really powerful tool for the prenatal diagnosis of genetic constitution.

I am sure these things will all be implemented because, once we recognize the physical and moral necessity to have only two children per couple — so that we won't have unlimited population growth — it is but a short step to a new morality that says: "Since we can have only two children, let them be free from genetic defects."

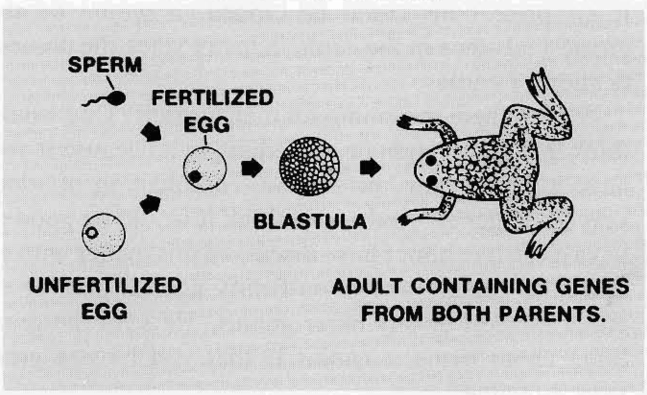
The next step might be a little harder to take. That's a newer new morality that will say: "Since we can have only two children, let us have them not only with no genetic defects, but let us endow them with the very best genes available in the world."

How could this goal be achieved in principle? One way is by the process known as cloning, which is not something inherently bad in spite of the adverse advertising it has had.

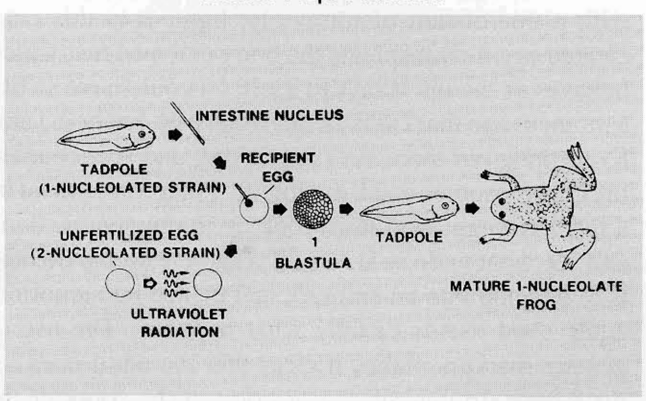
A clone is a group of genetically identical individuals derived, without the intervention of sex, from a single parent. A pair of identical human twins is a clone of two derived from a single fertilized egg. Essentially all of our fruit trees are cloned. Valencia oranges are one clone of orange trees, and navel orange trees are another. All of our ornamental shrubs are clones, and all patented roses are clones, propagated vegetatively from a single sexually produced parent. Dates have been multiplied vegetatively for over 5,000 years, and the same clones are still growing in the Middle East.

Cloning of animals hasn't been so successful. It has been carried through only with the African toad *Xenopus laevus* (by former Caltechian John Gurdon).

Sexual Reproduction



Clonal Reproduction



Vegetative cloning is almost as old as agriculture itself, but in the animal world so far only the toad has been successfully cloned. Normal sexual reproduction (left) is, of course, relatively simple, but the outcome is genetically random. To produce any desired number of genetically identical toads or frogs takes the more complex and rather recently developed process of clonal reproduction (right).

"I'm afraid, Son, this will never be yours. I'm having myself cloned."

When a toad wants to produce a toad normally, it produces some sperm that fertilizes a toad egg, which then divides and grows into the blastula, which then develops into a tadpole, and then into an adult toad containing genes from both parents.

The Gurdon method is to take a body cell from a toad (cells from the intestinal mucosa are convenient) and scoop the nucleus from that somatic cell. This body cell is a dead-end cell. It just produces digestive enzymes, and it's never going to divide again. It is going to be sloughed off into the intestine and digested. But Gurdon gets to it first, and gets the nucleus out of it. Then he takes an egg from a lady toad and destroys its nucleus with a microbeam of ultraviolet light. Into this enucleated egg he transplants the body cell nucleus, which behaves as though it says to itself: "I could have sworn a moment ago that I was an intestinal cell, but here I am. Everything out there says egg to me, and I've counted my chromosomes and I'm diploid. Therefore, I must be a fertilized egg. So I must look up in my genetic book and see what to do next." And what it is told to do next is to develop into an embryo, and thence into a normal adult. And that is exactly what happens. The use of genetic markers makes it clear that the adult does indeed have the genetic composition of the donor of the nucleus.

This is a very successful process for making completely normal, fertile toads. Furthermore, it is possible to produce clones of any desired number in this way, either by using large numbers of individual cell nuclei from the intestinal mucosa of a single donor, or by separating the cells of the developing embryo of the original transplant and using them as donors of nuclei to further enucleated eggs.

Such cloning has not yet been achieved with any mammal, because it is much more difficult to get the nucleus out of the mammalian cell, but I am sure that any day now somebody will announce successful nuclear transplantation and cloning of the mouse. Next will be the cow. The owner of the King Ranch says that if his prize bulls could be cloned, it would be the greatest advance in the cattle industry since the domestication of cattle.

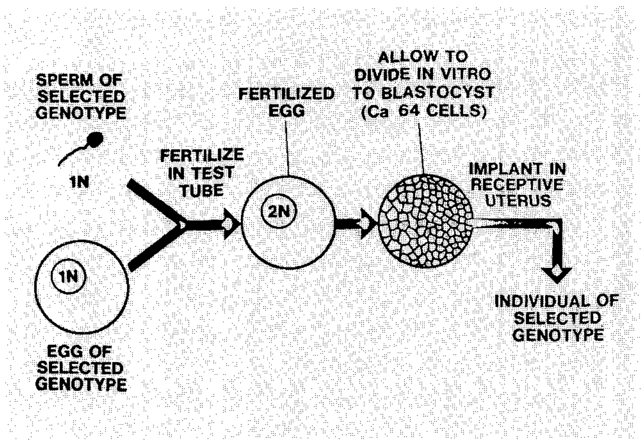
What is there in cloning for man himself? One would think that there might be something in it because if you have a genius, say, he's a rare combination of some very good genes. And you'd think it would be good to have more like him. I have discussed this matter with an authentic genius, and he is firmly against cloning of either himself or any other genius. He says the great thing about being a genius is that you have a great scarcity value.

So let's try some other method for improving people. The human gene pool is enormously diverse. It's so diverse that as between any two of us at least 15 percent of our genes are different. The human species includes people of all sorts of different resistances to diseases, different skills and abilities, so that amongst the population as a whole we should be able to survive almost any kind of catastrophe. Nonetheless, we might wish to increase in our population the frequency of particular genes that we all agree are good to have — like genes for longevity, for example. So how would we implement this newer new morality — making sure that if we have only two children they are not only free from genetic defects but have the best genes available to them in the world?

Well, here's how you would go about it. You take some sperm from an individual of selected genotype, and you take an egg from another person of selected genotype. You fertilize the egg with the sperm, and you let it grow into the 64-cell stage called the blastocyst. That's the size at which the fertilized egg implants itself into the uterine wall. You now implant the blastocyst into the uterine wall of a receptive uterus, and it grows in this host uterus into a normal baby and thence into a supernormal adult.

This is already done with cattle, of course, and with mice and rabbits. It has not been done with people so far as we know, and it would demand a certain humility on the part of humans. Each individual would have to say: "I'm not going to spray my genes around just because they're *my* genes. I want my children to have the best possible genes, even if they're not from me."

The next question is: On what basis do we choose the selected genotype? The points most of us could agree on, I think, are longevity (which is very hereditary), freedom from genetic defects, high energy (which has been shown to be controllable to a considerable degree and is also heritable), and broad spectrum high intelligence. On other points the selection would be more difficult, and there might be a wide diversity of opinion about them.



Idealized selective breeding is one way to improve the human species. The process begins with fertilization in a test tube of a chosen egg by chosen sperm, and continues through implantation in a receptive uterus to the birth of a genetically desirable baby.

A few years ago I participated in a round-table discussion on CBS News on this subject. The panel moderator, Eric Sevareid, asked: "Who will be the selectors?" And I said: "Well, it will be a committee of biologists, of course." My co-panel member, Cardinal Wright, disagreed. His view was that scientists would select only people suitable for being scientists, and not for special spiritual attributes. He wanted to be on the committee too. So you see the kind of trouble we would have right from the start.

The most extreme suggestion on how to go about selectively breeding human beings was made by the late geneticist and Nobel Prize winner H. J. Muller. He proposed that each child at birth have a sample of his or her germ cells removed and put in the deep freeze. The child would then be sterilized. The individual would live out his or her normal life span, and at a decent interval after he has died — so that all the heat of passion has gone away from the matter — the committee would meet and review the person's life. They would ask the question: "Would we like to have more people like that?" If the answer is no, the germ cells are thrown away. If the answer is yes, a selected egg is fertilized with a similarly selected sperm and goes through the ritual that I've already outlined.

That's a very logical suggestion, though it still leaves the thorny problem of how you select the reviewing committee. I think, however, that some anonymous and far-sighted way of conducting selective breeding of humans is not beyond the bounds of possibility.

Muller pointed out that if this sort of selective breeding of people were started in any country the average intelligence, average energy, and other aspects of human well-being could be increased very rapidly. So all the other nations of the world would have to conduct similar programs or face the fate of *Homo neanderthalensis* — elimination by the super people arising from selective breeding.

And so I conclude that man today stands in exactly the position in which *Homo habilis* found himself 2,000,000 years ago. Just as *Homo habilis* had in his hand the first rudimentary tool and just as the use of this tool led to his rapid evolution into us, so we stand today. We have in our hands the first rudimentary tools for escaping extinction and lifting our species to a new and better one. The only remaining question, to me at least, is not moral or judgmental, but temporal. *When* will we start on this new path? □

Action in Chemistry

There's a lot going on in chemistry these days — and much of it is likely to have an impact on the world's long-term needs in energy, food, and materials

by HARRY GRAY

I BELIEVE THAT in the last quarter of this century chemists are going to occupy center stage in fundamental science because of one central problem—the need to learn how to take very small, very abundant molecules and make them into larger ones, which will be used for fuel, for the production of food, and for materials. Much of the fundamental work in this area is already in progress — some of it at Caltech — and if it is successful, it could have a major impact in slowing or even reversing the deterioration of the quality of life on this planet.

The battle has been joined in laboratories around the world in work on two molecules that are extremely recalcitrant and sluggish in their chemical reactions — nitrogen (N_2) and carbon monoxide (CO). These two molecules are, in fact, among the most inert chemical substances known to man. In most cases you have to heat them to very high temperatures before they will react with other small molecules.

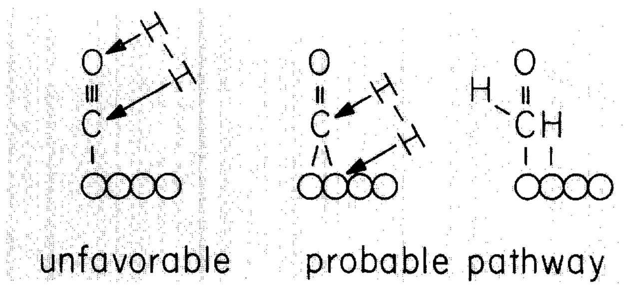
William A. Goddard, professor of theoretical chemistry: His studies are giving us some insight into the catalytic process.

A particularly important chemical reaction is the reduction of atmospheric nitrogen by hydrogen (H_2) to give ammonia (NH_3). Ammonia production is of great interest, because this chemical substance is a key component in fertilizer. Not only must we improve the methods for ammonia synthesis from nitrogen (often called nitrogen fixation), we must also find ways to convert nitrogen directly to an energy-rich molecule called hydrazine, as well as to many organic nitrogen-containing compounds.

At present nitrogen is fixed industrially by the Haber-Bosch process, in which the sluggishness of the nitrogen-hydrogen reaction is partially overcome by utilizing an iron-containing catalyst and very high temperatures and pressures. But nature has found a better way, in which an enzyme called nitrogenase effects nitrogen reduction under extremely mild conditions — room temperature and atmospheric pressure. We chemists need to learn how to catalyze the reduction of nitrogen to ammonia for fertilizer as beautifully as nitrogenase does it biologically.

The reduction of carbon monoxide is of equal importance. In the famous Fischer-Tropsch process, again involving high temperatures and pressures, carbon monoxide is reduced by hydrogen to energy-rich hydrocarbons and alcohols. But we can no longer afford the extreme conditions and the lack of specificity of the Fischer-Tropsch process. We must learn to reduce carbon monoxide with the ease that biological systems convert nitrogen to ammonia.

Currently, chemists are attacking these problems both theoretically and experimentally. Bill Goddard of Caltech is a theoretician who has chosen to look carefully at one of the key steps in the reduction of carbon monoxide by hydrogen directly to the simplest of the energy-rich hydrocarbons, methane (CH_4). This reaction is known to be catalyzed very effectively by metallic nickel; or, to put it another way, the catalysis occurs at a surface comprised of nickel atoms. Goddard is calculating the energies of all the molecular species that could be involved as carbon monoxide and hydrogen come together on a nickel atom surface. He is using sophisticated chemical theory — and a large computer — to see which molecular species are reasonable and which are unreasonable, thereby giving us some insight into the catalytic process. As a result, eventually we may be able to design much better catalysts for the conversion.



Bill Goddard's predicted pathway for the first step in the catalytic reduction of carbon monoxide (C≡O) on a nickel atom surface (0000) by hydrogen (H–H) involves the addition of one H atom to the carbon, and the second one to the nickel.

Goddard has already shown quite convincingly that one of the old thoughts in this field — that carbon monoxide sits on the metallic nickel surface while one atom of hydrogen adds to the oxygen and one to the carbon — is a terribly unfavorable way to get to methane. It is so unfavorable energetically that there is no chance of it being the pathway that this system chooses in proceeding from reactants to products. Goddard's calculations show equally convincingly that what probably happens is that one atom of hydrogen adds to the carbon of the carbon monoxide and one to the nickel surface, giving both a CHO group and a hydrogen bound to nickel atoms (above right). From this point it is quite favorable for the system to continue on to methane.

On the experimental side there has been considerable progress, particularly in nitrogen fixation. Some of the most exciting recent work has been done here at Caltech, as well as in England and in the Soviet Union. I've picked two examples to illustrate the progress that has been made. First, there's the work in Sussex, England, by Joseph Chatt's group. Chatt and his co-workers have been able to synthesize ammonia — under quite mild conditions — by simply adding acid to a compound in which atmospheric nitrogen is bound to atomic tungsten. Unfortunately, the reaction is not catalytic (that is, the atomic tungsten reagent is "used up" when one molecule of ammonia is made). But the fact that this reaction takes place at all under very mild conditions suggests strongly that we chemists should be able to design a catalytic nitrogen-reduction system that is just as good or better than the biological process.

Here at Caltech, John Bercaw and Juan Manriquez have prepared a zirconium compound that contains

Juan Manriquez, graduate student, and John Bercaw, assistant professor of chemistry: Their nitrogen-reduction system is a fundamental breakthrough in this field.

Fred Anson, professor of chemistry, and Robert Gagné, assistant professor: They are trying to reduce oxygen to water — directly.

three nitrogen molecules. This compound, when treated with acid under mild conditions, yields one molecule of hydrazine. Hydrazine is a very important substance. It has many chemical uses, and it is a good fuel. Again, the Bercaw-Manriquez nitrogen-reduction system is not catalytic; but the very demonstration that the reaction can be carried out under mild conditions is a terrific fundamental breakthrough in this field.

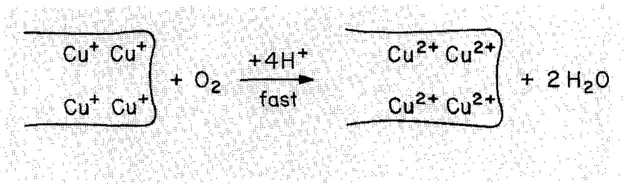
Devising better ways to make energy-rich molecules to be used as fuels is just part of the story. We still have much to learn about burning fuel. Strange as it may seem, reducing oxygen (from the air) to water is a major problem. Why do grown men worry about reducing oxygen to water when practically anybody and anything can do it? Why have such prominent men as Michel Boudart, James Collman, and Henry Taube at Stanford; Robert Gagné and Fred Anson at Caltech; and Howard Tennent of Hercules, Inc., banded together to try to figure out how to reduce oxygen to water? Well, nobody can reduce it directly — that is, reduce it without forming intermediates such as hydrogen peroxide, in an extremely rapid reaction. It's not enough to finally get to water; if you want to burn fuel really efficiently, you need to find out how to deliver four electrons to oxygen to form water in one burst, without being hung up in the usual way with all kinds of intermediates.

Although no chemist in the world has found a way to do a rapid-fire, four-electron reduction of oxygen to water, a few biological systems have, by using enzymes. One of the enzymes my group and I have been working with does the job. It is laccase, a beautiful blue copper-containing enzyme that can be extracted and purified from the Japanese lacquer tree. Each enzyme molecule contains four doubly positively charged copper ions, Cu^{2+}. When the four Cu^{2+} ions are reduced to Cu^{+}, the enzyme rapidly reacts with oxygen, giving two water molecules and four Cu^{2+} ions again (as shown by the formula below).

Not surprisingly, we (and other people) have been trying to figure out exactly how laccase manages to do this amazing trick. Some questions of importance are: How are the four copper ions structured? And which of the four copper ions interacts with the oxygen initially?

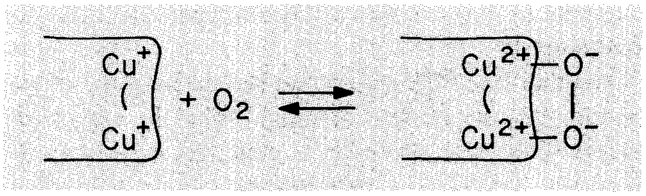
If we could answer those questions, we could provide some real help to Fred Anson and his co-workers, who are now struggling to design a catalytic oxygen electrode, which in turn could be used to fabricate an efficient fuel cell. One of the answers may come from study of another copper-containing protein,

laccase, a blue enzyme



Laccase is an enzyme containing four coppers, whose function is to reduce oxygen to water.

hemocyanin, a blue blood protein



Hemocyanin is a copper-containing protein that picks up and releases atmospheric oxygen (O_2).

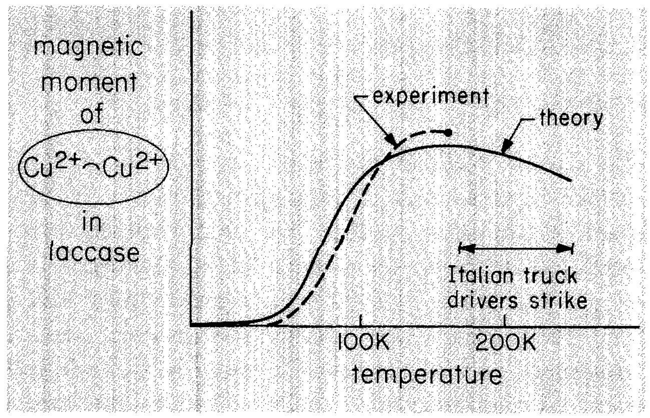
hemocyanin (above). This is a blue blood protein that is found in octopi, squid, lobsters, and snails, not to mention Caltech trustees! All these creatures have blue copper-protein blood.

What my group and several other groups around the world have found is that in blue blood two Cu^+ ions are needed to hold each oxygen molecule from the air. These two Cu^+ ions interact with the oxygen to give some type of complex species involving Cu^{2+} ions and peroxide (O_2^{2-}); this species is believed to be responsible for the blue color of the copper blood protein. We suspect from the results of these blue blood experiments that two of the four Cu^+ ions in a reduced sample of laccase are responsible for attaching oxygen in the first quick step. The other two coppers must be close by to shoot additional electrons into the oxygen once it is attached. The key to obtaining more information relating to this hypothesis is an experiment in magnetism.

If two of the Cu^+ ions in reduced laccase must be near neighbors, it is likely that they are in the normal (Cu^{2+}) form of the enzyme also. Now in molecules in which Cu^{2+} ions are neighbors, the magnetism has a very peculiar, distinctive temperature dependence. If we could measure the magnetism of the laccase enzyme, we could tell you whether or not it possesses two Cu^{2+} *ions that are neighbors. Since this is such a key problem* in the overall area of oxygen reduction, we've devoted a good bit of time to its solution. It is by no means an easy problem, unfortunately, owing to the fact that the magnetic effects we are looking for are so tiny in relationship to the enormous size of the laccase enzyme itself.

We thought we had the problem knocked several years ago, when two physicists at Caltech, Jim Mercereau and Han Wang, built a marvelous magnetometer in the low-temperature laboratory in Sloan. The magnetometer was so sensitive that we believed we could use it to find the peculiar and distinctive temperature dependence of the magnetism that was predicted for the laccase enzyme. Two of my co-workers, Bob Holwerda and Barry Dohner, carefully purified 10 milligrams of laccase, took the sample over to Han, and he inserted it into the magnetometer. Unfortunately, the magnetometer operated in too low a temperature range to see the effect that we were looking for, and, to make *matters worse, our sample was too small.*

One of the fellows who was working with Jim and Han at the time was an Italian by the name of Massimo Cerdonio. Massimo went back to Rome and built a second magnetometer, one that would operate in the temperature region that was so critical for our experiment. By the time the second magnetometer had been completed, I had attracted to my group two bright young men — Ed Solomon and Dave Dooley. Dave prepared a nice sample of laccase, which he gave to Ed to take to Rome. Ed arrived in Rome, after some delays, and put the sample into the magnetometer. Up to a point, the experiment gave results that were predicted for the model in which two Cu^{2+} ions were near

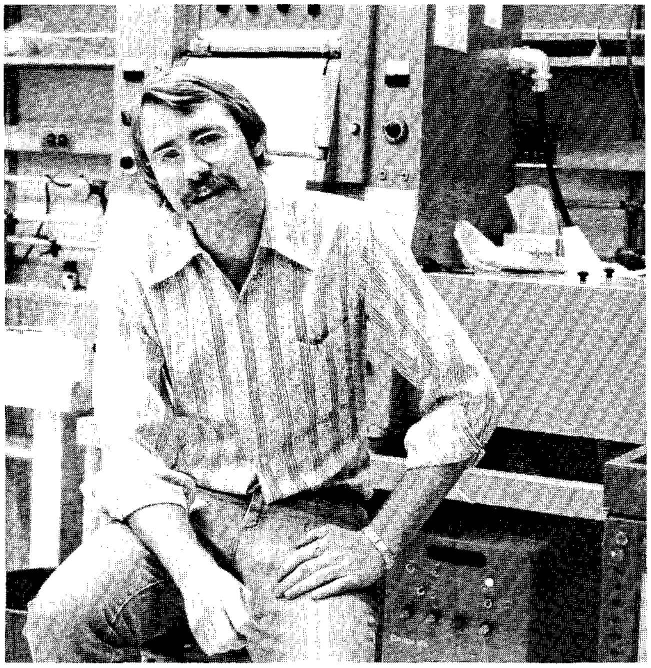


Results of the Gray-Solomon-Dooley-Cerdonio experiment on the magnetism of laccase. The experiment demonstrated for the first time that two of the four Cu^{2+} ions in the enzyme are close to each other. These two coppers are believed to be the site of oxygen attachment.

neighbors; but, before he could collect the final few data points he needed to settle the matter, Ed ran out of liquid helium, which is required for the operation of the damned machine. He and Massimo frantically called all over Rome for more liquid helium, but — you guessed it — the Italian truck drivers had just gone on strike and wouldn't deliver any. Dave Dooley is now preparing (in the sixth year of this experiment) still another sample of laccase, which he will soon take to Rome. If all goes well,* we should be able to finish this experiment before I start collecting my TIAA-CREF.

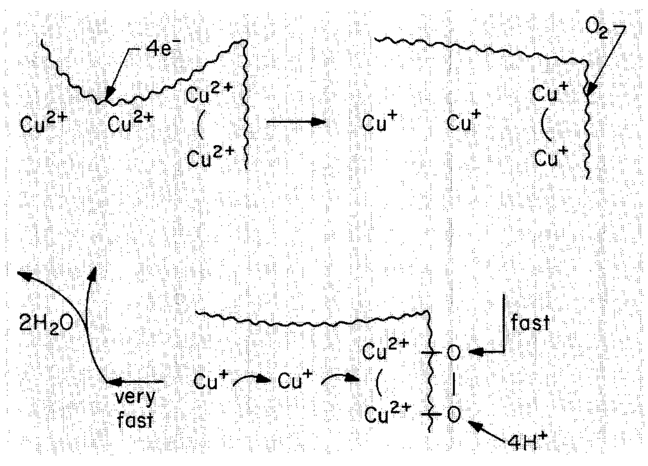
Although we need a few more data points, we're *pretty sure that two of the* Cu^{2+} *ions in laccase are very* close to one another. We believe the environment of these Cu^{2+} ions is very similar to that of the two coppers in blue blood protein, and further that in the reduced

*It didn't! This time someone soaked the magnetometer in pump oil. It now looks as if we're out of business for at least six more months.



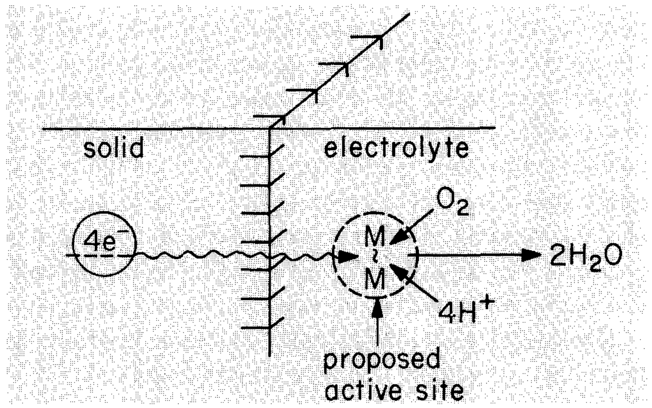
David Dooley, graduate student: He is now preparing still another sample of laccase — in the sixth year of this experiment.

(Cu^{+}) form, the pair provides a site on the enzyme surface for attachment of an oxygen molecule. We also know that the other two Cu^{2+} ions are differently structured, and are biding their time until they are needed for oxygen reduction. In a few words (and below), here's how the enzyme works: Four electrons enter laccase and reduce each of the four Cu^{2+} ions to Cu^{+}. At this point oxygen becomes attached to the two near-neighbor Cu^{+} ions, just as it does in blue blood protein. But the oxygen in laccase is not allowed to escape as it does in blue blood. As soon as it attaches, the two other Cu^{+} ions fire two extra electrons (one each) into the oxygen, thereby reducing it to water. (This mechanism — below — has influenced Gagné and Anson in their attempts to construct a catalytic oxygen electrode for fuel cells.)



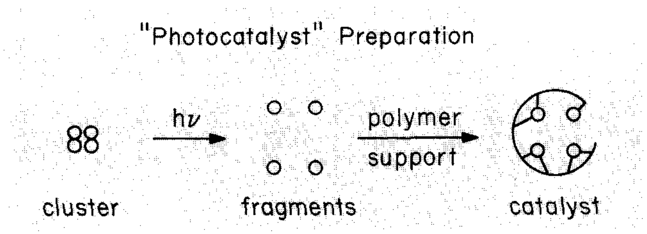
The proposed pathway of the reduction of oxygen by laccase. After initial attachment of O_2 at the near-neighbor Cu^{+} ions, electrons are delivered to the site rapidly from the other two Cu^{+}'s, which produces two molecules of water ($2H_2O$).

Another line of research that should have an impact on the general problem of small-molecule conversion involves the use of light to generate new types of catalysts. This is a research area that George Hammond (former chairman of Caltech's division of chemistry and chemical engineering and currently at UC, Santa Cruz) and I have been exploring in collaboration with a number of scientists at JPL — Alan Rembaum, Ami Gupta, Willie Volksen, and others. Here's our idea. You make a new kind of catalyst by taking a rather inactive cluster of metal atoms and irradiating it with ultraviolet or, in some cases, visible light. You have to do a lot of fundamental work to find out what wavelength to use to split the metal-atom cluster into fragments — if possible, all the way to fragments containing individual metal atoms. These single-atom fragments are terrific catalysts; they're fantastically active for the conversion of small molecules to bigger and better ones. But if we left the fragments alone, they would be so active the single atoms would recombine to give back the old inactive cluster of atoms. And so we not only have to generate the active fragments, but we have to trap them and keep them apart. We do this by attaching them to a polymer through chemical bonds. We call these new materials "photocatalysts," because they are generated using light, and we hope ultimately to make them as active as nature's enzyme catalysts are.



The Gagné-Anson-Taube-Tennent (or GATT) design of an electrode for the catalytic reduction of oxygen to water. One key component is the proposed active site, which features two near-neighbor metal (M) ions (as in the enzyme laccase). If such an electrode can be made to work as well as the enzyme, it could be used to fabricate an efficient fuel cell.

We've been successful in this work thus far. Alan, Ami, and Claude Frazier, a former Gray-Hammond student, showed a year ago that you could irradiate a "dicobalt" system (two cobalt atoms bound to eight



A new type of catalyst can be made by shining light (hν) on a cluster of metal atoms in the presence of a polymer. The light splits the cluster into atomic fragments, which are trapped by the polymer. The trapped fragments are the active sites of the "photocatalyst."

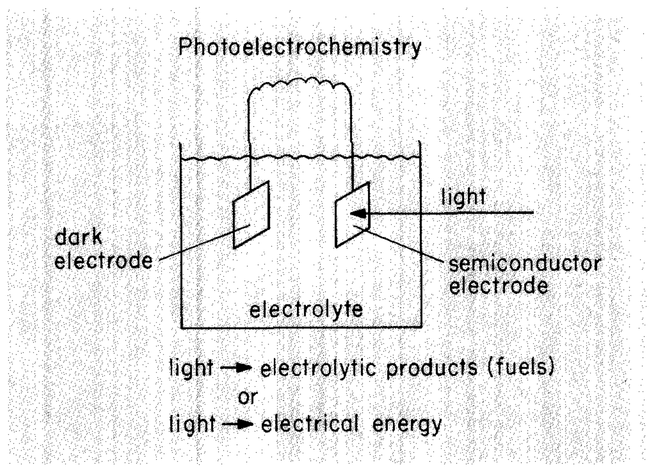
carbon monoxide molecules) with ultraviolet light, in the presence of a large polymer called polyvinylpyridine, and trap individual cobalt-atom fragments.

This cobalt-polyvinylpyridine system does some very interesting catalytic feats. One is the catalysis of the addition of carbon monoxide and hydrogen to organic olefins, giving organic aldehydes. This process, which is called "hydroformylation," is of great importance industrially — in fact, several billion dollars worth of chemicals per year are made by reactions of this type. At present hydroformylation and many other industrial chemical processes are operating under conditions that consume enormous amounts of energy. It is critically important to develop better ways to run these reactions, such as may be possible with the new photocatalysts, in order to cut down the energy-consumption requirements.

I've mentioned hydrogen a number of times. It is used to reduce nitrogen to ammonia, to reduce carbon monoxide to methane, and it's also a good fuel by itself. Clearly, we need to make more and more hydrogen at less and less cost. One way to do this is to combine photochemistry and electrochemistry. There are a lot of screwball schemes for doing this, but here is one that will work; it doesn't violate any of the laws of thermodynamics. You take semiconductor electrodes, immerse them in water solution, and allow one of them to be irradiated with light, preferably with sunlight. Upon irradiation, electrons in this semiconductor electrode system are stimulated to travel to the so-called dark electrode. Along the way these electrons can either be pulled off directly as electricity, or they can be used at the dark electrode to reduce the water in the system to hydrogen. If all goes well, other water molecules around the irradiated electrode are oxidized to oxygen. Thus, in this experiment, light is used to produce both hydrogen and oxygen from water, which is a very abundant starting material.

There are a large number of fundamental problems that must be solved before "water splitting" by sunlight will be a common means of storing energy. One of the biggest problems in the field has to do with the fact that semiconductor electrodes that are sensitive to sunlight fall apart rather quickly when they are irradiated. Neither water splitting nor direct electrical energy production from sunlight can ever be efficient as long as this problem remains unsolved. Recent progress in this area has been made at MIT, where Mark Wrighton, who was a joint Gray-Hammond student at Caltech a few years ago, directs a group of very active inorganic photochemists. Mark and his co-workers have immersed cadmium sulfide and cadmium selenide electrodes in polysulfide solutions, and in such media sustained conversion of visible light to electricity has been achieved. This experiment, which demonstrates that the "electrode instability problem" *can* be overcome, represents a major breakthrough in the field. The experiment also gives us real hope that similarly stable, sunlight-sensitive semiconductor electrodes can be fabricated for water splitting.

I hope that by now I have convinced you that there's a lot going on in chemistry these days. And an increasingly large fraction of what's going on is likely to have an important positive impact on the world's long-term needs in energy, food, and materials. I'd like to leave you with a few predictions: I am confident that within 30 years we will make hydrogen from water using solar energy. We will produce synthetic fuels by reduction of carbon monoxide and carbon dioxide. And we will catalytically convert nitrogen under mild conditions to ammonia, hydrazine, and new materials. For these reasons, and many others, it's a fantastically exciting time to be working in chemistry. □

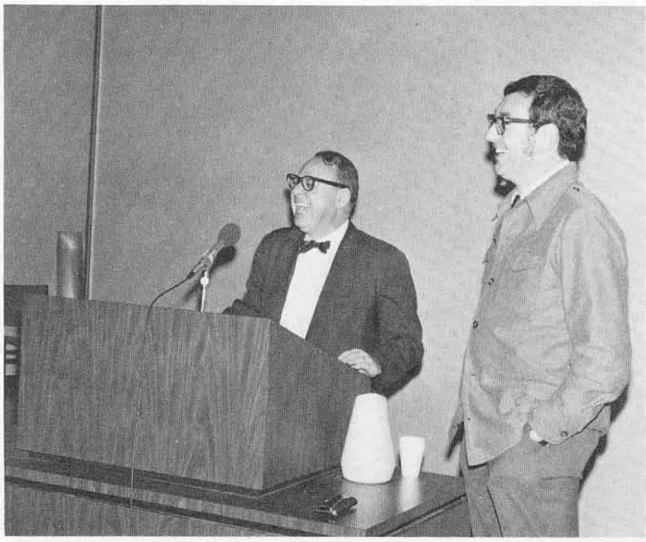


A promising scheme for the conversion of light to energy-rich molecules or directly to electricity involves irradiation of a semiconductor electrode immersed in solution. It is possible that research now in progress will lead to the development of a photoelectrochemical cell in which sunlight can be used to split water to hydrogen (at the dark electrode) and oxygen with reasonable efficiency.

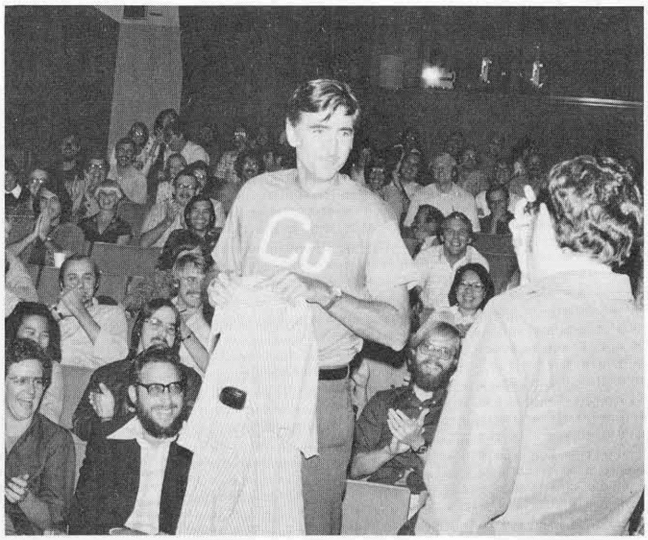
THE BIG COPPER CAPER

It all began when Dr. Bert L. Vallee came to the campus on November 15 to deliver the annual Buchman Memorial Lecture for the Caltech Division of Chemistry and Chemical Engineering. Dr. Vallee, who is Paul C. Cabot Professor of Biochemistry at the Harvard Medical School and the Peter Bent Brigham Hospital, spoke to a full house in Baxter Lecture Hall on "A Century of Zinc Biochemistry and Metabolism."

Dr. Vallee likes to end his talks on his Zn research with a slide showing that *all* the elements in the periodic table are really zinc — so his Caltech audience knew this was coming. As soon as it came, then, the Caltech Cu research group (see pages 16-21) went into action, as follows:

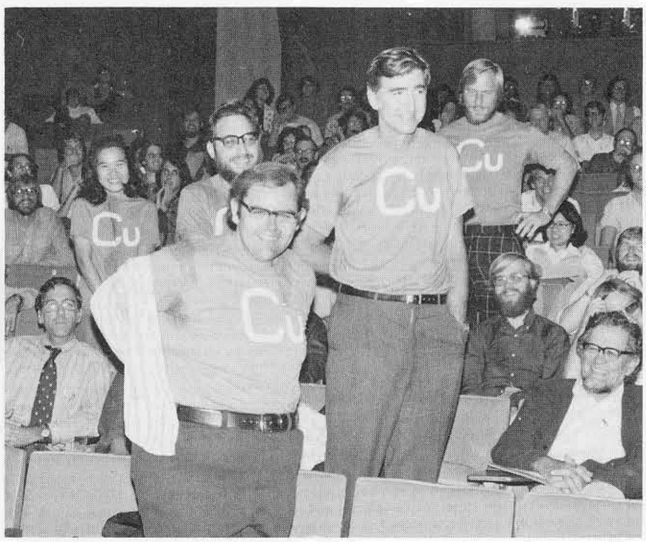


After Harry Gray had set up the speaker —

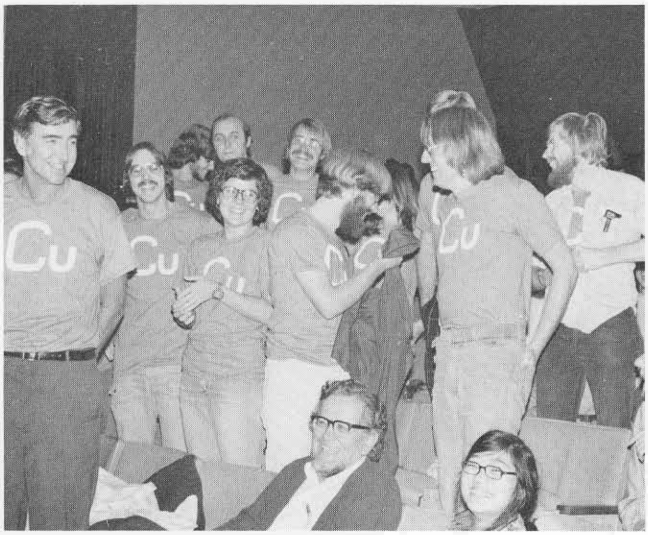


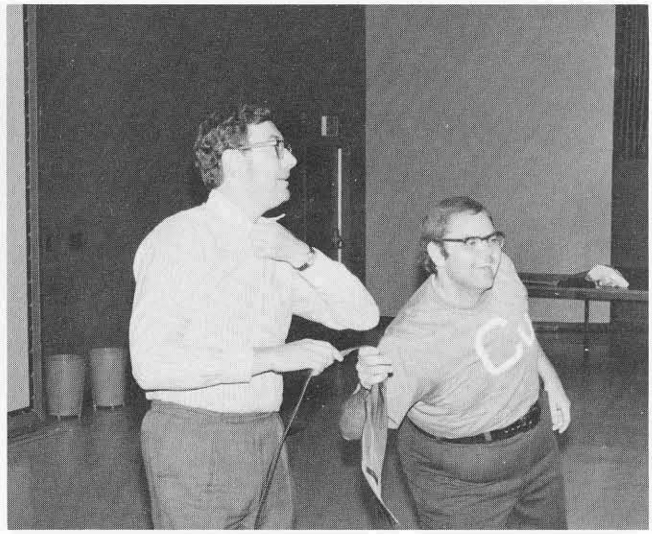
Fred Anson struck a blow for copper by removing his shirt —

and was shortly followed by John Dawson —

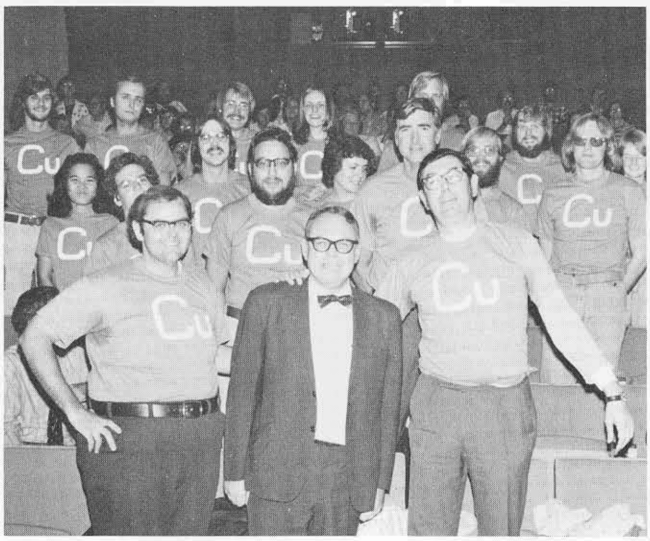


and by Pom Sailásuta, Barry Lever, and Bob Gagné —

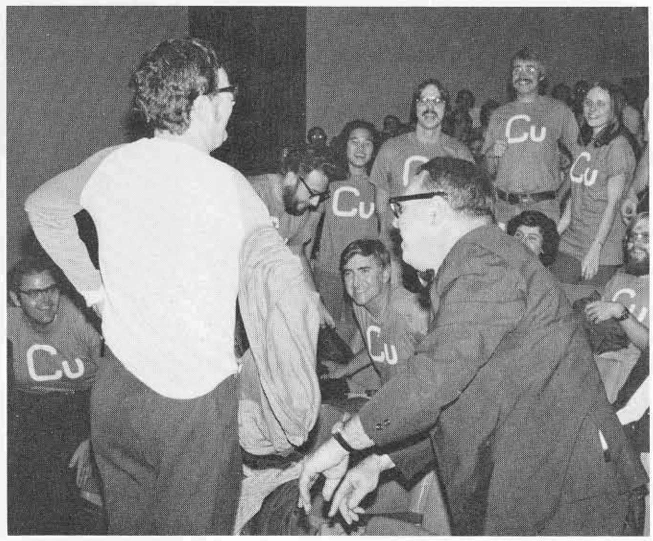




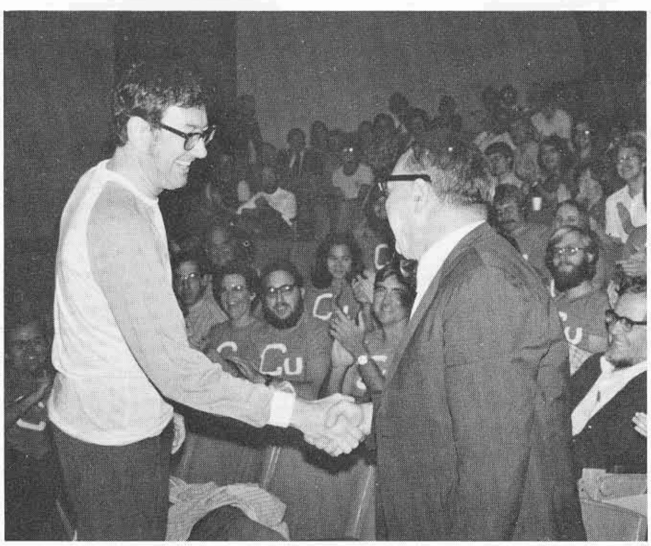
who were followed by a host of others — to the delight of Harry Gray, who then took off *his* shirt —



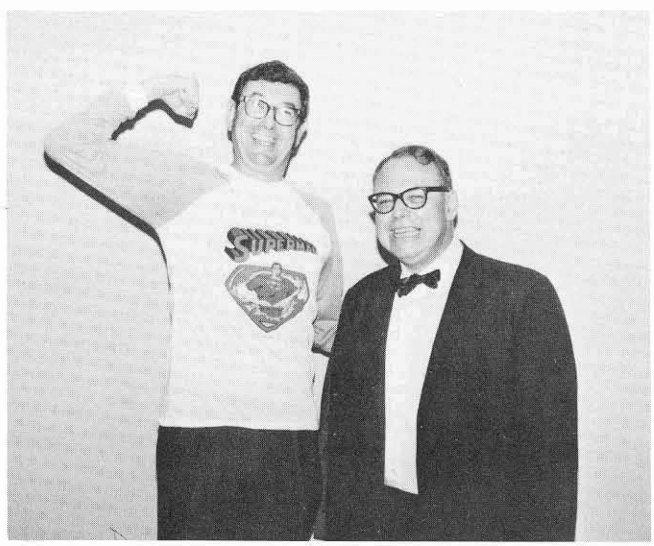
and joined the copper rebellion —



before peeling off one further layer of clothing —



to reveal his true identity —



and revel in it.

Donald Sherman Clark

1906–1976

A Tribute by William H. Corcoran

Don Clark devoted seven days a week for more than 50 years to Caltech, and he was happy to do it. From 1925, when he came here as a freshman student until his death on October 2, he gave Caltech everything he had.

Don received his BS in 1929, his MS in 1930, and his PhD in 1934. He was a teaching fellow and a teaching assistant during his graduate school years, and he then went through all the faculty ranks from instructor in mechanical engineering to emeritus professor of physical metallurgy.

His interest in research was the

dynamic behavior of metals, and he was greatly honored for his achievements. He and Dave Wood (who was first his student and then his colleague) received the Templin Metal Award from the American Society for Testing Materials in 1949. The same organization awarded him and Pol Duwez (professor of applied physics and materials science) the Dudley Medal in 1951. Don was the 1953 Campbell Memorial Lecturer for the American Society for Metals. He was president of the American Society for Metals in 1956-57, and national president of the engineering and science fraternity, Tau Beta Pi, in 1962-64.

As a metallurgist, Don had a special concern for materials and processes. Many a sophomore student would have been willing to guarantee that that concern was an all-consuming one. The students' name for his required course was "Memory 3." In fact, anyone who knew Don has to believe that God is probably now learning something about iron carbide diagrams that he never knew before.

Don's textbook *Engineering Materials and Processes,* which was first prepared in collaboration with Professor Howard Clapp, is now in its third edition, and more than 75,000 copies have been sold. Another textbook, written in collaboration with Professor Will Varney, was *Physical Metallurgy for Engineers,* and it is in a second edition, having sold over 50,000 copies.

Along with all this, Don handled a wide assortment of administrative functions at Caltech. In 1935 R. A. Millikan appointed him Director of Placement, and for 36 years he was the middleman between Caltech graduates and the corporations that were interested in hiring them.

In 1943 Dr. Millikan appointed him Director of the Alumni Association, and he served in that capacity until 1945. For 23 years, beginning in 1946, he was Secretary of the Alumni Association, and in 1965 the members of the Association tried to indicate their recognition of the quality of his devotion by establishing a fund in his name — the Donald S. Clark Alumni Award, to be given to sophomores or juniors (preferably in the engineering option) who demonstrate leadership potential and superior academic performance. By 1967 the fund had grown sufficiently for the first four awards to be made.

He was editor of the Caltech *Alumni Review* from 1942 to 1943, and when the magazine's name was changed to *Engineering and Science* in September of that year, he was named its first editor-in-chief, a position he filled until 1946.

I think he served on essentially every faculty committee, and at one time he was vice chairman of the faculty and the faculty board.

I suspect that one of the jobs Don liked best at Caltech was the one he held for eight years — from 1934 to 1942 — as Resident Associate of Dabney House. He might have held it much longer, but World War II intervened and made it necessary for Caltech to use the facility for the Navy V-12 Program. Because I lived in Dabney House during Don's tenure there, I can testify that he was an outstanding RA. Though we students did almost everything to bother him, he really made us shape up. He had no trouble at all with matters of discipline. One shake of his head was good and sufficient warning to a wayward undergraduate to tread cautiously thereafter.

Don also did a lot to introduce culture to Caltech when he purchased a Hammond electric organ and installed it in Dabney House. It was used by everybody on campus for years — at no cost to the administration.

Don worked hard as a teacher and researcher. He kept records of everything, including the fact that he had some 4,400 students in his classes during his career. And though, in prewar days, the number of weekly student-faculty contact hours was higher than today, the incredible median number of such hours for Don from 1934 to 1942 was 22. (If you asked a faculty member today to have 22 hours of class, you might have a revolution on your hands.)

Don liked good things, especially Cadillacs. In the depression period, he was probably the only one around here who drove one. He also liked bow ties, and he was probably the best advertisement for them that the industry has ever had. He enjoyed good food and good times, and he contributed some of his share to both as a chef. One of his specialties was crepes suzette.

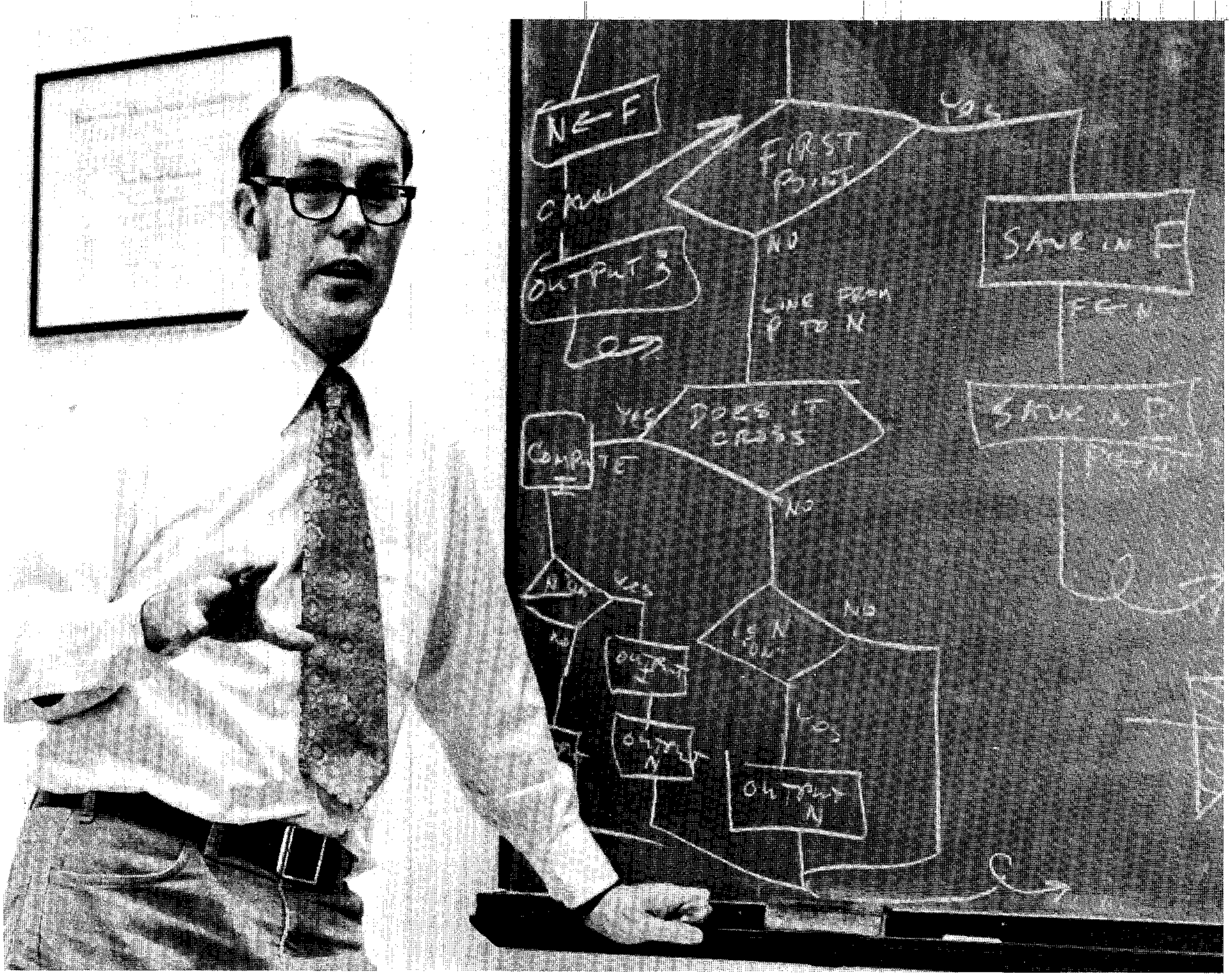
The grounds of his home in Corona del Mar showed how much joy he took in gardening. For many years he also had a lovely home in San Marino, which he shared with his mother. It had one of the most beautiful gardens in the area. Even when he moved to an apartment in Pasadena, he chose one that had an outdoor patio that he could landscape and care for.

One aspect of Don's personality is unforgettable. He was a tough-minded, straightforward guy. Whatever he had on his mind, he said. My recollection is that from my student days on he felt complete freedom to tell me precisely what he thought on any subject. He never stopped. Once when he was ill enough to be confined to the little convalescent hospital across the street from St. Luke's, I got a hurry-up call to come up and see him. I don't think he necessarily wanted to *see* me, but he did want to tell me to do something — right now. He waved an injection-molded part for some device or other in my face and said, "Did you ever see such a poor construction job as that? Fix it."

Well, there I was, 56 years old, still being told by Don (who was 69) to fix something right now. And I did. If you know Don, you know that if I had left there without fixing it I would have been in real trouble.

Don gave a great deal to his students, to his colleagues — and to Caltech — *because* he was so straightforward and hard-driving. The legacy of a positive imprint like that is indeed a measure of a great life. I am very thankful to have known him. □

As RA of Dabney House back in the late 1930's, Don Clark must have helped his undergraduate housemate, William H. Corcoran, onto the right track at Caltech. Corcoran has since become professor of chemical engineering and vice president for Institute relations.



Ivan Sutherland

Computer Science - A Timely Idea

THE WORD most often used to describe an idea whose time has come is "irresistible," and it may be the best word for Caltech's new computer science program too. Some of the components of irresistibility in this case are a handful of enthusiastic faculty members, a group of students who seem to have been born with a gene for computing, and solid administrative support for getting them together. It's a forceful combination.

Both the enthusiastic faculty and the program are headed by Ivan Sutherland, whose preparation for the job includes an educational tour that started with a BS from Carnegie Tech in 1959, an MS from Caltech in 1960, and a PhD from MIT in 1963 — all in electrical engineering and with increasing emphasis on computers. Sutherland's thesis at MIT was on computer graphics, for which he made a widely shown movie called *Sketchpad* that was a milestone in the graphics world.

From MIT he went to Washington, D.C., for three years, ending up as director of information-processing techniques for the Advanced Research Projects Agency (ARPA). That period was a very exciting one in computing. Time-sharing was just opening up, and Sutherland's office was responsible for a lot of major contracts for it. He also traveled extensively and thus got to know most of the people in the mushrooming computer field.

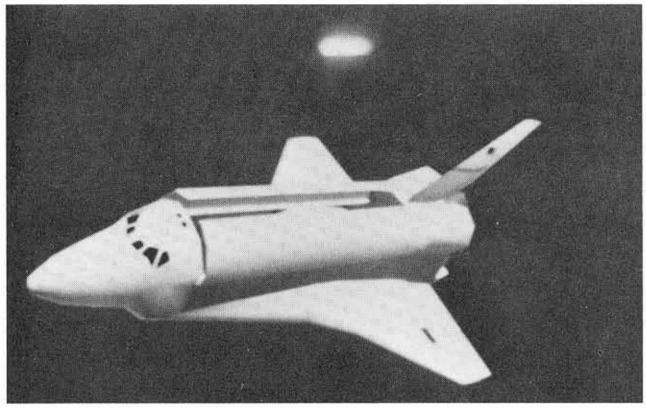
In 1966 Sutherland went to Harvard as an associate professor, and in 1968, with David Evans, he founded a company to make special-purpose display systems for scientific uses. The company, Evans & Sutherland Computer Corp., is located in Salt Lake City, because Evans, who came from an old Utah family, didn't want to uproot his wife and seven children. "Since I had only two children," says Sutherland, "I was the logical one to make the move. Fortunately, my family found Salt Lake a marvelous place to live."

In the next six years Evans & Sutherland developed a remarkable picture-making technology — describing objects in mathematical terms placed in a computer's memory, which then converted them into color pictures. Some of these pictures were so good that it was somewhere between hard and impossible to tell that they were computer-generated. In 1974 Sutherland decided that this technology could be used in the entertainment world to tell stories, so to try out the idea he started another company in Los Angeles. It was "a glorious failure." After about six months, he sold his interest to his partner and went to work for Rand Corporation in Santa Monica, where he did some studies on memory and on microfabrication technology.

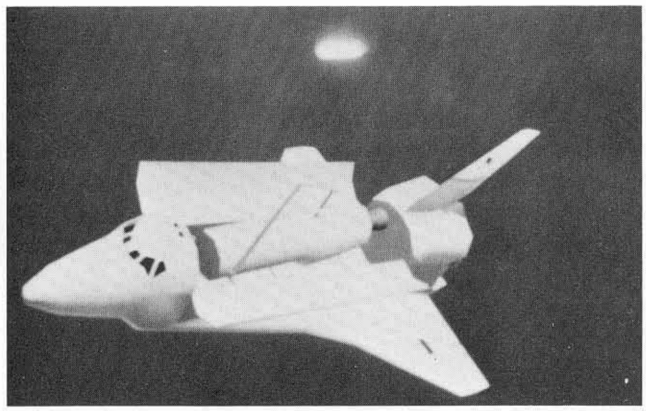
He needed help on these projects from an expert in semi-conductor physics, and Carver Mead, professor of electrical engineering at Caltech, turned out to be that person. It was an exciting and productive association from the beginning, and turned the thrust of Sutherland's interest from computer graphics to the possibilities of Mead's specialty — integrated circuits. So, when Sutherland was offered a faculty position at Caltech in which he could work to develop a computer science program that could build on Mead's expertise, he was delighted to accept. He was on campus on a part-time basis last year, and is now here full time.

At age 38, Sutherland is one of the young men who has grown up accepting the computer in the same way the members of the previous generation accepted airplanes. He is interested in their development, excited about their potential, and thoughtful about their implications. "In part," he says, "a computer is an end in itself. By reflecting on how computers do things, we are able to learn some things about the nature of knowledge. Learning what is ultimately computable — and what isn't — is a scientific activity in its own right. But using computers is also an engineering activity because of its importance to a lot of other things, from economics to design."

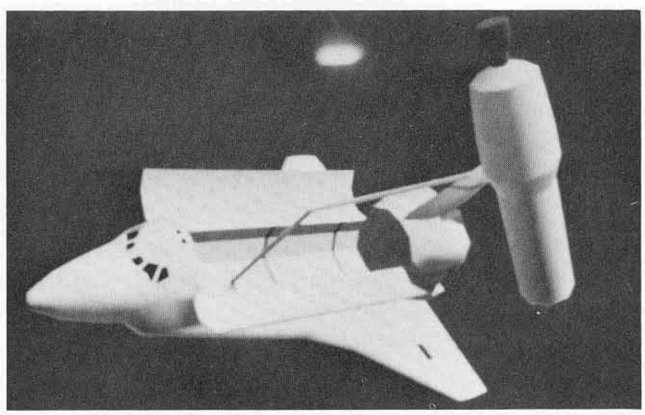
Computers have, of course, been developing for 30 years, and computer science programs are nothing new in college curriculums. Caltech's new program will certainly build on what others have learned, but it will also make maximum use of the Institute's own very special capabilities. The focus will be on the relationship between hardware (roughly, the physical components of a computer) and software (also roughly, the collection of information in a computer's memory) through the medium of the design of integrated circuits. As a matter of fact, the distinctions between hardware and software are fading, partly because of advances like integrated circuits.



Designing a computer simulation of the space shuttle to train NASA crews in payload and assembly tasks takes experts in computer graphics. The recent construction of such a machine by Evans & Sutherland Computer Corp. is the culmination of a 15-year effort in the field — an effort to which Ivan Sutherland has made major contributions. The company built a special-purpose digital computer to syn-



thesize the system's pictures from a mathematical model of the shuttle, and added some assumptions about the direction and quality of illumination. The three photos on this page (taken directly from a standard TV monitor with a hand-held 35mm camera and made available to us through the courtesy of Evans & Sutherland) are part of



a series that changes in real time as a simulation of the payload delivery mechanism changes the position of the simulated boom. A large special-purpose computer is required to generate pictures of this realistic action fast enough to observe motion as it happens. The system is now installed at NASA headquarters in Houston.

In brief, an integrated circuit is a way of placing — by a photographic process — a very large number of components on a very small piece of silicon at a very reasonable price. The digital watch and the pocket calculator are two results of the remarkable development of this technology in the last 10 to 15 years. Sutherland feels there is another 10 or 15 years of technological improvement ahead for integrated circuits, which will make them three or four orders of magnitude more complex and exciting than they are today.

Currently, the maximum number of circuits that can be placed on a silicon chip smaller than a fingernail is 20,000, but no one in the business boggles at the idea that the number will soon rise to a million. There is, of course, a limit to how small a circuit can be made, but it is not unreasonable to expect that eventually a single chip in a wrist watch will have all the power of today's biggest computers.

That raises a lot of questions. To Sutherland, answering them is what computer science at Caltech is all about. How do you build that kind of computer? What do the properties of silicon have to do with the eventual form of such a machine? What are the geometric complications? Anything that small can't have very many wires connected to it, so what kind of computations can you do with it? In fact, in a much larger sense, if you had one, what would you do with it? What could it do for you? One not-so-fantastic answer Sutherland envisions is having a machine in his office that would take over many of the tasks of a secretary — keeping his appointment book and reminding him of dates, besides handling the normal computer business of computations. It would probably have a written display output, but perhaps it would also be able to listen to oral communication — and to respond in kind.

How is Caltech going to contribute to this? By its special approach to computer science, which is based on outstanding capability in the design of integrated circuits. Thanks to the work of Carver Mead, Sutherland says, "Caltech is far ahead of any other school in this proficiency. We also have a body of students who realize that integrated circuits are not black magic, but can, in fact, be designed by ordinary humans using perfectly understandable design techniques. It's not easy, because sheer numbers of parts introduce difficulty even if all the physics of the system works. But that, too, is what computer science is about — the understanding of complexity, and then simulating in a computer what we have learned."

At the moment the computer science program has a faculty of three full-time professors: Sutherland, Mead, and Frederick Thompson, professor of applied science and philosophy. Thompson is an expert in languages and information-retrieval, which is a very important part of understanding how to use computers. There are two research associates: Dan Cohen, whose special field is design of algorithms for hardware and who spends full time in computer science; and Bozena Thompson, who spends much of her time in linguistics for the humanities.

Sutherland has recruited three "terrific" part-time people to help broaden the curriculum this year. During the fall term Robert Sproull and Alan Kay of Xerox Palo Alto Research Center spent a day per week each on campus — teaching computer graphics and philosophy of computers respectively. Sproull is coauthor of the leading text in his field. Kay's course draws together ideas on human creativity, representation of knowledge in computers, and input/output techniques, which he has put together in building the best "personal" computing system available today. Steve Caine, president of Caine, Farber and Gordon, a commercial programming enterprise in Pasadena, brings to his advanced programming class the lessons of practical experience.

In addition a number of faculty from other departments of the Institute are a part of the teaching program: Charles Wilts, for example, professor of applied physics and electrical engineering; Gilbert McCann, professor of applied science; and Charles Ray, who is lecturer in applied science and director of the Booth Computing Center.

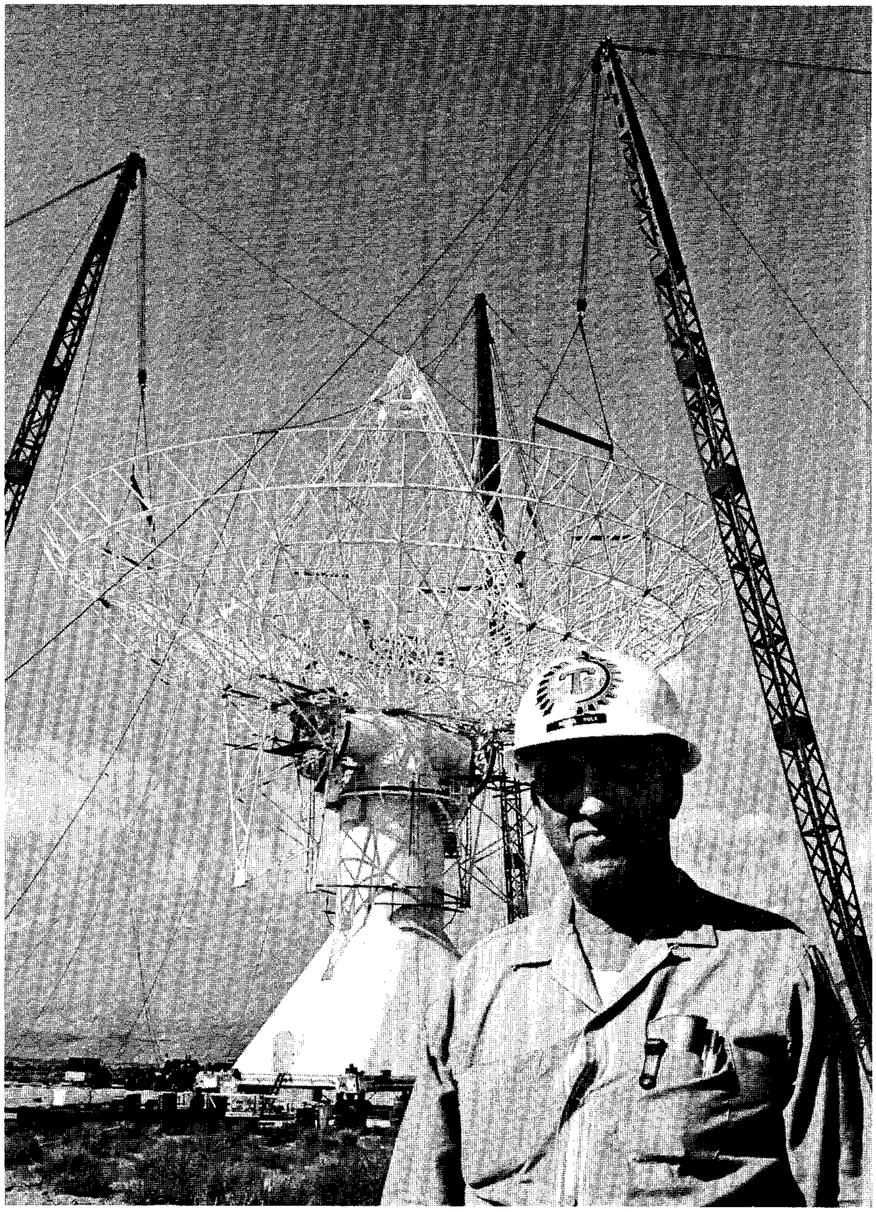
The program has openings for one senior professor and three assistant professors, and Sutherland is delighted with the interest expressed by a number of top-notch people that he's interviewed. Once those jobs are filled, the program can just about double in size and scope. There are 15 graduate students at present, and a great number of undergraduates take the courses. Computer science is a part of the engineering science option, but if things go as planned, it may soon be offered as an option in its own right.

"All we need," says Sutherland, "is people, research money, equipment, and time. But I think it's all going to happen. Right now we're working on a cooperative research program with industry, we're recruiting people, and we're trying every source we know for research money. In 1976 people can really see the relevance of our work in integrated circuits, so we're getting a tremendous response."

If you add that kind of optimism to the hard work that Sutherland and his colleagues are putting into it, computer science at Caltech could indeed be irresistible. □

Man of Parts

by GRAHAM BERRY



Bruce Rule relinquishes a few of his many titles

NOTING that the once lowly peanut has now achieved a certain prominence, Bruce Rule thinks the time is propitious to reveal the unique contribution that peanuts have made toward the advancement of astronomy.

For nearly three decades the roasted pods of *Arachis hypogaea* have played a key psychological role in the aluminizing of the Hale Telescope's 200-inch mirror at Palomar Observatory — a job that has to be done every now and then if the big mirror is to maintain its high reflectivity.

When Rule set up the aluminizing system nearly 30 years ago, it was a difficult, tedious job for his trained crew of opticians and technicians. They had to remove the 30-ton disk of pyrex glass from the telescope tube, clean it with solvents and lanolin, get it into what was then the world's largest vacuum tank for the actual aluminizing, and then get the refurbished mirror safely back in the telescope tube.

It was an exhausting task, physically and emotionally, and that's where the peanuts came in. Bruce Rule had sacks of them available for munching at the first break. *Eating* the peanuts was only a peripheral benefit, however. What the tired crew really enjoyed was scattering the peanut shells over the otherwise immaculate observatory floor. This decompression exercise relieved their tensions so well that it has become an important ritual in all subsequent realuminizings.

In April 1975, when the 40-inch mirror was to be aluminized at the Hale Observatories' new Chilean observatory at Las Campanas, Rule learned that there were plenty of peanuts in South America, but, unfortunately, they were all raw. That didn't rattle Rule. He saw to it that the 40-inch's auxiliary instruments were shipped from Pasadena to Las Campanas cushioned by North American roasted peanuts. The gesture was typical of the kind of consideration Rule always had for his staff.

Although officially retired as of last June 30 from such titles as chief engineer and staff member of the Hale Observatories, staff member of Caltech's Owens Valley Radio Observatory, and chief engineer and project officer of the 100-inch Irénée du Pont Telescope at Las Campanas, Rule is not substituting golf for telescopes. He'll continue to work on telescopes as long as he's able to make a contribution, he says.

Contributing is one of the things Rule does best. For 40 years he has designed and engineered astronomical instruments, and he has been associated with the design and construction of 18 of the world's major optical and radio observatories. He still maintains an office at the Hale Observatories building in Pasadena, where he consults on the overall design and logistics of large telescopes and also on wind tunnel optical systems.

Ironically, the 67-year-old engineer who has done so much to expand man's vision of the universe has suffered severe impairment of his own vision, including the loss of sight in one eye. He now carries on his work with the aid of dark spectacles and a magnifying glass.

Recently, Rule and his wife, Ethel, returned from the dedication of the DuPont Telescope at Las Campanas. It was, of course, a memorable occasion for him. He was especially happy to see Mr. and Mrs. Paul Scherer of Glenn Dale, Maryland, there because some 30 years earlier he had shown Mrs. Scherer — then Margaret Hale — the great Hale Telescope at Palomar soon after it was completed. Mrs. Scherer is the daughter of George Ellery Hale, for whom the big Palomar telescope and the Hale Observatories are named. Scherer is the son of the late James A. B. Scherer, who was president of Throop Polytechnic Institute — as Caltech was known in the early 1900's.

Bruce Rule has been associated with Caltech since he was a student, graduating from the Institute in 1932 with a BS in electrical engineering. While still in school he designed and installed power generators and equipment for wind tunnels and water tunnels. With a group of Caltech graduates he worked on the forerunner of dictating machines, using a magnetic steel cylinder instead of a magnetic tape. He held patents on switches for dictating machines and on instruments for directional drilling in oil wells.

He joined the Caltech staff in 1937 as superintendent of engineering projects and chief engineer. During World War II he developed an aerial reconnaissance camera for the Air Force and underwater sound devices, on which he held patents. He also worked on the design of antisubmarine rockets and torpedoes (and lost part of a finger in the process, in a scale model of a torpedo launcher in the basement of Robinson Laboratory). He organized underwater research at Morris Dam in the San Gabriel Mountains for the Navy, and received two Navy awards for his services. For 12 years he was chief engineer of Caltech's 1.2-billion-electron-volt synchrotron laboratory.

When he finally started working with telescopes after the war, Rule knew where he wanted to apply his engineering talents. He was largely responsible for the mechanical, electrical, and drive systems for all the Hale telescopes and for the design of the coudé spectrograph and other auxiliary instruments on the 200-inch telescope.

Rule's versatility was particularly useful to Jesse Greenstein — who is now Lee A. DuBridge Professor of Astrophysics — when he first came to Caltech in 1948 to start the graduate school in astronomy. "Bruce could do anything," Greenstein says. "He was always cheerful, always willing to cope with tasks concerning personnel, budget, the building, and general problem-solving. In a less highly organized and smaller Caltech, he was an essential element of my survival."

Rule worked with the three successive directors of the Hale Observatories—Walter S. Adams, Ira S. Bowen, and Horace W. Babcock. For all of them he was a key person in the design and construction of that strange combination of massive mechanical moving structures with high-precision delicate goals that is a telescope.

"As new instruments were being designed," says Horace Babcock, "Bruce was always available to the staff, always sympathetic and quick in his suggestions on how to plan it, how to make it work, how to fix it.

"As mechanical and electrical problems arose and were solved, Rule adapted himself to the coming age of electronic control. It is still a remarkable fact that the 200-inch Hale telescope drive and electrical design, in large part due to Rule, is still competitive after 30 years."

But Rule hasn't confined himself to working just for the Hale Observatories. He was consultant or adviser for such big instruments as the 236-inch Russian telescope; the 120-inch Lick Observatory instrument; the 84-inch one at Kitt Peak; the 156-inch at Cerro Tololo, Chile; the 156-inch Anglo-Australian telescope in Australia; the 140-inch of the European Southern Observatory at La Silla, Chile; and the 150-inch Canadian-French Hawaiian telescope at Mauna Kea, Hawaii.

His work on radio telescopes began in 1955 with the design and construction of the two mobile 90-foot dish antennae, and later, the 130-foot antenna at Caltech's Owens Valley Radio Observatory. He has also been consultant on numerous other large radio telescopes, as well as big solar and infrared telescopes.

He organized and was director of Caltech's Central Engineering Services, where large astronomical research equipment is built, and he started the observatories' Astro-Electronics Laboratory. From 1960 to 1964 he was a member of the National Academy of Sciences advisory panel on astronomical facilities.

Small wonder he has long been known by astronomers as Mr. Telescope. □

Books — by, about, or of interest to Caltech people

STATES OF MATTER

by David L. Goodstein

Prentice-Hall, Inc. $24.95

David L. Goodstein, professor of physics and applied physics at Caltech, has written a textbook for that rarity in a college curriculum — an advanced survey course. Developing the material through three years of teaching first-year graduate students in applied physics, Goodstein first tries to bring all participants up to the same level in thermodynamics and statistical mechanics and then to help them come to an understanding of the essential nature of the basic states — gases, solids, and liquids. These chapters are followed by discussions of some special states — superfluidity, superconductivity, and magnetism — and finally of phase transitions.

The problems at the ends of the chapters have been consumer-tested by use either as homework or examination problems in the course. The annotated bibliography at the end of each chapter is designed to list all the material Goodstein consulted in preparing the lectures on which this book is based as well as to guide any student who wants to read further.

WATCHING THE WILD APES: The Primate Studies of Goodall, Fossey, and Galdikas

by Bettyann Kevles

E. P. Dutton........................$8.95

This interesting and informative book is ostensibly written for children between the ages of 10 and 14, but it makes for very satisfying adult reading too. It reveals, through the observant eyes of three women scientists, the behavioral patterns of those three endangered primate species — the chimpanzees, the gorillas, and the orangutans. Equally interesting is what it reveals about the women—Jane Goodall, Dian Fossey, and Biruté Galdikas — who have based their lives and their laboratories in the equatorial rain forests of Africa and Borneo.

These three women have in common not only their research interest in primate ethology, but having been sponsored by the late L.S.B. Leakey, whose concept it was to set up the projects and to recruit women to head them because he believed that women would be able to establish rapport with wild animals more easily than men.

Bettyann Kevles was introduced to studies of the great apes when she attended a series of lectures in Pasadena sponsored by the Leakey Foundation. Among the speakers were Jane Goodall and Dian Fossey, and after she met Biruté Galdikas, she realized that there was an exciting story to be told about all their work. Mrs. Kevles has taught history and is the wife of a Caltech associate professor of history, Dan Kevles.

RUSSELL W. PORTER

Arctic Explorer, Artist, Telescope Maker

by Berton C. Willard

The Bond Wheelwright Company $12.50

From 1929 until his death in 1949, Caltech claimed Russell Porter's time and considerable talents. But in 1929 Porter was 58 years old and had already had a fascinating career in at least three fields — Arctic exploration, drawing and painting, and the building of telescopes.

In the fall of 1892, at the age of 20, Porter attended a lecture on arctic exploration by Robert E. Peary and was instantly infected with Arctic fever. From then, until 1905, Porter went on nine expeditions to the Arctic, as artist, astronomer, topographer, surveyor, and collector for natural history.

For many years Porter earned a rather precarious living as surveyor, builder, farmer, and, eventually, mechanical and optical tinkerer. He also designed and built his own observatory and telescope as a hobby (and taught many others to do it too), and he published articles on the subject that attracted the attention of distinguished scientists, including George Ellery Hale.

In 1929, at Hale's invitation, Porter became a member of the team that created and erected the 200-inch Hale Telescope on Palomar Mountain. At Caltech his title was Associate in Optics and Instrument Design, and his work included making preliminary designs for the three campus buildings needed to work on the 200-inch telescope — the machine shop, the astrophysical laboratory, and the optical shop. He developed a "cutaway" drawing technique — involving intricate mechanical detail — that made it possible to visualize the Hale project with extraordinary precision. Those drawings were works of art, and many of them can still be seen at Caltech.

Surprisingly, this is the first book-length biography of Russell Porter. Berton Willard's book grew out of a desire to share the many stories about Porter that he had grown up with. He has also had many of the same kinds of experiences. Willard is an optical engineer, a member of the Springfield Telescope Makers (founded by Porter in 1920), and he has made an expedition to Baffin Island and Greenland.

SEX AMERICAN STYLE

by Nasá Varvatsis

Ashley Books, Inc. $7.95

Because Athanassios D. Varvatsis got his MS from Caltech in electrical engineering (1965) and his PhD in 1968, there is a temptation to say that this book does not seem to be related to his professional interests. However, even a cursory reading reveals that, though Nasa Varvatsis was educated as an electrical engineer, he is a lifelong student of women. Born and brought up in Greece, Varvatsis came to the United States as a young graduate student, and

continued on p. 32

Books . . . *continued*

his book is the result of the cultural shock he experienced here, trying to cope with the complicated American female after years of carefree sex in his native Greece. Part true confession, part advice to the lovelorn, *Sex American Style* is by turns exasperating, perceptive, ingenuous, and ingenious.

WIND-CATCHERS

American Windmills of Yesterday and Tomorrow

by Volta Torrey

The Stephen Greene Press......$12.95

The meat of Torrey's book is the story of past windmill progress in America and its projection into the future of windmills as an energy source. Torrey, who feels that "the windmills built thus far may be mere points of reference from which much better ways of 'mining' the atmosphere for energy will soon be discovered," credits Caltech's Ernest E. Sechler and Homer J. Stewart with "grasping such technological nettles" by setting up a course that includes material on windmills (Ae 107, Case Studies in Engineering).

Torrey describes dozens of American windmills, giving details of their design, specifications, and capabilities, and he illustrates most of them with photographs and drawings. Whatever the future of the windmill as an answer to the energy problem, *Wind-Catchers* should dispel the image of the device as merely a picturesque part of the Dutch landscape or a target for Don Quixote.

Torrey has been a newspaper reporter, magazine writer, and editor of *Popular Science*. For the last 20 years he has concentrated on science writing.

McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS

McGraw-Hill Book Company........................ $39.50

Containing almost 100,000 definitions, this dictionary is a major compendium of the vocabulary of science and technology. Since experts in the various fields undoubtedly selected the terms to be included, and wrote or reviewed the definitions, the book can be approached with some confidence by the amateur. Amateur is, of course, a term that applies to all of us in at least some of the 100 fields into which these definitions are divided.

For nonscientifically trained amateurs, in addition to the definitions themselves the reference material in the Appendix — lists of symbols, abbreviations, and conversion tables, for example — is particularly useful. So is the cross-referencing of official abbreviations both at the end of the definitions and alphabetically in the main listing.

Unfortunately, as in most scientific dictionaries, pronunciation is not given. The editors say that this was for reasons of economy, but it is an economy that is costly to the very people who could find the dictionary most useful. It leaves students, secretaries, lab workers, and even some editors and writers dependent on learning how to pronounce many words only by hearing them from others — who may or may not say (not to mention spell) them correctly. "Lipid" or "spectroscopy" may be no cause for panic, but how about "Aspidorhynchidae" or "zygnemataceae"?

Letters

A Few Last Words

San Diego

Talking about Goldwynisms, particularly "the atom bomb — that's dynamite!" (John H. Knowles, "Clarity of Thought and Higher Education," *E&S*, October-November 1976), Herman Wouk, of all people, was guilty of this Goldwynism in his talk at CIT on March 6, 1973. Wouk referred to atomic explosive as "this horrible dynamite" ("Science — at the Leading Edge of Hope," *E&S*, March-April 1973).

NAOMI KASHIWABARA, BS'49

Beverly Hills

Dear Dr. Knowles:

I am reading with great satisfaction the report of the address you gave on Caltech's 82nd Commencement last June, (*E&S*, October-November) and regret that I did not have the opportunity to collaborate with you in its preparation to the extent of testing your interest in a word that I have coined, and which might have been used by you to bring your address to a conclusion.

I conceived the word as descriptive of the final stage of every possible course of events or program or period of time, or, for that matter, culmination of anything under the sun.

One component of the word had already reached an impressive level of connotation in the form "finalize," but it needed a suffix to obviate such odious expressions as "like I mean" and "like I mean, finalize, ya know."

How much simpler and more "meaningful" to say

FINALIZEWISE!

Now I shall set about reading the rest of your address.

RODD KELSEY

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Jim Mitchell helps make glass ultra-transparent...

so that hair-thin glass fibers can carry telephone calls as pulses of light in lightwave communications systems.

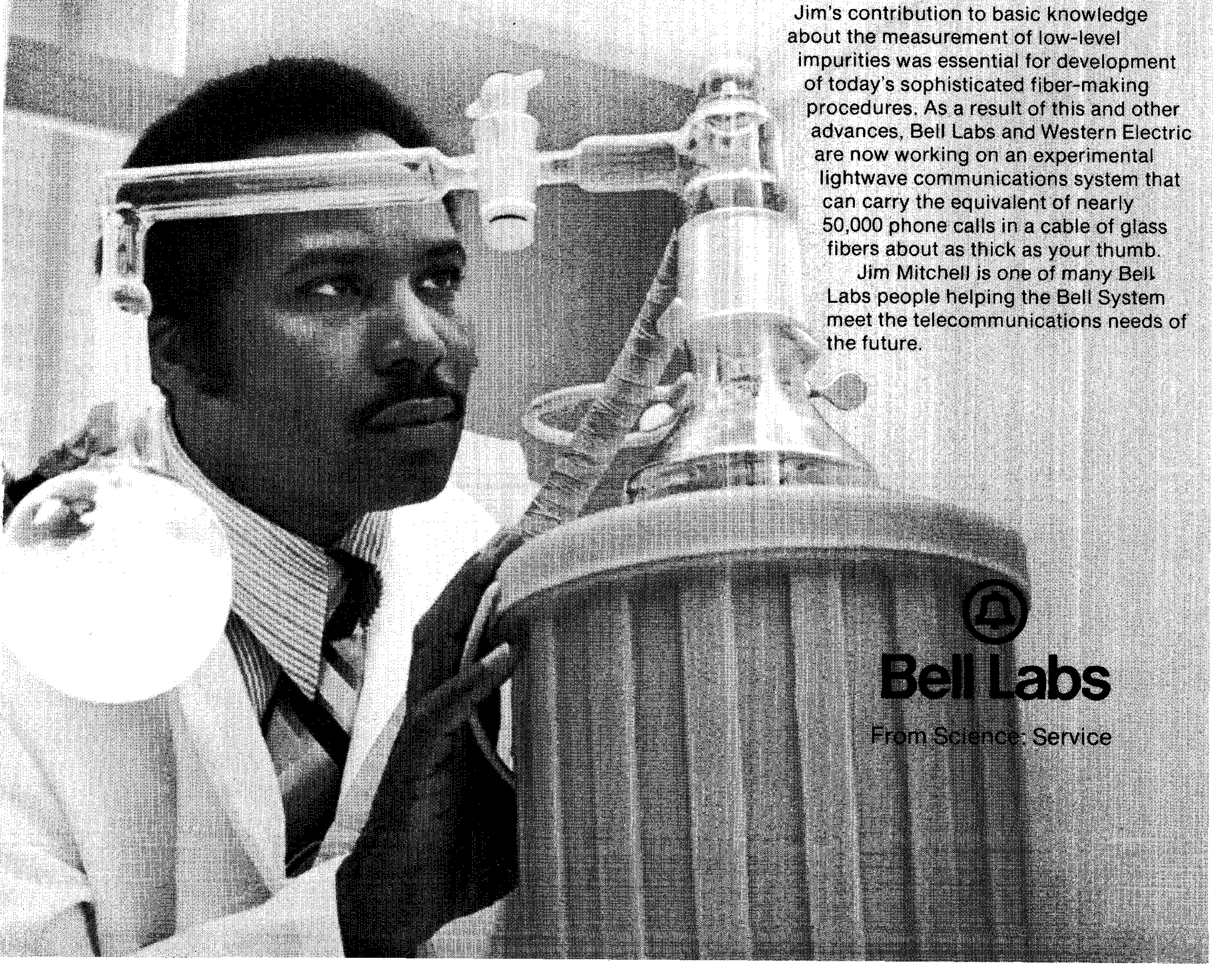
In this new technology, transparency of the glass fibers is a critical factor in their ability to carry light signals for communications. And thanks, in part, to advances in materials analysis achieved by Jim Mitchell and his colleagues, Bell Labs and Western Electric are producing some of the most transparent glass the world has ever known.

Jim led a task force that identified and measured extremely small amounts of impurities in raw materials used to make glass fibers. With a BS in chemistry from North Carolina A&T, and a PhD in analytical chemistry from Iowa State, he was well prepared for the job.

Since contamination could easily be caused by lab equipment and even the air in the room, Jim first designed a special "clean room" for the research and then devised highly sensitive analytical methods for measuring impurities as low as two parts per billion. One of his techniques, called cryogenic sublimation, is a promising low-temperature process for purifying chemical reagents.

Jim's contribution to basic knowledge about the measurement of low-level impurities was essential for development of today's sophisticated fiber-making procedures. As a result of this and other advances, Bell Labs and Western Electric are now working on an experimental lightwave communications system that can carry the equivalent of nearly 50,000 phone calls in a cable of glass fibers about as thick as your thumb.

Jim Mitchell is one of many Bell Labs people helping the Bell System meet the telecommunications needs of the future.



Bell Labs

From Science: Service